

EXHIBIT B

**IN THE UNITED STATES DISTRICT COURT
FOR THE SOUTHERN DISTRICT OF MISSISSIPPI
EASTERN DIVISION**

Capsa Solutions LLC.,

Plaintiff,

v.

Howard Industries, Inc.,

Defendants.

C.A. No. 2:22-cv-00065-HSO-BWR

**DECLARATION OF PINHAS BEN-TZVI IN SUPPORT OF PLAINTIFF CAPSA'S
OPENING CLAIM CONSTRUCTION BRIEF**

I, Pinhas Ben-Tzvi, declare as follows:

INTRODUCTION

1. I have been retained by Plaintiff Capsa Solutions LLC (or "Capsa").
2. I have personal knowledge of the facts stated herein, unless stated otherwise, and I would testify truthfully to those facts if called as a witness.

BACKGROUND AND QUALIFICATIONS

3. I received a BS degree in Mechanical Engineering (Summa Cum Laude) from the Israel Institute of Technology in 2000, a Master's degree in Mechanical Engineering from the University of Toronto in 2004, and a Ph.D. degree in Mechanical Engineering from the University of Toronto in 2008. Attached to this Declaration, as **Exhibit 1**, is a true and correct copy of my curriculum vitae (CV). I have authored numerous technical books and articles in the field. *See Exhibit 1*, CV. I've authored over 180 peer-reviewed articles in the field of engineering design and various mechanisms. I have also been

retained as an expert in support of patent litigation. *See*, **Exhibit 2**, list of cases. I have prior expert witness experience, written expert reports, and testified in depositions, IPR and ITC proceedings related to patent infringement cases and validity issues also related to medical equipment.

4. I am currently a Professor in the Department of Mechanical Engineering at Virginia Tech University, Blacksburg, Virginia. I am a tenured Professor of Mechanical Engineering and Electrical and Computer Engineering, and Founder and the Director of the Robotics and Mechatronics Lab at Virginia Tech. I am also a licensed Professional Engineer (P.E.).
5. I am currently also a Program Director for the Established Program to Stimulate Competitive Research (EPSCoR), Office of Integrative Activities (OIA), Office of the Director (OD), National Science Foundation (NSF), Alexandria, VA on an Intergovernmental Personnel Act (IPA) assignment as detail to NSF. My views in this declaration are my own, and do not represent the NSF in any way or form.
6. I am the named inventor on at least twelve U.S. patents and patent applications and a Canadian patent directed to various electromechanical devices.
7. My expertise includes mechatronics, robotics, automated control systems and automation, mechanical design, mechanism design, machine design, and product development and integration. I have additional knowledge in mobile robotics for military and police applications, human-robot interaction, microprocessor-based applications, and computer aided design (CAD).
8. In my many years of engineering, manufacturing, and product development experience, I have personally been involved in the design of many types of mechanical products,

including many designs using drivers (e.g., gas pistons or springs, hydraulic drivers, electro-mechanical drivers/linear actuators). I am intimately familiar with the technology, and concepts utilized in the products at issue in this case. In my experience, I have seen the importance of understanding how a product will be used and how chosen performance features will determine the predominant final product application.

9. I am an experienced mechanical/electromechanical design engineer and technical expert with extensive experience with various types of drivers, linear motion control, and ergonomic industrial design. I have over 23 years of combined industrial and academic experience in mechanical design, testing, prototyping, developing, and machine/mechanism design, synthesis, analysis, manufacturing and integration. I have industrial experience working for General Electric Medical Systems and other companies in product development that involved the use of height adjustment mechanisms that use drivers for various medical equipment. At General Electric Medical Systems, I designed and integrated various devices and related electronic components including height adjustment mechanisms and drivers used in conjunction with the development of two-degrees-of-motion beds for PET, CT and MRI machines.
10. I also teach courses at Virginia Tech in electro-mechanics that involve the design and construction of various drivers, actuators and linear motion control. I also frequently use and design drivers and linear motion control components in development of prototypes as part of my ongoing academic research funded by a variety of government agencies.

CLAIM CONSTRUCTION

11. The technology at-issue in the present case relates to patents relating to improvements to the field of mobile workstation cart technology, more particularly

to claim terms from U.S. Patent Nos. 7,594,668 (“the ‘668 Patent”), 8,215,650 (“the ‘650 Patent”), 8,109,527 (“the ‘527 Patent”), 9,039,016 (“the ‘016 Patent”), and D762,339 (“the D339 Patent”) (collectively, “the Asserted Patents” or “Patents-in-suit”). For the opening claim construction brief, I was only asked to review and provide my opinions relating to the ‘668 and ‘650 Patents. Thus, at this time, I have not reviewed the other Patents-in-suit. I reserve the right to review these other patents and provide opinions rebutting Defendant Howard’s, and their expert’s, positions in their opening brief on claim construction.

12. It is my understanding that Webster’s 3rd New International Dictionary is a dictionary often cited by the Court of Appeals for the Federal Circuit. It has a copyright date of 2002.

13. It is my understanding that the McGraw-Hill Dictionary of Scientific and Technical Terms, 6th Edition is a dictionary often cited by the Court of Appeals for the Federal Circuit. It has a copyright date of 2002.

14. I have been advised that the effective filing dates of each of the Patents-in-suit fall within the 2003-2004 date range for the ‘668 and ‘650 Patents, the 2008 timeframe for the ‘527 Patent, the 2012 timeframe for the ‘016 Patent, and the 2014 timeframe for the D’339 Patent (collectively between the 2003-2014 timeframe). My opinions regarding the meanings of the claim terms from these Patents-in-suit were derived from a review of these patents from the view of one of ordinary skill in the art at the time of the inventions (or the effective filing dates of each of the Patents-in-suit). For the opening claim construction brief, I was only asked to review and provide my opinions relating to the ‘668 and ‘650 Patents. Thus, currently, I have not reviewed the other Patents-in-suit. It

is my opinion that the definition of a person of ordinary skill in the art stayed consistent during the period between 2003-2014 (the period of invention of the Patents-in-suit). A person of ordinary skill in the art (POSITA) in the 2003-2014 timeframe would have had a bachelor's degree in a pertinent discipline involving mechanical product design, such as mechanical engineering, with 2-3 years of experience in in the design, manufacture, or analysis of mechanical devices. Alternatively, a POSITA would have been a person with a 2-year mechanical engineering diploma and 4-6 years of experience in in the design, manufacture, or analysis of mechanical components and devices.

15. Upon a review of the '650 Patent (and '668 Patent as it shares the same description with the '650 Patent), a person of ordinary skill in the art at the time of the invention (2003-2004 timeframe) would have understood that Plaintiff's proposed definition of "height adjustment" as "a set of components for adjusting the height of an object" is the correct definition when defined in the context of the intrinsic evidence (e.g., the claims, the specification, and prosecution history). This definition is consistent with the plain and ordinary meaning of the term "height adjustment mechanism." *See, e.g.,* '650 Patent, claims 1, 2; '650 Patent, Figure 1; '650 Patent, Figures 9A, 9B, 10A, 10B; '650 Patent, col. 3:38-39; '650 Patent, col. 8:29-38; '650 Patent, col. 14:5-17. Height adjustment mechanisms may use various types of drive mechanisms ("drivers") that use energy to drive motion to other components, e.g., gas pistons or other types of linear actuators using hydraulic or electro-mechanical mechanisms.
16. It is known in the art that a "linear actuator" is a type (subset) of driver (e.g., hydraulic, pneumatic/gas, electro-mechanical/motor) that converts energy/input into linear motion. Rotary type actuators are types of drivers/mechanisms that convert energy/input into

rotary motion. The '650 and '668 Patents relate to height adjustment mechanisms and drivers that drive motion in the linear direction (e.g., up and down in straight line for height adjustment) as opposed to in the rotary direction. For example, hydraulic drivers employ enclosed fluid to transfer energy from one source to another, and subsequently create rotary motion, linear motion, or force; pneumatic drivers (e.g., gas springs or gas driven pistons) use compressed gas; and electro-mechanical drivers may use electric motors to generate the motion. Electro-mechanical type drivers may include, for example, rack and pinion type drivers, ball screw type drivers, or cable and pulley type drivers.

17. Upon a review of the '650 Patent (and '668 Patent as it shares the same description with the '650 Patent), a person of ordinary skill in the art the time of the invention (2003-2004 timeframe) would have understood that Plaintiff's proposed definition of "driver" as "a mechanical component for imparting motion to another component" is the correct definition when defined in the context of the intrinsic evidence (e.g., the claims, the specification, and prosecution history). This definition is consistent with the plain and ordinary meaning of the term "driver." *See, e.g.*, '650 Patent, cl. 1, 8; '650 Patent, col. 8:29-38; '650 Patent, col. 8:52-54; '668 Patent, claims 2, 3, 4.

18. It is my opinion that Defendant Howard's proposed definition of "driver" as being limited to a "gas driven piston" is improper as a gas driven piston is only one example type of a driver and there is no evidence in the '650 and '668 Patents that the patentee intended to limit the term "driver" to a gas driven piston (either by clearly redefining the term or disclaiming other types of drivers). One of ordinary skill in the art, after reviewing the intrinsic evidence, would understand that the patentee did not intend to

limit the present invention to a specific type of driver as different types of drivers can be used interchangeably in the present invention to adjust the height of the work platform.

19. I have reviewed the Websites listed below. These Websites discuss different types of drivers that may be used as the drive mechanism in height adjustment mechanisms (e.g., linear actuators that use energy to drive motion in a linear direction, pneumatic (gas) actuators, hydraulic actuators, electro-mechanical/motor actuators).

- <https://www.linearmotiontips.com/main-types-linear-actuators/>, **Exhibit 3**
- <https://components101.com/articles/types-of-actuators>, **Exhibit 4**
- https://www.globalspec.com/learnmore/motion_controls/linear_actuators/linear_actuators, **Exhibit 5**

It was known to one of ordinary skill in the art at the time of the invention that different types of drivers may be used interchangeably for height adjustment applications.

20. Other U.S. Patents and Patent Applications as confirmation show that the term “height adjustment mechanism” and “driver” each refers to a general, known, class of structures. For example, U.S. Patent No. 9,367,061 to Miller, Fig. 2A, col. 6:52-7:38; col. 13:28-44; col. 13:60-14:15 (3rd party patent related to a medical cart discussing height adjustment mechanisms and “drivers,” and describing that different types of “drivers” can be used as the drive mechanism for the height adjustment mechanism, e.g., gas driven pistons and linear actuators as known structures in the art). See Exhibit E of Plaintiff’s Opening Claim Construction Brief for a copy of the Miller patent (U.S. Patent No. 9,367,061).

21. Upon a review of the ’650 Patent (and ’668 Patent as it shares the same description with the ’650 Patent), a person of ordinary skill in the art at the time of the invention (2003-2004 timeframe) would have understood that Plaintiff’s proposed definition of “actuator” as “a mechanism to activate or control equipment, e.g., by use of pneumatic, hydraulic, or electrical signals” is the correct definition when defined in the context of the intrinsic

evidence (e.g., the claims, the specification, and prosecution history). This definition is consistent with the plain and ordinary meaning of the term “actuator.” *See, e.g.*, ’668 Patent, cl. 1, 2, 3, 4 (claim 2 discussing how the actuator controls the driver for the height adjustment mechanism); ’668 Patent, col. 11:6-40, Fig. 22 (discussing the use of a “button” actuator to send “lock” control signals to drive the solenoid piston driver to lock or unlock the compartments); ’650, cl. 1, 5, 8; ’650 Patent, col. 9:1-4 (referring to “a button **444** of the actuator **440**”); ’650 Patent, Figure 9A, 9B, 10B; ’650 Patent, col. 8:52-56; ’650 Patent, col. 9:1-38.

22. “Actuators” have a well-known meaning in the art and they refer to a general, known class of structures that activate or control equipment. Actuators can come in various forms (e.g., push-button actuators, levers, knobs, switches, touchscreens).
23. Although the ’650 and ’668 Patent describe one example type of “actuator” – a push button actuator – it is my opinion that the term “actuator” can encompass other types of actuators (for example as listed in the immediately preceding paragraph 22).
24. The ’650 Patent, col. 9:1-38, claims 1, 8, describes one type of driver: – a gas driven piston or gas spring similar to those found in a height-adjustable office chair. The ’650 Patent describes pressing the button of the actuator which allows the valves of the gas piston (driver) to open to expel from the piston chamber (or inhale air) causing the piston to move up or down. The internal pressure of the sealed gas moving in the gas driven piston drives the piston, and thus the chair, up when the actuator is pressed (opening the internal valve). Releasing the button actuator allows the valve to close releasably locking the piston, and thus the chair, in place. Nowhere in the ’650 or ’668 Patents does the patentee redefine the term “actuator” as meaning one specific type of actuator (e.g., push-

button actuator) or disclaim coverage over other types of actuators (e.g., levers, knobs, switches, touch screens, etc.).

25. It was well-known to one of ordinary skill in the art at the time of the inventions, that gas driven pistons can be sealed/closed systems or unsealed/open systems. Gas driven pistons that are sealed, e.g., gas springs, do not accept an external source of gas as input energy. Instead, sealed systems have internal valves and use internal gas pressure to drive the internal piston. Unsealed/open gas driven pistons accept gas as external input to drive the internal piston of the gas driven piston. The example embodiment of the gas driven piston described in the '650 and '668 Patents is similar to a sealed/closed gas driven piston as it operates similar to a gas spring in a height adjustable office chair. *See, e.g., '650 Patent, col. 9:1-38, claims 1, 8.*

26. The following Websites provide good background discussions on the operation of various types of pneumatic drivers (e.g., gas driven pistons and gas springs). Again, gas driven pistons can be sealed/closed systems or unsealed/open systems:

- a. <https://tameson.com/pages/pneumatic-cylinders> (discussing an example double-acting pneumatic cylinder (e.g., an open system) where gas is input into the system from an external source to drive motion, **Exhibit 6**;
- b. <https://www.machinedesign.com/mechanical-motionsystems/article/21837752/aguide-to-gas-spring-designand-customization>, **Exhibit 7**;
- c. <https://officechairpicks.com/gas-cylinder/> (describing one example of a gas piston driver (e.g., gas spring or gas cylinder) with actuator using the example of an office chair and discussing using the gas spring for “locking to hold a position” by “[l]etting go of the button or lever lets the valve close and locks the piston so the seat remains at that height.” As stated, “a gas cylinder relies on compressed air to raise and lower your seat.” The site also discusses using “actuators” like levers to control the gas driver), **Exhibit 8**.
- d. <https://www.youtube.com/watch?v=hmz1h5fk2bI> (showing embodiments of a gas driver where air is supplied from an external source instead of a closed or sealed piston), **Exhibit 9, screenshots from YouTube video**.
- e. <https://www.explainthatstuff.com/gassprings.html> (explanation of how gas springs help to drive/lift heavier items using compressed gas by opening and

closing the release valve – similar to a gas spring used with a car engine hood that helps drive the hood open. Explaining that a person can lift a heavy car hood with one finger because the compressed gas is driving the hood open), **Exhibit 10**.

27. Upon a review of the '650 Patent (and '668 Patent as it shares the same description with the '650 Patent), a person of ordinary skill in the art the time of the invention (2003-2004 timeframe) would have understood that Plaintiff's proposed definition of "releasably lock/position" to mean "to releasably fix or hold in place" is the correct definition when defined in the context of the intrinsic evidence (e.g., the claims, the specification, and prosecution history). This definition is consistent with the plain and ordinary meaning of the term "releasably lock/position." The description of the '668 and '650 Patents demonstrates that the patentee used the term "releasably lock/position" broadly, and is consistent with its plain and ordinary meaning. *See, e.g.*, '650 Patent, col. 6:20-23, Figure 3C (discusses releasably locking or holding the work surface in position to prevent it from sliding); '650 patent, col. 9:11-38 (discussing the example of gas driven piston using internal gas pressure to releasably lock the work platform in place); '650 Patent, col. 10:1-22 (discusses the releasable connection to a medication module); '650 Patent, col. 12:39-67 (discussing using an example locking mechanism **170** to releasably lock the nested medication modules); *see also*, '650 Patent, col. 13:1-29. Nowhere in these sections of the '650 or '668 Patents does the patentee redefine the term "releasably lock/position" as meaning one specific type of lock (e.g., pin or latch) or disclaim coverage over other types of lock methods. In fact, gas driven pistons generally do not use pins or latches to releasably lock the component (e.g., work platform or seat) in place – it uses internal gas pressure.
28. Gas driven pistons use internal gas pressure, and the balancing of internal pressures, to

releasably lock/position the piston in place. If the actuator is re-activated, the driver (e.g., gas driven piston) is released from the locked position.

29. Upon a review of the '650 Patent (and '668 Patent as it shares the same description with the '650 Patent), a person of ordinary skill in the art the time of the invention (2003-2004 timeframe) would have understood that Plaintiff's proposed definition of "work platform" as "a height adjustable set of components for facilitating work configured to be raised and lowered together" is the correct definition when defined in the context of the intrinsic evidence (e.g., the claims, the specification, and prosecution history). *See, e.g.,* '650 Patent, Figures 1 and 7 (depicting one example of the work platform with work surfaces and compartment(s)); '650 Patent, col. 4:30-37 (describing one example embodiment of a work platform and that all of the items that make up the work platform can be ergonomically accessed because they are raised and lowered as part of the work platform); '650 Patent, col. 7:28-32 (again stating that the work platform, including the compartments, move up and down together); *see, also*, '650 Patent, col. 8:15-22; 25-28; '650 Patent, col. 9:32-38.

30. Upon a review of the '650 Patent (and '668 Patent as it shares the same description with the '650 Patent), a person of ordinary skill in the art the time of the invention (2003-2004 timeframe) would have understood that Plaintiff's proposed definition of "movable platform" as "a substantially flat, raised area or structure that can move" is the correct definition when defined in the context of the intrinsic evidence (e.g., the claims, the specification, and prosecution history). This definition is consistent with the plain and ordinary meaning of the term "movable platform." For example, it is generally known that "platforms" generally are comprised of a substantially flat, raised area. *See, e.g.,*

'650 Patent, cl. 6 (reciting “[t]he cart of claim 1, wherein the work platform further comprises a movable platform configured to move in at least one of the forward direction and the rearward direction.”); cl. 9, 12, 13 (claiming the “movable platform” separately from the “work surface.”) The description of the '668 and '650 Patents also demonstrates that the patentee used the term “movable platform” broadly, consistent with its plain and ordinary meaning. *See, e.g.*, '650 Patent, Fig. 1, 2A, 2B, 4A (describing one example movable platform **370** (e.g., laptop platform that moves in and out) separate from work surface **350**); *see, also*, '650 Patent, col. 4:30-col. 5:51; '650 Patent, col. 8:15-28.

31. Upon a review of the '650 Patent (and '668 Patent as it shares the same description with the '650 Patent), a person of ordinary skill in the art the time of the invention (2003-2004 timeframe) would have understood that the term “work surface” is used consistent with its plain and ordinary meaning in the art when read in the context of the intrinsic evidence (e.g., the claims, the specification, and prosecution history). The review of the intrinsic evidence demonstrates the meaning of this term is readily apparent and this term does not need construction as a jury would not have trouble understanding these commonly used words. *See, e.g.*, '650 Patent, Fig. 1, 2A, 2B, 4A (describing one example movable platform **370** (e.g., laptop platform that moves in and out) separate from work surface **350**); '650 Patent, col. 6:14-20. '650 Patent, col. 4:21-22; 41-44; 52-59; '650 Patent, col. 14:5-17 (stating that the invention is not restricted to the described embodiments in the patent and that the claims define the invention); '650 Patent, col. 5:42-44 (discussing secondary work surface **379** that is exposed when the laptop platform is pushed out – this secondary work surface is *not* curved).

32. The term “work surface” means just what it sounds like – a surface for doing work and there is no further need to define this claim term.

33. Defendant Howard’s proposed definition of “work surface” is improper as it redefines the term “work surface” to be “curved” and “large enough to dispense medication or hold work papers” even though the ’668 Patent does not demonstrate that the inventor intended to redefine the term.

34. The “curved” aspect and specific size (e.g., large enough to dispense medication or hold work papers) of the described “work surface” of the medical cart in the ’668 Patent are just example types of work surfaces but it is my opinion that the inventor did not intend to limit the described “work surface” to the specific type described (either by clear redefinition or disclaimer of claim scope).

I declare under penalty of perjury that the foregoing is true and accurate.

Executed this 26th day of May, 2023.



Pinhas Ben-Tzvi

EXHIBIT 1

Pinhas Ben-Tzvi, Ph.D., P.E., FASME, SMIEEE
College of Engineering Faculty Fellow
Professor of Mechanical Engineering
Professor of Electrical and Computer Engineering
Director, VT Robotics and Mechatronics Laboratory (RMLab)
Department of Mechanical Engineering, Virginia Tech
Tel: (202) 641-8011
Email: pinhas.bentzvi@gmail.com; Website: www.RMLab.org

Professional Experience

- 08/2022–Present: **Program Director**
Established Program to Stimulate Competitive Research (EPSCoR)
Office of the Director (OD), Office of Integrative Activities (OIA)
National Science Foundation (NSF), Alexandria, VA
- 06/2020–Present: **Professor**
Department of Mechanical Engineering,
Virginia Tech, Blacksburg, VA
- 06/2020–Present: **Professor** (by courtesy)
Bradley Department of Electrical and Computer Engineering,
Virginia Tech, Blacksburg, VA
- 08/2015–05/2020: **Associate Professor**
Department of Mechanical Engineering,
Virginia Tech, Blacksburg, VA
- 05/2016–Present: **Associate Professor** (by courtesy)
Bradley Department of Electrical and Computer Engineering,
Virginia Tech, Blacksburg, VA
- 08/2014–08/2015: **Associate Professor**
Department of Mechanical & Aerospace Engineering,
George Washington University, Washington, DC
- 09/2008–08/2014: **Assistant Professor**, Department of Mechanical & Aerospace Engineering,
George Washington University, Washington, DC
- 09/2008–Present: **Founder and Director**, Robotics and Mechatronics Laboratory,
Virginia Tech, Blacksburg, VA: Aug 2015 - Present
George Washington University, Washington, DC: Sep 2008 – Aug 2015
- 2006 – 2008: **Lecturer**, Department of Mechanical & Industrial Engineering,
University of Toronto, Ontario, Canada
- 2006 – 2008: **Consultant**, Mobile Robots Division, Engineering Services Inc., Toronto, Canada
Design, Development and Integration of Mobile Robot Systems/Mechanisms
- 2002 – 2008: **Graduate Research Assistant**, Department of Mechanical Engineering,
University of Toronto, Ontario, Canada
Mobile robot mechanisms with hybrid mobility and manipulation (Ph.D.);
Dispensing systems for microdrops generation in medical applications (M.S.)

- 2002 – 2008: **Graduate Teaching Assistant**, Department of Mechanical Engineering, University of Toronto, Ontario, Canada
- 2000 – 2002: **R&D Mechanical Engineer**, General Electric Medical Systems, Haifa, Israel
Conducted research on design, development, and integration of mechanisms and mechatronic/robotic systems for medical imaging systems (CT, PET, MRI)
- 1998 – 2000: **Research Assistant**, Technion – Israel Institute of Technology, Haifa, Israel
Developed sensors and control system for a deep drawing mechanical process
- 1993 – 1996: **First Sergeant**, Israeli Air Force Academy

Professional Credential

2020–present **Licensed Professional Engineer (P.E.)**, Maryland

Other Professional Affiliations/Experience:

- 08/2015–Present: **Core Faculty Member**
Virginia Center for Autonomous Systems (VaCAS)
Virginia Tech, Blacksburg, VA
- 08/2015–Present: **Affiliate Faculty Member**
Center for Bioinspired Science and Technology (BIST)
Virginia Tech, Blacksburg, VA

Education

- | | |
|---|------|
| Ph.D., University of Toronto
Department of Mechanical Engineering (GPA 4.0/4.0) | 2008 |
| M.Sc., University of Toronto
Department of Mechanical Engineering (GPA 4.0/4.0) | 2004 |
| B.Sc. (<i>Summa Cum Laude</i>), Technion – Israel Institute of Technology
Department of Mechanical Engineering (GPA 4.0/4.0) | 2000 |
| Practical Engineer Diploma , ORT Vocational College, Haifa, Israel
Mechanical Engineering (<i>with Highest Honors</i> , GPA 4.0/4.0) | 1993 |

Research Expertise and Interests

My research and industrial experiences and expertise span the areas of mechanical/mechatronics design, electromechanical systems design, smart precision sensors and actuators, precision engineering design, mechanism/product design and system integration, intelligent autonomous systems and robotics, precision healthcare technologies, cyber-physical systems, machine learning and AI, human-machine interactions, industrial automation systems, feedback motion control systems, system dynamics.

Examples of research expertise include:

- Electromechanical Systems Design, Integration and Prototyping
- Linear Motion Control, Drivers, Actuators and Sensors
- Ergonomic Industrial Design
- Mechatronic and Robotic Systems - Design, Modeling, Simulation, Analysis, Integration

- Precision Mechanism and Machine Design, Analysis and Synthesis
- Sensing, Precision Actuation Devices and Measurement Modalities for Applications (vehicles, biomedical, industrial, etc.)
- Microprocessor-based Distributed and Modular Control Systems
- System Dynamics and Control
- Computer Aided Design/Engineering CAD/CAE
- Industrial Automation and Manufacturing Systems
- Intelligent Autonomous Systems
- Modular and Reconfigureable Robotic and Mechanical Systems
- Dexterous Robotic Manipulation - Tele-Operation, Autonomous Navigation/Function
- Rehabilitation and Medical Robotics
- Robotic Vision/Perception and Visual Servoing
- Bioinspired & Biomimetic Robotic Locomotion and Manipulation
- Continuum/Flexible Mechanisms and Structures
- Haptics Interfaces and Devices for Robotics Applications

Awards and Honors

Certificate of Recognition, Celebration Innovation

April 2023

Virginia Tech Senior Vice President for Research & Innovation

"In recognition of being awarded and issued patents in FY 2022, and important Step in ensuring important discoveries reach the people who will benefit most".

Faculty Inventor Spotlight

May 2022

Virginia Tech Center for Technology Commercialization

<https://vt.edu/link/license/faculty-inventors/pinhas-ben-tzvi.html>

Fellow, American Society of Mechanical Engineers (ASME)

January 2022

Fellowship is bestowed upon members who have made significant contributions to mechanical engineering with less than 3400 of ASME's approximate 140,000 members receiving the honor

Certificate of Outstanding Professional Service

November 2021

ASME Journal of Mechanisms and Robotics

In recognition of your dedicated service to the *Journal of Mechanisms and Robotics* and the Mechanisms and Robotics community at large (2018-2021)

Featured Journal Publication

October 2021

Guo, Y., Xu, W., Pradhan, S., Bravo, C.J., **Ben-Tzvi, P.**, "Data Driven Calibration and Control for Compact Lightweight Series Elastic Actuators for Robotic Exoskeleton Gloves", *IEEE Sensors Journal*, Vol. 21, Issue 19, pp. 21120-21130, October 2021. DOI: 10.1109/JSEN.2021.3101143

* **Selected as a featured article**

Certificate of Outstanding Professional Service as Technical Editor

January 2021

IEEE/ASME Transactions on Mechatronics

In grateful appreciation for, and recognition of, your dedicated service in advancing the science and art of mechatronics as Technical Editor (2016-2020)

Certificate of Outstanding Service as Associate Editor

January 2021

International Journal of Control, Automation, and Systems (IJCAS)

In Grateful Recognition of Many Years of Dedicated Service to the Control Community as an Associate Editor of IJCAS (January 1, 2011 – December 31, 2020)

Certificate of Appreciation in Outstanding Professional Service

August 2019

The Design Engineering Division, ASME
In Recognition of Outstanding Service as Program Co-Chair of the 43rd Mechanisms and Robotics Conference (MR) 2019

Excellence in Teaching Award May 2019
College of Engineering, Virginia Tech
In Recognition of Extraordinary Performance in Teaching

IJCAS Academic Activity Award January 2019
International Journal of Control, Automation, and Systems (IJCAS)
"In recognition of his outstanding service and dedicated work as an editorial board member of the IJCAS and for his exceptional contributions in the advancement of the journal."

Faculty Fellow, College of Engineering April 2018
Virginia Tech
In Recognition of Extraordinary Performance in Research

Keynote Speech Award February 2018
International Conference on Mechatronics Systems and Control Engineering
"In honor of your excellent Keynote Speech and your significant contribution to the success of 2018 International Conference on Mechatronics Systems and Control Engineering (ICMSCE 2018), Amsterdam, Netherlands, Feb 21-23, 2018"

Virginia Tech Inventor of the Month August 2016
The Office of the Vice President for Research and Innovation recognizes Pinhas Ben-Tzvi as Inventor of the Month for August 2016 for his multiple inventions disclosed to Virginia Tech Intellectual Properties Inc.

IJCAS Academic Activity Award December 2013
International Journal of Control, Automation, and Systems (IJCAS)
"In recognition of his outstanding service and dedicated work as an editorial board member of the IJCAS and for his exceptional contributions in the development of the journal."

GW SEAS Outstanding Young Researcher Award April 2013
<http://www.rmlab.org/honors.php>
"In recognition of his demonstrated and exceptional contributions to robotics, mechatronics, mechanism design and integration, systems dynamics and control, and sensing and actuation. Developing a very strong and externally sponsored program that covers both theoretical and applied research, Prof. Ben-Tzvi has quickly established himself as one of the leading researchers in the field of robotics, mechatronics, and controls. He founded the GW Robotics & Mechatronics Research Laboratory, and used both the lab and his research to help launch the GW robotics program."

GW SEAS Outstanding Young Teacher Award April 2013
<http://www.rmlab.org/honors.php>
"In recognition of his dedicated pursuit of innovative curricula and teaching methods, his efforts to develop the robotics program at SEAS, and his STEM-related mentoring and outreach activities to the local community. Prof. Ben-Tzvi works tirelessly to improve and promote robotics education, in particular, and STEM-related education in general. He has developed new courses and new labs for students, initiated and spearheaded the development of a new robotics degree program option for undergraduate students, and created a variety of STEM-related educational outreach activities in robotics for the community beyond SEAS."

IEEE Senior Member (highest grade below fellow) April 2012

Winner of the Best Paper Award October 2011
for the paper entitled "MEMS-Based Microdroplet Generation with Integrated Sensing"

presented at the 2011 COMSOL Conference, Boston, MA, Oct 13–15, 2011
(with Doctoral Student William Rone)

Pi Tau Sigma

November 2009

Faculty Honorary Membership (elected by the students)

Featured Journal Publication

March 2009

Cover Article: "Design and Analysis of a Fast Steering Mirror for Precision Laser Beams Steering"; *Sensors & Transducers Journal*, 5(3): 104–118 (2009)

The Robotdalen Scientific Award

September 2008

Honorable Mention Recipient, Eskilstuna, Sweden

Governor General's Gold Medal Award of Canada - Finalist

May 2008

Nominated by the Dept. of Mechanical Engineering at the University of Toronto among 60 graduated Ph.D. students to honor academic excellence at the doctoral level

Winner of the Best Student Paper Award

October 2007

for the paper entitled "Implementation of Sensors and Control Paradigm for a Hybrid Mobile Robot Manipulator for Search and Rescue Operations" presented at the *2007 IEEE International Workshop on Robotic & Sensors Environments (ROSE 2007)*

University of Toronto Open Fellowship (four awards)

2004 – 2008

Doctorate Research, University of Toronto

University of Toronto Open Fellowship (two awards)

2002 – 2003

Masters Research, University of Toronto

Summa Cum Laude, B.Sc. in Mechanical Engineering

September 2000

Technion – Israel Institute of Technology (IIT)

President's Honors List Award (five awards)

1998 – 2000

Undergraduate Studies, Faculty of Mechanical Engineering, Technion – IIT

Dean's Honors List Award (two awards)

1996 – 1998

Undergraduate Studies, Faculty of Mechanical Engineering, Technion – IIT

Award for Outstanding Academic Achievements

1998

Undergraduate Studies at the Technion – Israel Inst. of Tech., Ministry of Education, Israel

Publications

Books

- [1] Kurdila, A.J., **Ben-Tzvi, P.**, Dynamics and Control of Robotic Systems. Wiley & Sons, Inc., December 2019, ISBN: 978-1-119-52483-0. (520 pages)

Peer-Reviewed Journal Publications (75 published, 1 accepted, 3 submitted/under review)

- [79] Liu, Y., **Ben-Tzvi, P.**, "VT Lemur: A Novel Quadruped Robot with a Serpentine Robotic Tail," *International Journal of Robotics Research*, **Under review**, January 2023.
- [78] Guo, Y., Xu, W., **Ben-Tzvi, P.**, "Vision Based Human Machine Interface for a Rehabilitation Robotic Exoskeleton Glove", *IEEE Transactions on Systems, Man, and Cybernetics:*

Systems, **Under review**, December 2022.

- [77] Liu, Y., **Ben-Tzvi, P.**, "How a Serpentine Tail Assists Agile Motions of Kangaroo Rats: A Dynamics and Control Approach", Nonlinear Dynamics, **Accepted with minor revisions**, February 2023. <https://doi.org/10.21203/rs.3.rs-1315822/v1>
- [76] Xu, W., Guo, Y., Bravo, C.J., **Ben-Tzvi, P.**, "Design, Control, and Experimental Evaluation of a Novel Robotic Glove System for Patients with Brachial Plexus Injuries", IEEE Transactions on Robotics, Vol. 39, Issue 2, pp. 1637-1652, April 2023. DOI: 10.1109/TRO.2022.3220973
- [75] Feng, S., Pressgrove, I., **Ben-Tzvi, P.**, "A Modular Robotic System with Self-Reconfiguration Strategies Demonstrating Autonomous Module-to-Module Alignment and Docking", Journal of Mechanisms and Robotics, Transactions of the ASME, **Under review**, April 2022.
- [74] Han, X., Ren, H., Qi, J., **Ben-Tzvi, P.**, "Autonomous Cricothyroid Membrane Detection and Manipulation using Neural Networks and Robot Arm for First-Aid Airway Management", Journal of Medical Devices, Transactions of the ASME, Vol. 17, Issue 1, pp. 014502: 1-9, March 2023. DOI: <https://doi.org/10.1115/1.4056505>
- [73] Guo, Y., Xu, W., Pradhan, S., Bravo, C.J., **Ben-Tzvi, P.**, "Personalized Voice Activated Grasping System for a Robotic Exoskeleton Glove", Mechatronics Journal, Vol. 83, pp. 102745:1-12, May 2022. DOI: 10.1016/j.mechatronics.2022.102745
- [72] Sohal, S.S., Sebastian, B., **Ben-Tzvi, P.**, "Autonomous Docking of Hybrid-Wheeled Modular Robots With an Integrated Active Genderless Docking Mechanism", Journal of Mechanisms and Robotics, Transactions of the ASME, Vol. 14, Issue 1, pp. 011010: 1-15, February 2022. DOI: doi.org/10.1115/1.4051519
- [71] Njaka, T., Brizzolara, S., **Ben-Tzvi, P.**, "Design and Experimental Validation of a Novel High-Speed Omnidirectional Underwater Propulsion Mechanism", IEEE/ASME Transactions on Mechatronics, Vol. 26, Issue 5, pp. 2339-2349, October 2021. DOI: 10.1109/TMECH.2020.3037887
- [70] Guo, Y., Xu, W., Pradhan, S., Bravo, C.J., **Ben-Tzvi, P.**, "Data Driven Calibration and Control for Compact Lightweight Series Elastic Actuators for Robotic Exoskeleton Gloves", IEEE Sensors Journal, Vol. 21, Issue 19, pp. 21120-21130, October 2021. DOI:10.1109/JSEN.2021.3101143 * **Selected as a featured article**
- [69] Yang, J., Saab, W., Liu, Y., **Ben-Tzvi, P.**, "Reuleaux Triangle Based Two Degrees of Freedom Bipedal Robot", Robotics Journal, Vol. 10, Issue 4, pp. 1-15, October 2021. DOI: 10.3390/robotics10040114
- [68] Liu, Y., **Ben-Tzvi, P.**, "Dynamic Modeling, Analysis, and Design Synthesis of a Reduced Complexity Quadruped with a Serpentine Robotic Tail", Integrative and Comparative Biology, Vol. 61, Issue 2, pp. 464-477, August 2021. DOI: 10.1093/icb/icab083
- [67] Liu, Y., **Ben-Tzvi, P.**, "A New Extensible Continuum Manipulator Using Flexible Parallel Mechanism and Rigid Motion Transmission", Journal of Mechanisms and Robotics, Transactions of the ASME, Vol. 13, Issue 3, pp. 031112: 1-7, June 2021. DOI: doi.org/10.1115/1.4050097
- [66] Feng, S., Sebastian, B., **Ben-Tzvi, P.**, "A Collision Avoidance Method Based on Deep Reinforcement Learning", Robotics Journal, Vol. 10, Issue 2, pp. 1-19, May 2021.

- [65] Ren, H., Qi, J., **Ben-Tzvi, P.**, “Learning Flatness-Based Controller Using Neural Networks”, ASME Letters in Dynamic Systems and Control, Vol. 1, Issue 2, pp. 021003: 1-6, April 2021. DOI: 10.1115/1.4046776
- [64] Wang, J., Liu, Y., **Ben-Tzvi, P.**, “Robust Adaptive Input-Output Control for a Class of Modular Robotic Systems via Inverse Optimality Theory”, International Journal of Control, Vol. 95, Issue 7, pp. 1898-1912, July 2022. DOI:10.1080/00207179.2021.1885741
- [63] Liu, Y., **Ben-Tzvi, P.**, “Dynamic Modeling, Analysis, and Comparative Study of A Quadruped With Bio-Inspired Robotic Tails”, Multibody System Dynamics, Vol. 51, Issue 2, pp. 195-219, February 2021. DOI: 10.1007/s11044-020-09764-8
- [62] Vanteddu, T., **Ben-Tzvi, P.**, “Stable Grasp Control with a Robotic Exoskeleton Glove”, Journal of Mechanisms and Robotics, Transactions of the ASME, Vol. 12, Issue 6, pp. 061015: 1-14, December 2020.
- [61] Wang, X., Ren, H., Kumar, A., **Ben-Tzvi, P.**, “Design and Analysis of a Variable Inertia Spatial Robotic Tail for Dynamic Stabilization”, Biomimetics, Vol. 5, Issue 4, pp. 1-16, November 2020. DOI: 10.3390/biomimetics5040055
- [60] Liu, Y., **Ben-Tzvi, P.**, “An Articulated Closed Kinematic Chain Planar Robotic Leg for High Speed Locomotion”, Journal of Mechanisms and Robotics, Transactions of the ASME, Vol. 12, Issue 4, pp. 041003: 1-15, August 2020. DOI: 10.1115/1.4045689
- [59] Liu, Y., **Ben-Tzvi, P.**, “Design, Analysis and Integration of a New Two-DOF Articulated Multi-link Robotic Tail Mechanism”, Journal of Mechanisms and Robotics, Transactions of the ASME, Vol. 12, Issue 2, pp. 021101: 1-9, April 2020. DOI: 10.1115/1.4045842
- [58] Ren, H., **Ben-Tzvi, P.**, “Advising Reinforcement Learning Towards Scaling Agents in Continuous Control Environments with Sparse Rewards”, Journal to Engineering Applications of Artificial Intelligence, Vol. 90, pp. 103515: 1-12, April 2020. DOI: 10.1016/j.engappai.2020.103515
- [57] Ren, H., **Ben-Tzvi, P.**, “Learning Inverse Kinematics and Dynamics of a Robotic Manipulator using Generative Adversarial Networks”, Robotics and Autonomous Systems, Vol. 124, pp. 103386: 1-12, February 2020. DOI: 10.1016/j.robot.2019.103386
- [56] Chauhan, R., Sebastian, B., **Ben-Tzvi, P.**, “Grasp Prediction Towards Naturalistic Exoskeleton Glove Control”, IEEE Transaction on Human-Machine Systems, Vol. 50, Issue 1, pp. 22-31, February 2020. DOI: 10.1109/THMS.2019.2938139
- [55] Refour, E., Sebastian, B., Chauhan, R., **Ben-Tzvi, P.**, “A General Purpose Robotic Hand Exoskeleton with Series Elastic Actuators”, Journal of Mechanisms and Robotics, Transactions of the ASME, Vol. 11, Issue 6, pp. 060902: 1-9, December 2019.
- [54] Williams, A., Sebastian, B., **Ben-Tzvi, P.**, “Review and Analysis of Search, Extraction, Evacuation, and Medical Treatment Field Robots”, Journal of Intelligent and Robotic Systems, Vol. 96, Issue 3, pp. 401-418, December 2019.
- [53] Budolak, D., **Ben-Tzvi, P.**, “Series Elastic Actuation for Improved Transparency in Time Delayed Haptic Teleoperation”, Mechatronics Journal, Vol. 63, pp. 102278:1-8, November 2019. DOI: 10.1016/j.mechatronics.2019.102278
- [52] Sebastian, B., **Ben-Tzvi, P.**, “Support Vector Machine Based Real-time Terrain Estimation

- for Tracked Robots”, *Mechatronics Journal*, Vol. 62, pp. 102260: 1-10, October 2019.
- [51] Liu, Y., Wang, J., **Ben-Tzvi, P.**, “A Cable Length Invariant Robotic Tail Using a Circular Shape Universal Joint Mechanism”, *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 11, Issue 5, pp. 051005: 1-14, October 2019.
 - [50] Kumar, P., **Ben-Tzvi, P.**, “Estimation of Wind Conditions Utilizing RC Helicopter Dynamics”, *IEEE/ASME Transactions on Mechatronics*, Vol. 24, Issue 5, pp. 2293-2303, October 2019.
 - [49] **Ben-Tzvi, P.**, Saab, W., “A Hybrid Tracked-Wheeled Multi-Directional Mobile Robot”, *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 11, Issue 4, pp. 041008: 1-10, August 2019.
 - [48] Rone, W., Saab, W., Kumar, A., **Ben-Tzvi, P.**, “Controller Design, Analysis and Experimental Validation of a Robotic Serpentine Tail to Maneuver and Stabilize a Quadrupedal Robot”, *Journal of Dynamic Systems, Measurement and Control, Transactions of the ASME*, Vol. 141, Issue 8, pp. 081002: 1-9, August 2019.
 - [47] Sebastian, B., **Ben-Tzvi, P.**, “Physics Based Path Planning for Autonomous Tracked Vehicle in Challenging Terrain”, *Journal of Intelligent and Robotic Systems*, Vol. 95, Issue 2, pp. 511-526, August 2019.
 - [46] Racioppo, P., **Ben-Tzvi, P.**, “Design and Control of an Articulated Cable-Driven Modular Snake Robot”, *IEEE/ASME Transactions on Mechatronics*, Vol. 24, Issue 3, pp. 893-901, June 2019.
 - [45] Ren, H., Kumar, A., **Ben-Tzvi, P.**, “LOSA-X: Expandable 3D Motion Tracking System”, *IEEE Sensors Journal*, Vol. 19, Issue 9, pp. 3288-3295, May 2019.
 - [44] Saab, W., Rone, W., Kumar, A., **Ben-Tzvi, P.**, “Design and Integration of a Novel Spatial Articulated Robotic Tail”, *IEEE/ASME Transactions on Mechatronics*, Vol. 24, Issue 2, pp. 434-446, April 2019.
 - [43] Sebastian, B., **Ben-Tzvi, P.**, “Active Disturbance Rejection Control for Handling Slip in Tracked Vehicle Locomotion”, *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 11, Issue 2, pp. 021003: 1-12, April 2019.
 - [42] Williams, A., Sebastian, B., **Ben-Tzvi, P.**, “A Robotic Head Stabilization Mechanism for Medical Transport”, *Robotics Journal*, Vol. 8, Issue 1, pp. 1-16, March 2019.
 - [41] Saab, W., Racioppo, P., Kumar, A., **Ben-Tzvi, P.**, “Design of a Miniature Modular Inchworm Robot with an Anisotropic Friction Skin”, *Robotica Journal*, Vol. 37, Issue 3, pp. 521-538, March 2019.
 - [40] Saab, W., Racioppo, P., **Ben-Tzvi, P.**, “A Review of Coupling Mechanism Designs for Modular Reconfigurable Robots”, *Robotica Journal*, Vol. 37, Issue 2, pp. 378-403, February 2019.
 - [39] Rone, W., Liu, Y., **Ben-Tzvi, P.**, “Maneuvering and Stabilization Control of a Bipedal Robot with a Universal-Spatial Robotic Tail”, *Bioinspiration and Biomimetics Journal*, Vol. 14, Issue 1, pp. 016014: 1-16, January 2019.
 - [38] Liu, Y., Kong, M., Wan, N., **Ben-Tzvi, P.**, “A Geometric Approach to Obtain the Closed-Form Forward Kinematics of H4 Parallel Robot”, *Journal of Mechanisms and Robotics*,

- Transactions of the ASME, Vol. 10, Issue 5, pp. 051013: 1-9, October 2018.
- [37] Saab, W., Rone, W., **Ben-Tzvi, P.**, "Robotic Tails: A State-of-The-Art Review", Robotica Journal, Vol. 36, Issue 9, pp. 1263-1277, September 2018.
 - [36] Lee, J., Williams, A., **Ben-Tzvi, P.**, "Intelligent Object Grasping with Sensor Fusion for Rehabilitation and Assistive Applications", IEEE Transactions on Neural Systems & Rehabilitation Engineering, Vol. 26, Issue 8, pp. 1556-1565, August 2018.
 - [35] Rone, W., Saab, W., **Ben-Tzvi, P.**, "Design, Modeling and Integration of a Flexible Universal Spatial Robotic Tail", Journal of Mechanisms and Robotics, Transactions of the ASME, Vol. 10, Issue 4, pp. 041001: 1-14, August 2018.
 - [34] Saab, W., Rone, W., **Ben-Tzvi, P.**, "Discrete Modular Serpentine Robotic Tail: Design, Analysis and Experimentation", Robotica Journal, Vol. 36, Issue 7, pp. 994-1018, July 2018.
 - [33] Kumar, A., **Ben-Tzvi, P.**, "Novel Wireless Sensing Platform for Experimental Mapping and Validation of Ship Air Wake", Mechatronics Journal, Vol. 52, pp. 58-69, June 2018.
 - [32] Refour, E., Sebastian, B., **Ben-Tzvi, P.**, "Two-Digit Robotic Exoskeleton Glove Mechanism: Design and Integration", Journal of Mechanisms and Robotics, Transactions of the ASME, Vol. 10, Issue 2, pp. 025002: 1-9, April 2018.
 - [31] Yanga, Y., Ren, H., Yang, X., **Ben-Tzvi, P.**, He, Z., "Optimal Interval of Periodic Polarity Reversal for Maximizing Hydrogen Production in Microbial Electrolysis Cells", International Journal of Hydrogen Energy, Vol. 42, Issue 31, pp. 20260–20268, Aug. 2017.
 - [30] Saab, W., Rone, W., **Ben-Tzvi, P.**, "Robotic Modular Leg: Design, Analysis and Experimentation", Journal of Mechanisms and Robotics, Transactions of the ASME, Vol. 9, Issue 2, pp. 024501: 1-6, April 2017.
 - [29] Saab, W., **Ben-Tzvi, P.**, "A Genderless Coupling Mechanism with 6-DOF Misalignment Capability for Modular Self-Reconfigurable Robots", Journal of Mechanisms and Robotics, Transactions of the ASME, Vol. 8, Issue 6, pp. 061014: 1-9, December 2016.
 - [28] Ma, Z., **Ben-Tzvi, P.**, Danoff, J., "Hand Rehabilitation Learning System with an Exoskeleton Robotic Glove", IEEE Transactions on Neural Systems & Rehabilitation Engineering, Vol. 24, Issue 12, pp.1323–1332, December 2016.
 - [27] Zhao, H., **Ben-Tzvi, P.**, "Synchronous Position Control Strategy for Bi-Cylinder Electro-pneumatic Systems", International Journal of Control, Automation and Systems, Vol. 14, Issue 6, pp. 1501-1510, December 2016.
 - [26] Kumar, A., **Ben-Tzvi, P.**, "Spatial Object Tracking System Based on Linear Optical Sensor Arrays", IEEE Sensors Journal, Vol. 16, Issue 22, pp. 7933-7940, November 2016.
 - [25] **Ben-Tzvi, P.**, Danoff, J., Ma, Z., "The Design Evolution of a Sensing and Force-Feedback Exoskeleton Robotic (SAFER) Glove for Hand Rehabilitation Application", Journal of Mechanisms and Robotics, Transactions of the ASME, Vol. 8, Issue 5, pp. 051019: 1-9, October 2016.
 - [24] Rone, W., **Ben-Tzvi, P.**, "Dynamic Modeling and Simulation of a Yaw-Angle Quadruped Maneuvering with a Robotic Tail", Journal of Dynamic Systems, Measurement and Control, Transactions of the ASME, Vol. 138, Issue 8, pp. 084502: 1-7, August 2016.

- [23] Kumar, A., **Ben-Tzvi, P.**, Saab, W., Snyder, M.R., "Wireless Telemetry System for Real-time Estimation of Ship Air Wake with UAVs", *Mechatronics Journal*, Vol. 36, pp. 18-26, June 2016.
- [22] **Ben-Tzvi, P.**, Ma, Z., "Sensing and Force-Feedback Exoskeleton (SAFE) Robotic Glove", *IEEE Transactions on Neural Systems & Rehabilitation Engineering*, Vol. 23, Issue 6, pp. 992-1002, November 2015.
- [21] Ma, Z., **Ben-Tzvi, P.**, "Design and Optimization of a Five-Finger Haptic Glove Mechanism", *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 7, Issue 4, pp. 041008: 1–8, November 2015.
- [20] Ma, Z., **Ben-Tzvi, P.**, "RML Glove – An Exoskeleton Glove Mechanism with Haptics Feedback", *IEEE/ASME Transactions on Mechatronics*, Vol. 20, Issue 2, pp. 641-652, April 2015.
- [19] Rone, W., **Ben-Tzvi, P.**, "Mechanics Modeling of Multi-Segment Rod-Driven Continuum Robots", *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 6, Issue 4, pp. 041006: 1–12, November 2014.
- [18] Moubarak, P., **Ben-Tzvi, P.**, "A Tristate Rigid Reversible and Non-Back-Drivable Active Docking Mechanism for Modular Robotics", *IEEE/ASME Transactions on Mechatronics*, Vol. 19, Issue 3, pp. 840-851, June 2014.
- [17] Rone, W., **Ben-Tzvi, P.**, "Continuum Robot Dynamics Utilizing the Principle of Virtual Power", *IEEE Transactions on Robotics*, Vol. 30, Issue 1, pp. 275–287, February 2014.
- [16] Moubarak, P., **Ben-Tzvi, P.**, "A Globally Converging Algorithm for Adaptive Manipulation and Trajectory Following for Mobile Robots with Serial Redundant Arms", *Robotica Journal*, Vol. 31, Issue 8, pp. 1299-1312, December 2013.
- [15] Rone, W., **Ben-Tzvi, P.**, "Design and FE Analysis of Integrated Sensing using Gas Compressibility for Microdroplet Generation", *Mechatronics Journal*, Vol. 23, Issue 4, pp. 397–408, June 2013.
- [14] Moubarak, P., **Ben-Tzvi, P.**, "On the Dual-Rod Slider Rocker Mechanism and its Applications to Tri-State Rigid Active Docking", *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 5, Issue 1, pp. 011010: 1–10, February 2013.
- [13] Rone, W., **Ben-Tzvi, P.**, "Mapping, Localization and Motion Planning in Mobile Multi-Robotic Systems", *Robotica Journal*, Vol. 31, Issue 1, pp. 1-24, January 2013.
- [12] Moubarak, P., **Ben-Tzvi, P.**, "Modular and Reconfigurable Mobile Robotics", *Journal of Robotics and Autonomous Systems*, Vol. 60, Issue 12, pp. 1648-1663, December 2012.
- [11] Moubarak, P., **Ben-Tzvi, P.**, Zaghloul, M.E., "A Self-Calibrating Mathematical Model for the Direct Piezoelectric Effect of a new MEMS Tilt Sensor", *IEEE Sensors Journal*, Vol. 12, Issue 5, pp. 1033-1042, May 2012.
- [10] **Ben-Tzvi, P.**, Bai, S., Zhou, Q., Huang, X., "Fuzzy Sliding Mode Control of Rigid-Flexible Multi-Body Systems with Bounded Inputs", *Journal of Dynamic Systems, Measurement and Control, Transactions of the ASME*, Vol. 133, Issue 6, pp. 061012: 1–8, November 2011.
- [9] Bai, S., **Ben-Tzvi, P.**, Zhou, Q., Huang, X., "Variable Structure Controller Design for Linear

Systems with Bounded Inputs", *International Journal of Control, Automation and Systems*, Vol. 9, Issue 2, pp. 228–236, April 2011.

- [8] **Ben-Tzvi, P.**, Goldenberg, A.A., Zu, J.W., "Articulated Hybrid Mobile Robot Mechanism with Compounded Mobility and Manipulation and On-Board Wireless Sensor/Actuator Control Interfaces", *Mechatronics Journal*, Vol. 20, Issue 6, pp. 627–639, September 2010.
- [7] **Ben-Tzvi, P.**, "Experimental Validation and Field Performance Metrics of a Hybrid Mobile Robot Mechanism", *Journal of Field Robotics*, Vol. 27, Issue 3, pp. 250–267, May 2010.
- [6] **Ben-Tzvi, P.**, Rone, W., "Microdroplet Generation in Gaseous and Liquid Environments", *Microsystem Technologies Journal*, Vol. 16, Issue 3, pp. 333–356, March 2010.
- [5] **Ben-Tzvi, P.**, Ito, S., Goldenberg, A.A., "A Mobile Robot with Autonomous Climbing and Descending of Stairs", *Robotica Journal*, Vol. 27, Issue 02, pp. 171–188, Feb. 2009.
- [4] Zhou, Q., **Ben-Tzvi, P.**, Fan, D., "Design and Analysis of a Fast Steering Mirror for Precision Laser Beams Steering", *Sensors & Transducers Journal*, Vol. 5, Issue 3, pp. 104-118, March 2009. *** Listed in the Top 25 List of Most Downloaded Articles in June 2011**
- [3] Bai, S., **Ben-Tzvi, P.**, Zhou, Q., Huang, X., "A Study on Dynamic Stiffening of a Rotating Beam with a Tip Mass", *Sensors & Transducers Journal*, Vol. 5, Issue 3, pp. 53-68, 2009.
- [2] **Ben-Tzvi, P.**, Goldenberg, A.A., Zu, J.W., "Design and Analysis of a Hybrid Mobile Robot Mechanism with Compounded Locomotion and Manipulation Capability", *Journal of Mechanical Design, Transactions of the ASME*, Vol. 130, Issue 7, pp. 1–13, July 2008.
- [1] **Ben-Tzvi, P.**, Ben Mrad, R., Goldenberg, A.A., "A Conceptual Design and FE Analysis of a Piezoceramic Actuated Dispensing System for Microdrops Generation in Microarray Applications", *Mechatronics Journal*, Vol. 17, Issue 1, pp. 1-13, February 2007.

Journal Editorials

- [2] **Ben-Tzvi, P.**, Notash, L., Voglewede, P., "Special Issue: Selected Papers from IDETC 2020", *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 13, Issue 3, pp. 030301: 1-2, June 2021. DOI: 10.1115/1.4050855
- [1] Kim, C., Purwar, A., **Ben-Tzvi, P.**, "Special Issue: Selected Papers from IDETC 2019", *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 12, Issue 2, pp. 1-3, April 2020. DOI: 10.1115/1.4046177

Patents (8 Issued/Allowed, 5 Non-provisional, 7 Abandoned)

- [20] **Ben-Tzvi, P.**, Kamidi, V., "An Articulated Closed Kinematic Chain Planar Monopod", U.S. Patent Application No. 17/813,772, Filed July 20, 2022. Published online November 24, 2022
- [19] **Ben-Tzvi, P.**, Liu, Y., Rone, W.S., Saab, W., "Articulated Multi-Link Robotic Tail Systems and Methods", U.S. Patent Application No. 17/697,353, Published June 30, 2022.
- [18] **Ben-Tzvi, P.**, Njaka, T., Brizzolara, S., "High-Speed Omnidirectional Underwater Propulsion Mechanism", U.S. Patent Application No. 17/531,007, Published December 8, 2022.
- [17] **Ben-Tzvi, P.**, Refour, E., Sebastian, B., Xu, W., Guo, Y., Pradhan, S., "Robotic Exoskeleton Glove System", U.S. Patent Application No. 16/888,993, Filed June 1, 2020.

- [16] **Ben-Tzvi, P.**, Liu, Y., "Extensible Continuum Manipulator", U.S. PCT Patent Application No. PCT/US2021/034564, Filed May 27, 2021.
- [15] **Ben-Tzvi, P.**, Kamidi, V., "Articulated Closed Kinematic Chain Planar Monopod", U.S. Patent No. 11,413,475, Issued August 16, 2022.
- [14] **Ben-Tzvi, P.**, Liu, Y., Rone, W.S., Saab, W., "Articulated Multi-Link Robotic Tail Systems and Methods", U.S. Patent 11,305,420, Issued April 19, 2022.
- [13] **Ben-Tzvi, P.**, Kumar, A., "Linear Optical Sensor Arrays (LOSA) Tracking System for Active Marker Based 3D Motion Tracking", U.S. Patent 10,295,651, Issued May 21, 2019.
- [12] **Ben-Tzvi, P.**, Moubarak, P., "Active Docking Mechanism for Modular and Reconfigurable Robots", U.S. Patent 9,616,948, Issued April 11, 2017.
- [11] **Ben-Tzvi, P.**, Goldenberg, A.A., and Zu, J.W., "Hybrid Mobile Robot", Canadian Patent No. CA2631116, Issued, September 2016.
- [10] **Ben-Tzvi, P.**, Moubarak, P., "A mobile Robot with Hybrid Traction and Mobility Mechanism", U.S. Patent 9,004,200, Issued April 14, 2015.
- [9] **Ben-Tzvi, P.**, "A Mobile Robot with Symbiosis of Locomotion and Manipulation", U.S. Patent 8,225,892, Issued July 24, 2012.
- [8] **Ben-Tzvi, P.**, Goldenberg, A.A., and Zu, J.W., "Hybrid Mobile Robot", U.S. Patent 7,874,386, Issued January 25, 2011.
- [7] **Ben-Tzvi, P.**, Yang, J., Saab, W., "Robotic Modular Leg V2 Utilizing the Reuleaux Triangle Drive Mechanism to Build Legged Mobile Robots", U.S. Provisional Patent Application No. 62/855,968, June 1, 2019. (abandoned)
- [6] **Ben-Tzvi, P.**, Williams, A., Sebastian, B., Kumar, A., Saab, W., "Semi-Autonomous Victim Extraction Robot (SAVER)", U.S. Provisional Patent Application No. 62/836,915, April 22, 2019. (abandoned)
- [5] **Ben-Tzvi, P.**, Kumar, A., "An Expandable 6D Motion Tracking System Using Linear Optical Sensors Arrays (LOSA-X)", U.S. Patent Application No. 16/356,568, Filed March 18, 2019. (abandoned)
- [4] **Ben-Tzvi, P.**, Saab, W., "Discrete Modular Serpentine Robotic Tail Mechanism for Mobile Legged Robots", U.S. Provisional Patent Application No.62/340,140, May 23, 2016. (abandoned)
- [3] **Ben-Tzvi, P.**, Saab, W., "Robotic Modular Leg Mechanism for Legged Mobile Robots", U.S. Provisional Patent Application No.62/340,136, May 23, 2016. (abandoned)
- [2] **Ben-Tzvi, P.**, "A Hybrid Suspension and Tension Mechanism for Mobile Robots", U.S. Patent Application No. 13/507,180, June 12, 2012. (abandoned)
- [1] **Ben-Tzvi, P.**, "Mobile Robot with Symbiosis of Locomotion and Manipulation", U.S. Patent Application No. 12/925,145, October 14, 2010. (abandoned)

Peer-Reviewed Conference Proceedings (full articles with full review) ¹

- [99] Guo, Y., Xu, W., Bravo, C., **Ben-Tzvi, P.**, "Voice-based Human Machine Interface for Rehabilitation Exoskeleton Robotic Glove with Speaker Verification Feature Using One-shot Learning", *Proceedings of the 2023 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2023)*, Detroit, Michigan, October 1-5, 2023.
- [98] Xu, W., Guo, Y., **Ben-Tzvi, P.**, "Robotic Exoskeleton Glove System Design and Simulation for Patients with Brachial Plexus Injuries", *Proceedings of the 2023 ASME IDETC/CIE, 47th Mechanisms & Robotics Conference*, Boston, MA, August 20-23, 2023. Accepted.
- [97] Xu, W., Guo, Y., Bravo, C.J., **Ben-Tzvi, P.**, "Design, Control, and Experimental Evaluation of a Novel Robotic Glove System for Patients with Brachial Plexus Injuries", *Proc. of the 2023 IEEE International Conference on Robotics and Automation (ICRA2023)*, London, UK, May 2-June 2, 2023.
- [96] Xu, W., Guo, Y., Bravo, C., **Ben-Tzvi, P.**, "Development and Experimental Evaluation of a Novel Portable Haptic Robotic Exoskeleton Glove System for Patients with Brachial Plexus Injuries", *Proceedings of the 2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2022)*, Kyoto, Japan, October 23-27, 2022.
- [95] Xu, W., Liu, Y., **Ben-Tzvi, P.**, "Development of a Novel Low-profile Robotic Exoskeleton Glove for Patients with Brachial Plexus Injuries", *Proceedings of the 2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2022)*, Kyoto, Japan, October 23-27, 2022.
- [94] Xu, W., Liu, Y., **Ben-Tzvi, P.**, "Design, Analysis, and Prototyping of a Novel Single DOF Index Finger Exoskeleton Mechanism", *Proceedings of the 2022 ASME IDETC/CIE, 46th Mechanisms & Robotics Conference*, St. Louis, Missouri, August 14-17, 2022.
- [93] Pressgrove, I., Liu, Y., **Ben-Tzvi, P.**, "Design and Implementation of a Power-Dense, Modular, and Compact Serpentine Articulated Robotic Tail", *Proceedings of the 2022 ASME IDETC/CIE, 46th Mechanisms & Robotics Conference*, St. Louis, Missouri, Aug 14-17, 2022.
- [92] Liu, Y., **Ben-Tzvi, P.**, "Systematic Development of a Novel, Dynamic, Reduced Complexity Quadruped Robot Platform for Robotic Tail Research", *Proc. of the 2022 IEEE International Conference on Robotics and Automation (ICRA2022)*, Philadelphia, PA, pp. 4664-4670, May 23-27, 2022.
- [91] Liu, Y., **Ben-Tzvi, P.**, "Feedback Control of the Locomotion of a Tailed Quadruped Robot", *Proceedings of the 2021 ASME IDETC/CIE, 45th Mechanisms & Robotics Conference*, Virtual, Online, Aug. 17-20, 2021.
- [90] Guo, Y., Xu, W., Pradhan, S., Bravo, C.J., **Ben-Tzvi, P.**, "Integrated and Configurable Voice Activation and Speaker Verification System for a Robotic Exoskeleton Glove", *Proceedings of the 2020 ASME IDETC/CIE, 44th Mechanisms & Robotics Conference*, St. Louis, MO, Aug. 16-19, 2020.

¹ Although in some areas conference papers are considered non-peer reviewed publications, in my field all conference papers are peer reviewed. For example, **ICRA and IROS** are the largest robotics conferences organized by IEEE society. The acceptance rate for ICRA in 2022 was **43.1%**, **38.7%** in 2006, **44.3%** in 2007, **43%** in 2009, **41.0%** in 2010, **40.25%** in 2012, **38.5%** in 2013, **43.1%** in 2022. The acceptance rate for IROS in 2022 was **48%**, and in 2017 and 2018 **45%**. The journals IEEE Transactions on Robotics, IEEE/ASME Transactions on Mechatronics, IEEE Transactions on Neural Systems & Rehabilitation Engineering, IEEE Sensors Journal, Journal of Field Robotics, ASME Journal of Mechanical Design, and ASME Journal of Mechanisms and Robotics have the highest impact factors in my discipline (Robotics/ Mechatronics/ Design).

- [89] Xu, W., Pradhan, S., Guo, Y., Bravo, C.J., **Ben-Tzvi, P.**, "A Novel Design of a Robotic Glove System for Patients with Brachial Plexus Injuries", *Proceedings of the 2020 ASME IDETC/CIE, 44th Mechanisms & Robotics Conference*, St. Louis, MO, Aug. 16-19, 2020.
- [88] Han, X., Ren, H., **Ben-Tzvi, P.**, "Autonomous Cricothyroid Membrane Detection Using Neural Networks for First-Aid Surgical Airway Management", *Proceedings of the 2020 ASME IDETC/CIE, 44th Mechanisms & Robotics Conference*, St. Louis, MO, Aug. 16-19, 2020.
- [87] Liu, Y., **Ben-Tzvi, P.**, "A New Extensible Continuum Manipulator Using Flexible Parallel Mechanism and Rigid Motion Transmission", *Proceedings of the 2020 ASME IDETC/CIE, 44th Mechanisms & Robotics Conference*, St. Louis, MO, Aug. 16-19, 2020.
- [86] Sohal, S.S., **Ben-Tzvi, P.**, "Sensor Based Target Tracking with Application to Autonomous Docking and Self-Reconfigurability", *Proceedings of the 2020 ASME IDETC/CIE, 44th Mechanisms & Robotics Conference*, St. Louis, MO, Aug. 16-19, 2020.
- [85] Liu, Y., **Ben-Tzvi, P.**, "Maneuvering and Stabilization of Reduced Complexity Legged Robots Using Bioinspired Robotic Tails", *2019 Do Good Robotics Symposium (DGRS)*, University of Maryland, College Park, MD, Oct. 3-4, 2019.
- [84] Chauhan, R., **Ben-Tzvi, P.**, "A Series Elastic Actuator Design and Control in a Linkage Based Hand Exoskeleton", *Proceedings of the ASME 2019 Dynamic Systems and Control Conf. (DSCC 2019)*, Park City, Utah, Oct. 8-11, 2019.
- [83] Ren, H., Qi, J., **Ben-Tzvi, P.**, "Learning Flatness-Based Controller Using Neural Networks", *Proceedings of the ASME 2019 Dynamic Systems and Control Conf. (DSCC 2019)*, Park City, Utah, Oct. 8-11, 2019.
- [82] Liu, Y., **Ben-Tzvi, P.**, "A New Approach to Model the Constant Curvature Continuum Robot Dynamics", *Proceedings of the ASME 2019 Dynamic Systems and Control Conf. (DSCC 2019)*, Park City, Utah, Oct. 8-11, 2019.
- [81] Yang, J., Saab, W., **Ben-Tzvi, P.**, "A Two-DOF Bipedal Robot Utilizing the Reuleaux Triangle Drive Mechanism", *Proceedings of the 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2019)*, Macau, China, pp. 4660-4665, Nov. 3-8, 2019.
- [80] Sebastian, B., Ren, H., **Ben-Tzvi, P.**, "Neural Network Based Heterogeneous Sensor Fusion for Robot Motion Planning", *Proceedings of the 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2019)*, Macau, China, pp. 2899-2904, Nov. 3-8, 2019.
- [79] Budolak, D., Chauhan, R., **Ben-Tzvi, P.**, "Semi-Autonomous Teleoperation, Guidance, and Obstacle Avoidance with Path Adherence", *Proceedings of the 2019 ASME IDETC/CIE, 43rd Mechanisms & Robotics Conference*, Anaheim, CA, Aug. 18-21, 2019.
- [78] Sohal, S.S., **Ben-Tzvi, P.**, "Image-Based Motion Analysis for Self-Reconfigurable Mobile Robots with Integrated Docking", *Proceedings of the 2019 ASME IDETC/CIE, 43rd Mechanisms & Robotics Conference*, Anaheim, CA, Aug. 18-21, 2019.
- [77] Njaka, T., Brizzolara, S., **Ben-Tzvi, P.**, "Design and Simulation of a Novel High-Speed Omnidirectional Fully-Actuated Underwater Propulsion Mechanism", *Proceedings of the 2019 ASME IDETC/CIE, 43rd Mechanisms & Robotics Conference*, Anaheim, CA, Aug. 18-21, 2019.
- [76] Feng, S., Ren, H., Wang, X., **Ben-Tzvi, P.**, "Mobile Robot Obstacle Avoidance Based on

- Deep Reinforcement Learning”, *Proceedings of the 2019 ASME IDETC/CIE, 43rd Mechanisms & Robotics Conference*, Anaheim, CA, Aug. 18-21, 2019.
- [75] Liu, Y., **Ben-Tzvi, P.**, “Design, Analysis, and Optimization of a New Two-DOF Articulated Multi-link Robotic Tail”, *Proceedings of the 2019 ASME IDETC/CIE, 43rd Mechanisms & Robotics Conference*, Anaheim, CA, Aug. 18-21, 2019.
- [74] Kamidi, V., Williams, A., **Ben-Tzvi, P.**, “A Framework for Modeling Closed Kinematic Chains with a Focus on Legged Robots”, *Proceedings of the 2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2018)*, Madrid, Spain, pp. 2733-2738, Oct. 1–5, 2018.
- [73] Saab, W., Yang, J., **Ben-Tzvi, P.**, “Modeling and Control of an Articulated Tail for Maneuvering a Reduced Degree of Freedom Legged Robot”, *Proceedings of the 2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2018)*, Madrid, Spain, pp. 2695-2700, Oct. 1–5, 2018.
- [72] Vanteddu, T., Sebastian, B., **Ben-Tzvi, P.**, “Design Optimization of RML Glove for Improved Grasp Performance”, *Proceedings of the ASME 2018 Dynamic Systems and Control Conf. (DSCC 2018)*, Atlanta, GA, Sep. 30 – Oct. 3, 2018.
- [71] Ren, H., Kumar, A., Wang, X., **Ben-Tzvi, P.**, “Parallel Deep Learning Ensembles for Human Pose Estimation”, *Proceedings of the ASME 2018 Dynamic Systems and Control Conf. (DSCC 2018)*, Atlanta, GA, Sep. 30 – Oct. 3, 2018.
- [70] Wang, J., Kamidi, V., **Ben-Tzvi, P.**, “A Multibody Toolbox for Hybrid Dynamic System Modeling Based on Nonholonomic Symbolic Formalism”, *Proceedings of the ASME 2018 Dynamic Systems and Control Conf. (DSCC 2018)*, Atlanta, GA, Sep. 30 – Oct. 3, 2018.
- [69] Chauhan, R., **Ben-Tzvi, P.**, “Latent Variable Grasp Prediction for Exoskeletal Glove Control”, *Proceedings of the ASME 2018 Dynamic Systems and Control Conf. (DSCC 2018)*, Atlanta, GA, Sep. 30 – Oct. 3, 2018.
- [68] Refour, E., Sebastian, B., **Ben-Tzvi, P.**, “Design and Implementation of an Exoskeleton Glove for Infant Medical Rehabilitation”, *Proceedings of the 2018 ASME IDETC/CIE, 42nd Mechanisms & Robotics Conference*, Quebec City, Canada, Aug. 26-29, 2018.
- [67] Sohal, S.S., Saab, W., **Ben-Tzvi, P.**, “Improved Alignment Estimation for Autonomous Docking of Mobile robots”, *Proceedings of the 2018 ASME IDETC/CIE, 42nd Mechanisms & Robotics Conference*, Quebec City, Canada, Aug. 26-29, 2018.
- [66] Liu, Y., **Ben-Tzvi, P.**, “Dynamic Modeling of a Quadruped with a Robotic Tail Using Virtual Work Principle”, *Proceedings of the 2018 ASME IDETC/CIE, 42nd Mechanisms & Robotics Conference*, Quebec City, Canada, Aug. 26-29, 2018.
- [65] Sebastian, B., Williams, A., **Ben-Tzvi, P.**, “Gaussian Kernel Controller for Path Tracking in Mobile Robots”, *Proceedings of the 2018 ASME IDETC/CIE, 42nd Mechanisms & Robotics Conference*, Quebec City, Canada, Aug. 26-29, 2018.
- [64] Lee, J., **Ben-Tzvi, P.**, “Design of a Wearable 3-DOF Forearm Exoskeleton for Rehabilitation and Assistive Purposes”, *Proceedings of the 2017 ASME International Mechanical Engineering Congress and Exposition (IMECE 2017)*, Tampa, Florida, Nov. 3–9, 2017.
- [63] Sebastian, B., Williams, A., **Ben-Tzvi, P.**, “Control of a Head Stabilization System for Use in

- Robotic Disaster Response”, *Proceedings of the 2017 ASME International Mechanical Engineering Congress and Exposition (IMECE 2017)*, Tampa, Florida, Nov. 3–9, 2017.
- [62] Rone, W., **Ben-Tzvi, P.**, “Design, Modeling and Optimization of the Universal-Spatial Robotic Tail”, *Proceedings of the 2017 ASME International Mechanical Engineering Congress and Exposition (IMECE 2017)*, Tampa, Florida, Nov. 3–9, 2017.
- [61] Kumar, A., **Ben-Tzvi, P.**, “An Inertial Sensor to Measure Wind Turbulence with RC Helicopters”, *Proceedings of the ASME 2017 Dynamic Systems and Control Conf. (DSCC 2017)*, Tysons Corner, VA, Oct 11-13, 2017.
- [60] Saab, W., **Ben-Tzvi, P.**, “Maneuverability and Heading Control of a Quadruped Robot Utilizing Tail Dynamics”, *Proceedings of the ASME 2017 Dynamic Systems and Control Conf. (DSCC 2017)*, Tysons Corner, VA, Oct 11-13, 2017.
- [59] Kumar, A., Ren, H., **Ben-Tzvi, P.**, “Obstacle Identification for Vision Assisted Control Architecture of a Hybrid Mechanism Mobile Robot”, *Proceedings of the ASME 2017 Dynamic Systems and Control Conf. (DSCC 2017)*, Tysons Corner, VA, Oct 11-13, 2017.
- [58] Kamidi, V., Saab, W., **Ben-Tzvi, P.**, “Design And Analysis of a Novel Planar Robotic Leg For High-Speed Locomotion”, *Proceedings of the 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2017)*, Vancouver, Canada, pp. 6343–6348, Sep. 24–28, 2017.
- [57] Rone, W., **Ben-Tzvi, P.**, “Maneuvering and Stabilizing Control of a Quadrupedal Robot using a Serpentine Robotic Tail”, *2017 IEEE Conference on Control Technology and Applications*, Kohala Coast, Hawai’i, pp. 1763–1768, Aug. 27–30, 2017.
- [56] Racioppo, P., **Ben-Tzvi, P.**, “Modeling and Control of a Cable Driven Modular Snake Robot”, *2017 IEEE Conference on Control Technology and Applications*, Kohala Coast, Hawai’i, pp. 468–473, Aug. 27–30, 2017.
- [55] Williams, A., Saab, W., **Ben-Tzvi, P.**, “Analysis of Differential Mechanisms for a Robotic Head Stabilization System”, *Proceedings of the 2017 ASME IDETC/CIE, 41st Mechanisms & Robotics Conference*, Cleveland, Ohio, Aug. 6-9, 2017.
- [54] Refour, E., Sebastian, B., **Ben-Tzvi, P.**, “Design and Integration of a Two-Digit Exoskeleton Glove”, *Proceedings of the 2017 ASME IDETC/CIE, 41st Mechanisms & Robotics Conference*, Cleveland, Ohio, Aug. 6-9, 2017.
- [53] Racioppo, P., Saab, W., **Ben-Tzvi, P.**, “Design and Analysis of Reduced Degree-of-Freedom Modular Snake Robot”, *Proceedings of the 2017 ASME IDETC/CIE, 41st Mechanisms & Robotics Conference*, Cleveland, Ohio, Aug. 6-9, 2017.
- [52] Kumar, P., Saab, W., **Ben-Tzvi, P.**, “Design of a Multi-Directional Hybrid-Locomotion Modular Robot with Feedforward Stability Control”, *Proceedings of the 2017 ASME IDETC/CIE, 41st Mechanisms & Robotics Conference*, Cleveland, Ohio, Aug. 6-9, 2017.
- [51] Burns, C., Francom, M., Repisky, P., Kinney, A., Medina, B., Tello, E., **Ben-Tzvi, P.**, “Development of Autonomous Robotic Cataract Surgery Device”, *Proceedings of the 2016 ASME IDETC/CIE, 40th Mechanisms & Robotics Conference*, Charlotte, North Carolina, Aug. 21-24, 2016.
- [50] Saab, W., **Ben-Tzvi, P.**, “Design and Analysis of a Miniature Modular Inchworm Robot”,

Proceedings of the 2016 ASME IDETC/CIE, 40th Mechanisms & Robotics Conference, Charlotte, North Carolina, Aug. 21-24, 2016.

- [49] Saab, W., **Ben-Tzvi, P.**, "Design and Analysis of a Discrete Modular Robotic Tail for Improved Performance of Mobile Robots", *Proceedings of the 2016 ASME IDETC/CIE, 40th Mechanisms & Robotics Conference*, Charlotte, North Carolina, Aug. 21-24, 2016.
- [48] Saab, W., **Ben-Tzvi, P.**, "Design and Analysis of a Robotic Modular Leg Mechanism", *Proceedings of the 2016 ASME IDETC/CIE, 40th Mechanisms & Robotics Conference*, Charlotte, North Carolina, Aug. 21-24, 2016.
- [47] Kumar, A., **Ben-Tzvi, P.**, "Extraction of Impact of Wind Turbulence on RC Helicopters using Machine Learning", *Proceedings of the 2016 ASME IDETC/CIE, 40th Mechanisms & Robotics Conference*, Charlotte, North Carolina, Aug. 21-24, 2016.
- [46] Saab, W., **Ben-Tzvi, P.**, "Development of a Novel Coupling Mechanism for Modular Self-Reconfigurable Mobile Robots", *Proceedings of the 2015 ASME IDETC/CIE, 39th Mechanisms & Robotics Conference*, Boston, MA, Aug. 2-5, 2015.
- [45] Rone, W., **Ben-Tzvi, P.**, "Static Modeling of a Multi-Segment Serpentine Robotic Tail", *Proceedings of the 2015 ASME IDETC/CIE, 39th Mechanisms & Robotics Conference*, Boston, MA, Aug. 2-5, 2015.
- [44] Ma, Z., **Ben-Tzvi, P.**, Danoff, J., "Sensing and Force-Feedback Exoskeleton Robotic (SAFER) Glove Mechanism for Hand Rehabilitation", *Proceedings of the 2015 ASME IDETC/CIE, 39th Mechanisms & Robotics Conference*, Boston, MA, Aug. 2-5, 2015.
- [43] Kumar, A., **Ben-Tzvi, P.**, Snyder, M.R., "UAV-based Wireless Telemetry System for the Estimation of Ship Air Wake Patterns", *Proc. of the 2015 ASME IDETC/CIE, 2015 ASME/IEEE International Conference on Mechatronic and Embedded Systems and Applications*, Boston, MA, Aug. 2-5, 2015.
- [42] Ma, Z., **Ben-Tzvi, P.**, "Modeling Human Hand and Sensing Hand Motions with the Five-Fingered Haptic Glove Mechanism", *Proc. of the 2014 ASME Int'l Design Engineering Technical Conferences & Computers and Information in Engineering Conf. (IDETC/CIE 2014), 38th Mechanisms & Robotics Conference*, Buffalo, NY, Aug. 17-20, 2014.
- [41] Rone, W., **Ben-Tzvi, P.**, "Continuum Robotic Tail Loading Analysis for Mobile Robot Stabilization and Maneuvering", *Proceedings of the 2014 ASME Int'l Design Engineering Technical Conferences & Computers and Information in Engineering Conf. (IDETC/CIE 2014), 38th Mechanisms & Robotics Conference*, Buffalo, NY, Aug. 17-20, 2014.
- [40] Snyder, M.R., Kumar, A., **Ben-Tzvi, P.**, "Off Ship Measurement of Ship Air Wakes Using Instrumented Unmanned Aerial Vehicles", *32nd AIAA Applied Aerodynamics Conference, AIAA Aviation and Aeronautics Forum and Exposition 2014*, AIAA Paper 2014-3100, Atlanta, GA, 16-20 June 2014.
- [39] Rone, W., **Ben-Tzvi, P.**, "Multi-Segment Continuum Robot Shape Estimation Using Passive Cable Displacements", *Proceedings of the 2013 IEEE International Symposium on Robotic and Sensors Environments (ROSE 2013)*, Washington, DC, pp. 37-42, Oct. 21-23, 2013.
- [38] Ma, Z., **Ben-Tzvi, P.**, "Tendon Transmission Efficiency of A Two-finger Haptic Glove", *Proceedings of the 2013 IEEE International Symposium on Robotic and Sensors Environments (ROSE 2013)*, Washington, DC, pp. 13-18, Oct. 21-23, 2013.

- [37] Kumar, A., **Ben-Tzvi, P.**, Snyder, M.R., Saab, W., "Instrumentation System for Ship Airwake Measurement", *Proceedings of the 2013 IEEE Int'l Symposium on Robotic and Sensors Environments (ROSE 2013)*, Washington, DC, pp. 118–123, Oct. 21-23, 2013.
- [36] Moubarak, P., Alvarez, E., **Ben-Tzvi, P.**, "Reconfiguring a Modular Robot into a Humanoid Formation: A Multi-Body Dynamic Perspective on Motion Scheduling for Modules and their Assemblies", *Proc. of the 2013 IEEE International Conference on Automation Science and Engineering (CASE2013)*, Madison, Wisconsin, pp. 687–692, Aug. 17-21, 2013.
- [35] Moubarak, P., **Ben-Tzvi, P.**, "Globally Converging MIMO Optimal Controller for Adaptive Manipulation of Mobile Robots with Redundant Arms", *Proceedings of the 2013 American Control Conference*, Washington, DC, pp. 5729–5734, June 17–19, 2013.
- [34] Moubarak, P., **Ben-Tzvi, P.**, Ma, Z., Alvarez, E., "An Active Coupling Mechanism with Three Modes of Operation for Modular Mobile Robotics", *Proc. of the 2013 IEEE International Conference on Robotics and Automation (ICRA2013)*, Karlsruhe, Germany, pp. 5469–5474, May 6-10, 2013.
- [33] Snyder, M.R., Kumar, A., **Ben-Tzvi, P.**, Kang, H.S., "Validation of Computational Ship Air Wakes for a Naval Research Vessel", *American Institute of Aeronautics and Astronautics (AIAA) 51st Aerospace Sciences Meeting*, AIAA Paper 2013-0959, Grapevine, Texas, January 7-10, 2013. DOI: 10.2514/6.2013-959
- [32] Rone, W., **Ben-Tzvi, P.**, "Continuum Manipulator Statics Based on the Principle of Virtual Work", *Proceedings of the 2012 ASME International Mechanical Engineering Congress and Exposition (IMECE 2012)*, Houston, TX, pp. 321-328, November 9–15, 2012.
- [31] Moubarak, P., **Ben-Tzvi, P.**, Ma, Z., Alvarez, E., "Kinematic Synthesis and Dynamic Analysis of the Dual-Rod Slider Crank Mechanism: An Application to Modular Robotics", *Proceedings of the 2012 ASME IDETC/CIE, 36th Mechanisms & Robotics Conference*, Chicago, IL, pp. 1073-1078, Aug. 12–15, 2012.
- [30] Ma, Z., **Ben-Tzvi, P.**, "An Admittance Glove Mechanism for Controlling a Mobile Robot", *Proceedings of the 2012 ASME IDETC/CIE, 36th Mechanisms & Robotics Conference*, Chicago, IL, pp. 1109-1114, Aug. 12–15, 2012.
- [29] Moubarak, P., Barsky, D., **Ben-Tzvi, P.**, Zaghloul, M., "A Self-Calibrating Temperature Independent Model of a Bi-Axial Piezoelectric MEMS Tilt Sensor," *Proceedings of SPIE - Defense, Security, and Sensing, Micro- and Nanotechnology Sensors, Systems, and Applications IV Conference*, Vol. 8373, 83732L-1, Baltimore, MD, April 23-27, 2012.
- [28] Gilman, C., **Ben-Tzvi, P.**, Yessin, G., Danoff, J., "A Robotic Wrist Exoskeleton Device for Augmenting Wrist Movement and Grip Function in Debilitated Patients", *Proceedings of the 2011 ASME International Mechanical Engineering Congress and Exposition (IMECE 2011)*, Denver, CO, pp. 1041-1050, November 11–17, 2011.
- [27] Ma, Z., **Ben-Tzvi, P.**, "An Admittance Type Haptic Device: RML Glove", *Proceedings of the 2011 ASME International Mechanical Engineering Congress and Exposition (IMECE 2011)*, Denver, CO, pp. 1219-1226, November 11–17, 2011.
- [26] Gilani, O., **Ben-Tzvi, P.**, "Bioinspired Jumping Mobility Concepts for Rough Terrain Mobile Robots", *Proceedings of the 2011 ASME International Mechanical Engineering Congress and Exposition (IMECE 2011)*, Denver, CO, pp. 207-214, November 11–17, 2011.

- [25] Gilani, O., **Ben-Tzvi, P.**, "The Application of Bipinspired Jumping Locomotion Principles to Mobile Robots: Modeling and Analysis", *Proceedings of the 2011 ASME Annual Dynamic Systems and Control Conf. (DSCC 2011)*, Arlington, VA, pp. 427-434, Oct 31–Nov 2, 2011.
- [24] Rone, W., **Ben-Tzvi, P.**, "MEMS-Based Microdroplet Generation with Integrated Sensing", *COMSOL Conference*, Boston, MA, October 13-15, 2011.
*** **Winner of the Best Paper Award** ***
- [23] Moubarak, P., **Ben-Tzvi, P.**, "Design and Analysis of a New Piezoelectric MEMS Tilt Sensor", *Proceedings of the 2011 IEEE International Symposium on Robotic and Sensors Environments (ROSE 2011)*, Montreal, Quebec, Canada, pp. 83–88, Sep. 17-18, 2011.
- [22] Moubarak, P., **Ben-Tzvi, P.**, "Adaptive Manipulation of a Hybrid Mechanism Mobile Robot", *Proceedings of the 2011 IEEE International Symposium on Robotic and Sensors Environments (ROSE 2011)*, Montreal, Quebec, Canada, pp. 113–118, Sep. 17-18, 2011.
- [21] Rone, W., **Ben-Tzvi, P.**, "Finite Element Modeling of a Microdroplet Generator with Integrated Sensing", *Proceedings of the 2011 ASME International Design Engineering Technical Conferences & Computers and Information in Engineering Conference (IDETC/CIE 2011)*, 2011 ASME/IEEE International Conference on Mechatronic and Embedded Systems and Applications (MESA2011), Washington, DC, Aug. 28–31, 2011.
- [20] Moubarak, P., **Ben-Tzvi, P.**, Ma, Z., Dumas, M., "A Mobile Robotic Platform for Autonomous Navigation and Dexterous Manipulation in Unstructured Environments", *Proceedings of the 2010 ASME International Mechanical Engineering Congress and Exposition (IMECE 2010)*, Vancouver, British Columbia, Canada, November 12–18, 2010.
- [19] **Ben-Tzvi, P.**, Zhuk, M., "Real-time Dynamic Modeling and Virtual Prototype Simulation of Mechanical systems", *Proceedings of the 2010 ASME International Mechanical Engineering Congress and Exposition (IMECE 2010)*, Vancouver, British Columbia, Canada, November 12–18, 2010.
- [18] Charifa, S., **Ben-Tzvi, P.**, "Using Backpropagation Neural Network in Object Recognition for Hybrid Mechanism Mobile Robot", *Proceedings of the 2010 ASME International Mechanical Engineering Congress and Exposition (IMECE 2010)*, Vancouver, British Columbia, Canada, November 12–18, 2010.
- [17] Moubarak, P., **Ben-Tzvi, P.**, and Ma, Z., "A Generic Configuration of a Compact Dexterous and Self-Contained End-Effector for Mobile Robotic Platforms", *Proceedings of the 2010 IEEE International Workshop on Robotic and Sensors Environments (ROSE 2010)*, Phoenix, Arizona, pp. 116–121, October 15-16, 2010.
- [16] **Ben-Tzvi, P.**, Xu, X., "An Embedded Feature-Based Stereo Vision System for Autonomous Mobile Robots", *Proceedings of the 2010 IEEE International Workshop on Robotic and Sensors Environments (ROSE 2010)*, Phoenix, Arizona, pp. 176–181, October 15-16, 2010.
- [15] **Ben-Tzvi, P.**, Charifa, S., Shick, M., "Extraction of 3D Images Using Pitch-Actuated 2D Laser Range Finder for Robotic Vision", *Proceedings of the 2010 IEEE International Workshop on Robotic and Sensors Environments (ROSE 2010)*, Phoenix, Arizona, pp. 140–145, October 15-16, 2010.
- [14] Zhou, Q., **Ben-Tzvi, P.**, Iqbal, A., Fan, D., "Design, Analysis and Optimization of Magnetic Microactuators", *Proceedings of the 2009 ASME Int'l Mechanical Engineering Congress and Exposition (IMECE 2009)*, Lake Buena Vista, Florida, pp. 503-512, Nov. 13-19, 2009.

- [13] Bai, S., **Ben-Tzvi, P.**, Zhou, Q., Huang, X., “Fuzzy Sliding Mode Control of Flexible Spacecraft with Input Saturation”, *Proceedings of the 2009 ASME International Mechanical Engineering Congress and Exposition (IMECE 2009)*, Lake Buena Vista, Florida, pp. 1055-1061, November 13-19, 2009.
- [12] **Ben-Tzvi, P.**, “Experimental Validation of a Hybrid Mobile Robot Mechanism with Interchangeable Locomotion and Manipulation”, *Proceedings of the 2009 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2009)*, St. Louis, Missouri, pp. 420–421, October 11–15, 2009.
- [11] **Ben-Tzvi, P.**, “Wireless Modular Control Hardware Architecture for Hybrid Mechanism Mobile Robot”, *Proceedings of the 2009 ASME International Design Engineering Technical Conferences & Computers and Information in Engineering Conf. (IDETC/CIE 2009)*, 33rd Mechanisms & Robotics Conference, San Diego, CA, pp. 675–680, Aug. 30–Sep. 2, 2009.
- [10] Zhao, H., **Ben-Tzvi, P.**, Tingqi Lin, T., Goldenberg, A.A., “Two–layer Sliding Mode Control of Pneumatic Position Synchro System with Feedback Linearization Based on Friction Compensation”, *Proceedings of the 2008 IEEE International Workshop on Robotic and Sensors Environments (ROSE 2008)*, Ottawa, ON, Canada, pp. 41–45, Oct 17–18, 2008.
- [9] Zhou, Q., **Ben-Tzvi, P.**, Fan, D., Goldenberg, A.A., “Design of Fast Steering Mirror Systems for Precision Laser Beams Steering”, *Proceedings of the 2008 IEEE International Workshop on Robotic and Sensors Environments (ROSE 2008)*, Ottawa, Ontario, Canada, pp. 144–149, October 17–18, 2008.
- [8] Bai, S., **Ben-Tzvi, P.**, Zhou, Q., Huang, X., “Dynamic Modeling of a Rotating Beam Having a Tip Mass”, *Proceedings of the 2008 IEEE International Workshop on Robotic and Sensors Environments (ROSE 2008)*, Ottawa, Ontario, Canada, pp. 52–57, October 17–18, 2008.
- [7] **Ben-Tzvi, P.**, Goldenberg, A.A., and Zu, J.W., “Design, Simulations and Optimization of a Tracked Mobile Robot Manipulator with Hybrid Locomotion and Manipulation Capabilities”, *Proceedings of the 2008 IEEE International Conference on Robotics and Automation (ICRA2008)*, Pasadena, California, pp. 2307–2312, May 19–23, 2008.
- [6] **Ben-Tzvi, P.**, Goldenberg, A.A., “Mobile Robots for Hazardous Environments: New Technology for Mobility”, *ANS 2nd Int. Joint Topical Meeting on Emergency Preparedness & Response and Robotic & Remote Systems (12th Robotics & Remote Systems for Hazardous Environments)*, Albuquerque, NM, Mar 9–12, 2008.
- [5] Raoufi, C., **Ben-Tzvi, P.**, Goldenberg, A.A., and Kucharczyk, W., “A MR-Compatible Tele-Robotic System for MRI-Guided Intervention: System Overview and Mechanical Design”, *Proceedings of the 2007 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2007)*, San Diego, California, pp. 1975–1800, October 29 – Nov 2, 2007.
- [4] **Ben-Tzvi, P.**, Goldenberg, A.A., and Zu, J.W., “Implementation of Sensors and Control Paradigm for a Hybrid Mobile Robot Manipulator for Search and Rescue Operations”, *Proceedings of the 2007 IEEE International Workshop on Robotic and Sensors Environments (ROSE 2007)*, Ottawa, Ontario, Canada, pp. 92–97, October 12–13, 2007.
*** **Winner of the Best Student Paper Award** ***
- [3] **Ben-Tzvi, P.**, Ito, S., and Goldenberg, A.A., “Autonomous Stair Climbing with Reconfigurable Tracked Mobile Robot”, *Proceedings of the 2007 IEEE International Workshop on Robotic and Sensors Environments (ROSE 2007)*, Ottawa, Canada, pp. 104–

109, October 12–13, 2007.

- [2] **Ben-Tzvi, P.**, Raoufi, C., Goldenberg, A.A., Zu, J.W., “Virtual Prototype Development and Simulations of a Tracked Hybrid Mobile Robot”, *Proceedings of MSC Software 2007 Virtual Product Development Conference*, Detroit, Michigan, October 10–12, 2007.
- [1] **Ben-Tzvi, P.**, Goldenberg, A.A., Zu, J.W., “A Novel Control Architecture and Design of Hybrid Locomotion and Manipulation Tracked Mobile Robot”, *Proceedings of the 2007 IEEE International Conference on Mechatronics and Automation (ICMA 2007)*, Harbin, China, pp. 1374–1381, August 5–8, 2007.

Magazine / Letter / Newsletter Publications

- [2] **Ben-Tzvi, P.**, Liu, Y., “Robots with Tails”, *Mechanical Engineering Magazine*, Vol. 143, Issue 6, pp. 32-37, October 2021.
- [1] **Ben-Tzvi, P.**, Rone, W., “Tiny Robots, Massive Potential”, *IEEE Nanotechnology Newsletter*, pp. 4-7, March 2011.

Peer-Reviewed Abstracts

- [8] Feng, S., **Ben-Tzvi, P.**, “A Modular Robotic System with Self-Reconfiguration Strategy”, *Southeast Control Conference 2021 (SECC 2021)*, Blacksburg, VA, November 29-30, 2021.
- [7] Xu, W., **Ben-Tzvi, P.**, “Data Driven Calibration and Model-based Backlash Compensation of Compact Series Elastic Actuators for Robotic Exoskeleton Gloves”, *Southeast Control Conference 2021 (SECC 2021)*, Blacksburg, VA, November 29-30, 2021.
- [6] Pressgrove, I., **Ben-Tzvi, P.**, “Development of a Compact and Easily Packageable Serpentine Robotic Tail System”, *Southeast Control Conference 2021 (SECC 2021)*, Blacksburg, VA, November 29-30, 2021.
- [5] Liu, Y., **Ben-Tzvi, P.**, “Towards Dynamic Locomotion of Legged Robots Using Biomimetic Articulated Robotic Tails”, *2021 Annual Symposium of the Society for Integrative and Comparative Biology (SICB 2021)*, Washington, DC, January 3-7, 2021.
- [4] Fisher, N., Gilbert, G., German, S., **Ben-Tzvi, P.**, “Toward Robotic-Assisted Casualty Extraction in Multi-Domain Operations”, *Military Health System Research Symposium (MHSRS 2019)*, Kissimmee FL, August 2019.
- [3] Rone, W.S., **Ben-Tzvi, P.**, “Design and Control of Bioinspired Articulated Robotic Tails for Stabilization and Maneuvering of Legged Robots”, *Robotics Science and Systems (RSS 2018)*, Pittsburgh, PA, June 26–30, 2018.
- [2] Rone, W.S., Saab, W., **Ben-Tzvi, P.**, “Serpentine Robotic Tails for Maneuvering and Stabilizing Mobile Robots”, *Proceedings of the 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2017)*, Vancouver, Canada, pp. 5487, Sep. 24–28, 2017.
- [1] Kamidi, V., **Ben-Tzvi, P.**, “Experimental Validation of Dynamic Legged Locomotion Utilizing a Single-DOF Robotic Leg”, *Proceedings of the 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2017)*, Vancouver, Canada, pp. 5504, Sep. 24–28, 2017.

Monographs/Books

- [2] **Ben-Tzvi, P.**, Hybrid Mobile Robot Systems: Symbiosis of Locomotion and Manipulation. Germany: LAP LAMBERT Academic Publishing, 2010 (ISBN-13: 978-3-8433-6890-2)
- [1] **Ben-Tzvi, P.**, A Dispensing System for Microdrops Generation in Medical Applications. Germany: LAP LAMBERT Academic Publishing, 2010 (ISBN-13: 978-3-8383-6000-3)

Book Chapters

- [1] **Ben-Tzvi, P.**, Moubarak, P., "A Mechatronic Perspective on Robotic Arms and End-Effectors" in Intelligent Mechatronics. Vienna, Austria: InTech Open Access Publisher, 28 Feb. 2011, pp. 3–20. (ISBN-13: 978-953-307-300-2, DOI: 10.5772/16234)
Note: this book chapter has been downloaded over 7197 times as of December 2016.

Refereed Conference Posters / Video Proceedings

- [6] Kamidi, V., **Ben-Tzvi, P.**, "Experimental Validation of Dynamic Legged Locomotion Utilizing a Single-DOF Robotic Leg", *Proceedings of the 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2017)*, Vancouver, Canada, Sep. 24–28, 2017 – Poster Presentation.
- [5] Rone, W.S., Saab, W., **Ben-Tzvi, P.**, "Serpentine Robotic Tails for Maneuvering and Stabilizing Mobile Robots", *Proceedings of the 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2017)*, Vancouver, Canada, Sep. 24–28, 2017 – Poster Presentation.
- [4] Moubarak, P., Ma, Z., **Ben-Tzvi, P.**, "A Tri-state Rigid Reversible and Non-Back-Drivable Docking Mechanism for Modular Robotics Applications," *Proceedings of the 2012 ASME International Design Engineering Technical Conferences & Computers and Information in Engineering Conference (IDETC/CIE 2012)*, 36th Mechanisms & Robotics Conference, Chicago, IL, Aug. 12–15, 2012 – Poster Presentation.
***** Second place winner of the Graduate Robotics & Mechanisms Category*****
- [3] Moubarak, P., Barsky, D., **Ben-Tzvi, P.**, Zaghloul, M., "A Self-Calibrating Temperature Independent Model of a Bi-Axial Piezoelectric MEMS Tilt-Sensor," *Proceedings of SPIE - Defense, Security, and Sensing, Micro- and Nanotechnology Sensors, Systems, & Applications IV Conf.*, Vol. 8373-93, Baltimore, MD, April 23-27, 2012 – Poster Presentation.
- [2] Rone, W., **Ben-Tzvi, P.**, "MEMS-Based Microdroplet Generation with Integrated Sensing", *COMSOL Conference*, Boston, MA, October 13-15, 2011 – Poster Presentation.
- [1] **Ben-Tzvi, P.**, Cole, K, Gilman, C., Goktas, H., Haque, S., Ma, Z., Moubarak, P., Ouellette, J., Rone, W., Sharathi, S., Torrey, J., Zambrana, E., "RAIL: Robotic Arm for Interactive Learning", *Proceedings of the 2011 ASME International Design Engineering Technical Conferences & Computers and Information in Engineering Conference (IDETC/CIE 2011)*, Washington, DC, Aug. 28–31, 2011 – Poster Presentation.
***** Third place winner of the Graduate Robotics & Mechanisms Category*****

Invited Keynote Lectures / Research Presentations and Seminars

- [29] *Novel Field Robots and Robotic Exoskeletons: Design, Control and Applications*, University of Virginia, Department of Mechanical and Aerospace Engineering, Charlottesville, VA, March 30, 2023. (Invited Research Presentation)

- [28] *Novel Field Robots and Robotic Exoskeletons: Design, Integration and Applications*, Florida State University, Department of Mechanical Engineering, Tallahassee, FL, May 5, 2022. (Invited Research Presentation)
- [27] *Novel Field Robots and Robotic Exoskeletons: Design, Integration and Applications*, Northeastern University, Department of Mechanical and Industrial Engineering, Boston, MA, February 28, 2022. (Invited Research Presentation)
- [26] Towards Dynamic Locomotion of Legged Robots Using Biomimetic Articulated Robotic Tails, *2021 Annual Symposium of the Society for Integrative and Comparative Biology (SICB 2021)*, Washington, DC, January 3-7, 2021. (**Invited Symposium Speaker**)
- [25] *Novel Field Robots and Robotic Exoskeletons: Design, Integration and Applications*, 2020 SPIE Smart Structures and Nondestructive Evaluation (EAPAD 2020) Conference, Anaheim, CA, April 26-30, 2020. (**Keynote Presentation**)
- [24] *Novel Field Robots and Robotic Exoskeletons: Design, Integration and Applications*, Stevens Institute of Technology, Department of Mechanical Engineering, Hoboken, NJ, February 8, 2019. (Invited Research Presentation)
- [23] *Novel Field Robots and Robotic Exoskeletons: Design, Integration and Applications*, University of Waterloo, Department of Mechanical and Mechatronics Engineering, Waterloo, Ontario, Canada, January 18, 2019. (Invited Research Presentation)
- [22] *Design and Control of Bioinspired Articulated Robotic Tails for Stabilization and Maneuvering of Legged Robots*, Carnegie Mellon University, *Robotics Science and Systems Conference (RSS 2018)*, Pittsburgh, PA, June 26–30, 2018. (Invited Workshop Presentation on “Unusual Appendages: Novel, multi-modal, or multi-functional uses for limbs, tails, and other body parts”)
- [21] *Novel Field Robots and Robotic Exoskeletons: Design, Integration and Applications*, The Jet Propulsion Laboratory (JPL), California Institute of Technology, Pasadena, CA, March 4-6, 2018. (Invited Research Presentation)
- [20] *Recent Trends on Modeling and Integration of Novel Field Robots and Robotic Exoskeletons and Their Applications*, 2018 International Conference on Mechatronics Systems and Control Engineering (ICMSCE 2018), Amsterdam, Netherlands, February 21-23, 2018. (**Keynote Lecture**)
- [19] *Integrating Novel Field Robots and Robotic Exoskeletons of the Future*, Maxon Precision Motors, Inc. Annual Executive Meeting, Washington, DC, June 1, 2016. (Invited Research Presentation)
- [18] *Novel Field Robots and Robotic Exoskeletons: Design, Integration and Applications*, University of Toronto, Department of Mechanical and Industrial Engineering, Toronto, ON, Canada, February 26, 2016. (**Distinguished Seminar Series** – Research Presentation)
- [17] *Novel Field Robots and Robotic Exoskeletons: Design, Integration and Applications*, Vanderbilt University, Department of Mechanical Engineering, Nashville, Tennessee, October 19, 2015. (Invited Research Presentation)
- [16] *Intelligent Biomimetic Flexible Robots for Stabilizing and Agile Maneuvering of Legged Robots*, Virginia Tech, Center for Bioinspired Science and Technology (BIST), Blacksburg,

VA, October 9, 2015. (Research Presentation)

- [15] *Novel Field Robots and Robotic Exoskeletons: Design, Integration and Applications*, Virginia Tech, Virginia Center for Autonomous Systems (VaCAS), Blacksburg, VA, October 9, 2015. (Invited Research Presentation)
- [14] *Design and Integration of Novel Field Robots and Robotic Exoskeletons*, University of Maryland, Maryland Robotics Center, Department of Mechanical Engineering, College Park, MD, April 24, 2015. (Invited Research Presentation)
- [13] *Design and Integration of Novel Field Robots and Robotic Exoskeletons*, State University of New York at Buffalo (UB), Mechanical and Aerospace Engineering Department, Buffalo, NY, March 12, 2015. (Invited Research Presentation)
- [12] *Design and Integration of Novel Field Robots and Robotic Exoskeletons*, Worcester Polytechnic Institute, Mechanical Engineering Department, Robotics Engineering Department, Worcester, MA, March 9, 2015. (Invited Research Presentation)
- [11] *Design and Integration of Novel Field Robots and Robotic Exoskeletons*, Virginia Tech, Department of Mechanical Engineering, Blacksburg, VA, March 2, 2015. (Invited Research Presentation)
- [10] *Design and Integration of Novel Field Robots and Robotic Exoskeletons*, University of California, San Diego, Department of Mechanical & Aerospace Engineering, San Diego, CA, February 27, 2015. (Invited Research Presentation)
- [9] *Symbiosis of Mobile Robotic Locomotion and Manipulation on Rough Terrain - Towards Modularity and Reconfigurability*, State University of New York at Buffalo (UB), Mechanical and Aerospace Engineering Department, Buffalo, NY, February 28, 2013. (Invited Research Presentation)
- [8] *Autonomous Symbiosis of Mobile Robotic Locomotion and Manipulation on Rough Terrain*, DARPA Defense Sciences Office Maximum Mobility and Manipulation (M3) Conference, Philadelphia, Pennsylvania, July 17-18, 2012. (Invited Research Presentation)
- [7] *STORM: Self-configurable and Transformable Omni-directional Robotic Modules for Rough Terrain Maximum Mobility and Manipulation*, Carnegie Mellon University (CMU), Robotics Institute, Pittsburgh, PA, March 5, 2012. (Invited Research Presentation)
- [6] *Autonomous Symbiosis of Mobile Robotic Locomotion and Manipulation on Rough Terrain*, DARPA Defense Sciences Office Maximum Mobility and Manipulation (M3) Conference, Miramar Beach, FL, January 24-25, 2012. (Invited Research Presentation)
- [5] *Symbiosis of Mobile Robotic Locomotion and Manipulation on Rough Terrain*, 2011 Symposium on Advanced Intelligent Systems, University of Waterloo, Waterloo, Canada, December 1-2, 2011. (**Keynote Lecture**)
- [4] *Sensor-Controlled Autonomous Compounded Manipulation and Locomotion of Mobile Robots*, Örebro University, School of Science and Technology, Centre for Applied Autonomous Sensor Systems (AASS), Sweden, September 10, 2008. (Research Talk)
- [3] *Autonomous Mobile Manipulation for Rough-Terrain Environments*, Mälardalen University, Intelligent Sensor Systems Division, Eskilstuna, Sweden, Sep. 11, 2008. (Research Talk)
- [2] *Hybrid Mobile Robot System for Field Operations: Interchanging Locomotion and*

Manipulation, Robotdalen Day, Volvo CE Democenter, Eskilstuna, Sweden, Sep 10, 2008. (Research Presentation)

- [1] *Wireless Hybrid Mobile Robot system: Adaptive and Interchanging Locomotion and Manipulation*, The George Washington University, Washington, DC, March 2008. (Invited Research Presentation)

Outreach Presentations (in my role as Program Director at NSF)

- [1] *Navigating Research Funding Opportunities in the Established Program to Stimulate Competitive Research (EPSCoR)*, Mississippi State University, National Science Foundation (NSF) Days, Starkville, Mississippi, November 21-22, 2022.

Other Conference /Scholarly/Technical Presentations

- [1] Guo, Y., Xu, W., **Ben-Tzvi, P.**, "Medical Robotic Exoskeleton Glove Designed for Patients with Hand Disabilities", *2022 Association for Uncrewed Vehicle Systems International (AUVSI) Ridge & Valley Conference: Partnerships for Autonomy*, Blacksburg, VA, October 25, 2022.
- [2] **Ben-Tzvi, P.**, "Field Performance of an Articulated Mobile Manipulator for Rough Terrain Applications", *Association for Unmanned Vehicle Systems International (AUVSI) Conference*, Denver, CO, August 24–27, 2010.
- [3] **Ben-Tzvi, P.**, "Mobile Robots for Security and Defense", *National Defense Industrial Association (NDIA) 2010 Ground Robotics Capabilities Conference & Exposition*, Miami, FL, March 16–18, 2010.
- [4] **Ben-Tzvi, P.**, "Demonstrations of a Mobile Robot with Compounded Mobility and Manipulation Capabilities", *Robotics Technology Consortium (RTC) Annual Meeting*, Miami, Florida, March 16, 2010.
- [5] **Ben-Tzvi, P.**, "Experimental Validation and Performance Metrics of a Hybrid Mechanism Mobile Robot", *Standard Test Methods for Response Robots Meeting, ASTM International Committee on Homeland Security Applications, National Institute of Standards and Technology (NIST), Intelligent Systems Division*, Gaithersburg, MD, June 8–10, 2009.
- [6] **Ben-Tzvi, P.**, "Field Performance Metrics of a Novel Hybrid Mobile Robot System", *National Institute of Standards and Technology (NIST), Intelligent Systems Division*, Gaithersburg, MD, March 16, 2009.
- [7] **Ben-Tzvi, P.**, "Swarms of Autonomously Self-Assembling Mobile Robots for Search & Rescue Missions", *National Science Foundation (NSF), Robust Intelligence Cluster, Information and Intelligent Systems*, Arlington, Virginia, February 27, 2009.
- [8] **Ben-Tzvi, P.**, "Proposal for Study on Autonomous Coupling of Navigation & Locomotion for a Hybrid Mechanism Mobile Robot", *Defense Advanced Research Projects Agency (DARPA), Information Processing Techniques Office (IPTO)*, Arlington, Virginia, Jan. 23, 2009.
- [9] **Ben-Tzvi, P.**, Goldenberg, A.A., "Mobile Robots with Hybrid Configuration for Military and Security Applications," *3rd Annual Conference on Robotics and Unmanned Systems*, Washington, DC, May 16-18, 2007.
- [10] **Ben-Tzvi, P.**, Ben Mrad, R., Goldenberg, A.A., "A Dispensing System for Microdrops

Generation in Genomics and Proteomics Applications”, *MMO Partnership Conference 2004*, Toronto Congress Centre, Toronto, Ontario, June 22, 2004.

Technical Reports

- [1] *Self-driving Modular AI-based Robot for Rough Terrain (SMARRT)*, Defense Advanced Research Projects Agency (DARPA), Contract # FA8100-19-P-0022, March 2021.
- [2] *Semi-Autonomous Victim Extraction Robot (SAVER) Design*, US Army Medical Research and Materials Command (USAMRMC/TATRC), Contract # W81XWH-16-C-0062, Sep 2018.
- [3] *Symbiosis of Locomotion and Manipulation with Hybrid Mechanisms Mobile Robot*, Defense Advanced Research Projects Agency (DARPA), Contract # HR0011-11-1-0012, July 2013.
- [4] *Autonomous Symbiosis of Mobile Robotic Locomotion and Manipulation*, Defense Advanced Research Projects Agency (DARPA), Contract # HR0011-11-1-0012, July 2012.
- [5] *Field Experimental Results of a Hybrid Mechanism Mobile Robot*, Defense Advanced Research Projects Agency (DARPA), Contract # HR0011-09-1-0049, March 2011.
- [6] *Study on Autonomous Coupling of Navigation & Locomotion for a Hybrid Mechanism Mobile Robot*, Defense Advanced Research Projects Agency (DARPA), Contract HR0011-09-1-0049, Feb 2010.
- [7] *A Dispensing System for Microdrops Generation for Genomics and Proteomics Applications*, prepared for Materials & Manufacturing Ontario (MMO) Collaborative Project with Engineering Services Inc. (ESI), MMO Final Technical Report, July 2004.
- [8] *Survey on Droplet Generators – Assessment of Technologies and Applications*, MMO Technical Report, Toronto, Canada, September 2002.

Sponsored Research Funding

Total Extramural funding: \$4,225,471

Personal Share: \$2,445,286

Project title	Sponsor	PI	Funding Amount	Project Duration	Status
Robotic Hand Orthosis Providing Grasp Assistance for Patients with Brachial Plexus Injuries	NIH – National Institutes of Health Award # R21HD095027	Ben-Tzvi, P., Bravo, C (co-PI)	\$393,823	5/6/19 – 04/30/21	Complete
Closing the Loop between Robust Control of Agile Legged Robots and Bioinspired Robotic Tails: A Hybrid Systems Approach for Intrinsic Coupling	NSF – National Science Foundation Award # 1906727	Ben-Tzvi, P., Akbari (Co-PI)	\$396,036 (my portion \$244,366)	5/10/19-05/31/22	Complete

Collaborative Modular Robot Teammates for Shipboard Inspection and Maintenance	ONR – Office of Naval Research (DOD - Navy - SECNAV) Award # N00014-19-1-2026	Ben-Tzvi, P., Furukawa, T (PI for UVA)	\$416,924 (my portion \$58,497)	1/01/20 – 12/31/21	Complete
Phase I: Self-driving Modular AI-based Robot for Rough Terrain (SMARTT)	DARPA – Defense Advanced Research Projects Agency (Through Intelligent Automation Inc.) Contract # FA8100-19-P-0022	Ben-Tzvi, P. (VT), Charifa, S. (IAI)	\$225,000 (my portion \$90,000)	4/1/20-3/31/21	Complete
Phase II SBIR: Design of a Mobile Robot for LIFELINE-equipped Squad – Multipurpose Equipment Transport UGV	U.S. Army Medical Research and Material Command -Through RE2, Inc. Phase II SBIR Award # W81XWH-16-C-0062	Ben-Tzvi, P.	\$200,028	10/2016 - 09/2018	Complete
MRI: Development of a System for High-Resolution Uninterrupted Capture of Complex Animal Motions	NSF – National Science Foundation	R. Muller, Ben-Tzvi (Senior Personnel) +8 other SP	\$265,666 (my portion \$25,000)	10/2018-9/2020	Active/ Ongoing
Trawl-Resistant Self-Mooring Autonomous Underwater Vehicle (AUV)	NAVO – US Naval Oceanographic Office	Ben-Tzvi, P. (Co-PI), Stilwell, D. (PI)	\$379,057 (my portion \$71,373)	05/2017-05/2018	Complete
Active Dynamic Continuum Tails for Maneuvering and Stabilizing Legged Robots	NSF – National Science Foundation Award #1334227/1557312	Ben-Tzvi, P.	\$307,672	09/2013-08/2017	Complete
IRES: US-China Collaboration: Bats as Model Organisms for Bioinspired Engineering	NSF – National Science Foundation	R. Muller, Ben-Tzvi (Senior Personnel) +11 other SP	\$250,000 (my portion \$20,000)	02/2017-01/2020	Active/ Ongoing
Analysis of Ship Air Wakes with UAVs	ONR – Office of Naval Research Grant # N00014-15-1-2043	Ben-Tzvi, P. (Co-PI), Snyder, M.R (PI)	\$655,000 (my portion \$356,759)	01/2015-01/2018	Complete
Development of Two-Finger Haptic Glove Exoskeleton for Delivery of Somatosensory Stimuli for Measurement of Cortical Responses in Neurologically Impaired Children	NCH - Nationwide Children's Hospital Research Institute, Through National Institutes of Health (NIH)	Ben-Tzvi, P.	\$50,028	02/2016 - 10/2016	Complete

A Mechatronics Measurement System and Data Processing for Ship Air Wake Studies with UAVs	USN – United States Navy Grant # N00189-12-P-1183	Ben-Tzvi, P.	\$244,030	08/2012-02/2015	Complete
Autonomous Symbiosis of Robotic Locomotion & Manipulation	DARPA –Defense Advanced Research Projects Agency Grant #HR0011-11-1-0012	Ben-Tzvi, P.	\$100,000	09/2011-04/2013	Complete
Study on Autonomous Coupling of Navigation and Locomotion for a Hybrid Mechanism Mobile Robot	DARPA – Defense Advanced Research Projects Agency Grant #HR0011-09-1-0049	Ben-Tzvi, P.	\$299,707	07/2009-12/2010	Complete
Kinetic Universal Robotic Assistive Joint	GWIBE – GW Institute for Biomedical Eng.	Ben-Tzvi, P.	\$10,000	11/2010-07/2011	Complete
A Precise Piezoceramic Actuated Dispensing Array for Microdrops Generation and a Vision Based Testing Setup	UFF/Dilthey Award – GWU Facilitating Fund	Ben-Tzvi, P.	\$20,000	07/2009-08/2010	Complete
Application of Electroactive Polymer (EAP) Artificial Muscles for Development of Bioinspired Walking Micro-Mobile Robot	COBRE – GW Center for Biomimetics and Bioinspired Engineering	Ben-Tzvi, P.	\$12,500	01/2009-12/2009	Complete

Other Awards and Recognitions

Awards of graduate students whose research I am directing

Torgersen Graduate Research Excellence Award, Finalist

May 2022

Prof. Ben-Tzvi's doctoral student, Mr. Yujiong Liu, was selected for an oral and poster presentation category of the Torgersen Graduate Research Award for the research entitled "Novel Legged Robots with a Serpentine Robotic Tail: Modeling, Control, and Implementations". He was one among the 3 selected from all PhD applicants in the College of Engineering.

Torgersen Graduate Research Excellence Award, Poster

May 2019

Prof. Ben-Tzvi's doctoral student, Mr. Bijo Sebastian, was selected for the poster presentation category of the Torgersen Graduate Research Award for the research entitled "Traversability Estimation Techniques for Improved Navigation of Tracked Robots". He was one among the 8 selected from 59 PhD applicants in the College of Engineering.

GW Research Day, 1st place

April 2014

Prof. Ben-Tzvi's doctoral student, Mr. Will Rone, won 1st place for the research entitled "Biomimetic Robotic Tails for Agile Maneuvering of Field Mobile Robots"

Article published by *GW Today* in Summer 2014 issue pg. 11 is available here: <http://bit.ly/1e87Gui>

ASME Graduate Mechanism & Robot Design Competition, 2nd place

August 2012

Prof. Ben-Tzvi's doctoral student, Mr. Paul Moubarak, presented his research project titled "A Tri-state Rigid Reversible and Non-Back-Drivable Docking Mechanism for Modular Robotics Applications" at the ASME IDETC/CIE 2012, August 12-15, Chicago, IL and won 2nd place

SEAS/GWU R&D Showcase, 3rd place

February 2012

for the research entitled "STORM: Self-configurable and Transformable Omni-directional Robotic Modules", Article available here: <http://bit.ly/VNEXh> (with Doctoral Student Paul Moubarak)

Mechanism & Robot Design Competition, 3rd place

August 2011

Students from my graduate robotics course presented their class project entitled "RAIL – Robotic Arm for Interactive Learning", at the ASME IDETC/CIE 2011, August 28-31, Washington, DC and won 3rd place
<https://sites.google.com/site/asmesmrdc/past-winners>

Recognitions & Media Coverage

Media Coverage, Featured Article in *Virginia Tech News Daily*

January 2023

Article titled "Pinhas Ben-Tzvi, a professor and researcher in mechanical engineering, is partnering with physician Cesar Bravo of Carilion Clinic to develop a new tool for those who have suffered a brachial plexus injury", January 12, 2023 Issue.
Article available at: <https://tinyurl.com/52x5pmur>

Media Coverage, Featured Video in *Virginia Tech ME LinkedIn*

December 2022

Article titled "Pinhas Ben-Tzvi teamed up with Carilion Clinic to create a robotic hand for use by those with brachial plexus injuries", December 7, 2022.
Article available at: <https://tinyurl.com/2p9fcpwn>

Media Coverage, Featured Article in *Virginia Tech News Daily*

September 2022

Article titled "Inventor Spotlight: Pinhas Ben-Tzvi, professor of mechanical engineering", September 27, 2022 Issue.
Article available at: <https://www.vt.edu/link/license/faculty-inventors/pinhas-ben-tzvi.html>

Media Coverage, Cover Article Featured in *VT/ME Momentum Magazine*

July 2022

Article titled "Pinhas Ben-Tzvi named Fellow of the ASME", Vol. 7, Issue 1, pp. 15, Spring 2022. Article available at: <https://bit.ly/3zFTjdh>

Media Coverage, Featured Article in *Virginia Tech News Daily*

March 2022

Article titled "Pinhas Ben-Tzvi named fellow of the American Society of Mechanical Engineers", March 15, 2022 Issue.
Article available at: <https://tinyurl.com/mu8zpv5j>

Media Coverage, Article Featured in *VT/ME Annual Report*

Dec. 2021

Article titled "Robots with Tails"
December 2021 Issue. Article available at: <https://bit.ly/3Dw1130>

Media Coverage, Article Featured in *Mechanical Engineering Magazine*

Oct. 2021

Article titled "Robots with Tails", Vol. 143, Issue 6, pp. 32-37, October/November 2021.
Article available at: <https://www.asme.org/topics-resources/content/engineers-could-put-tails-on-robots>

Media Coverage, Cover Article Featured in *VT/ME Annual Report*

Dec. 2018

Article titled "Robotic Tails: High-Tech Tails May Provide Bio-Inspired Solution to Robot Stability", December 2018 Issue. Article available at: <https://vtechworks.lib.vt.edu/handle/10919/81207>

- Media Coverage**, Cover Article Featured in *VT/ME Momentum Magazine* June 2018
Article titled "Tails: The evolution of robots? Robotic tails facilitate robot movement", Vol. 3, Issue 2, pp. 10-15, Summer 2018. Article available at: <https://joom.ag/c9jY>
- Media Coverage**, Article Featured in *Roanoke Times* May 2018
Article titled "Virginia Tech animal-inspired robot tails", May 14, 2018 issue. Article available at: <https://bit.ly/2Gdi6rq>
- Media Coverage**, Article Featured in *VT/ME Momentum Magazine* June 2017
Article titled "UG lab gets students engaged in robotics", Vol. 2, Issue 2, pp. 23, Summer 2017. Article available at: <https://joom.ag/1sBW>
- Media Coverage**, Featured Article in *Virginia Tech News Daily* April 2017
Article titled "New robotics teaching lab enhances engineers' skills", April 10, 2017 Issue. Article available at: <https://vtnews.vt.edu/articles/2017/04/me-roboticsteachinglab.html>
- Media Coverage**, Featured Video and Article in *WDBJ-7 CBS-Affiliated TV Station* June 2016
Article titled "Exoskeleton glove developed at Virginia Tech could diagnose cerebral palsy in children", June 17, 2016. Video/Article available at: <http://www.wdbj7.com/content/news/love-modified-to--383468791.html>
- Media Coverage**, Featured Article in *Cerebral Palsy News Today* June 2016
Article titled "Cerebral Palsy Might Be Detected in Toddlers with Glove by Exoskeleton Engineer", June 22, 2016 Issue. Article available at: <http://bit.ly/2kOU0Mi>
- Media Coverage**, Featured Article in *3D Printer and 3D Printing News* June 2016
Article titled "VT engineer 3D prints robotic exoskeleton glove to help cerebral palsy diagnosis in children", June 23, 2016 Issue. Article available at: <http://bit.ly/28RVu3H>
- Media Coverage**, Featured Article in *Global News Connect* June 2016
Article titled "Engineer Modifies Robotic Exoskeleton Glove to Assistance Intelligent Palsy Diagnosis in Children", June 13, 2016 Issue. Article available at: <http://bit.ly/2fDTxf1>
- Media Coverage**, Featured Article in *ASEE* First Bell Magazine* June 2016
Article titled "Virginia Tech Engineer Develops Robotic Exoskeleton Hand to Diagnose Children", June 21, 2016 Issue. Article: <http://mailview.bulletinmedia.com/mailview.aspx?m=2016062101asee&r=2892555-5e40>
* ASEE – American Society of Engineering Education
- Media Coverage**, Article Featured in *VT/ME Momentum Magazine* July 2016
Article titled "Exoskeleton to help cerebral palsy diagnosis in children", Vol. 1, Issue 2, pp. 12, July 2016. Article available at: <http://bit.ly/2aytqSW>
- Media Coverage**, Featured Article in *Virginia Tech News Daily* June 2016
Article titled "Engineer modifies robotic exoskeleton glove to help cerebral palsy diagnosis in children", June 10, 2016 Issue. Article available at: <https://vtnews.vt.edu/articles/2016/06/me-roboticdiagnosticglove.html>
- Recognition**, Robotics and Mechatronics Laboratory (RML) December 2013
Cited on the newly published list of 99 Superb Sites on Mechatronics & Robotics Engineering, <http://www.electricalengineeringschools.org/mechatronics>

- Media Coverage**, Featured Article in **GW Alumni Magazine** June 2013
Article titled "The Body Robotics", Summer 2013 Issue, pp. 56-59.
Article available at: <http://magazine.gwu.edu/body-robotic>
- Media Coverage**, Featured Article in **GW Research Magazine** April 2013
Article titled "The Body Robotics: Form, function, and the future as seen through the eyes and handiwork of three GW roboticists", Spring 2013 Issue, pp. 19-23.
Article available at: http://www.gwu.edu/~magazine/2013_research_spring/feature1.html
- Media Coverage**, television interview to **CTV News (Canadian Television Network)** Nov. 2012
Live interview on [The Advancement of Robots](#)
Interview available at: <http://bit.ly/1yU7DX2>
- Media Coverage**, blog posting on the **Scientific American** May 2012
Article titled "School Turns Engineering Faculty into Superheroes"
Article available at: <http://bit.ly/KzAADF>
- Media Coverage**, GW's Newspaper published by **GW Today** April 2012
Article titled "Engineering Interest - New SEAS marketing campaign uses superheroes to highlight ground-breaking research"
Article available at: <http://bit.ly/KrooQr>
- Newspaper Article**, published by **The GW Hatchet** April 2012
"SEAS shows off 'superhero' engineers", Vol. 108, Issue 56, pp. 3, Apr 16, 2012
Featured article on my research on modular and reconfigurable mobile robotics
Article available at: <http://bit.ly/HLUGJB>
- Media Coverage**, published by **SEAS/GWU** April 2012
SEAS features Prof. Ben-Tzvi as a "superhero" – RobotronMan
Article available at: <http://bit.ly/1AfmE89>
- Media Coverage**, Featured Article by **The GW Hatchet** April 2012
Robotics Workshop for GW's Science, Technology and Engineering Day
Article available at: <http://bit.ly/HHnTmz>
- Media Coverage**, GW's Newspaper published by **GW Today** March 2012
For winning 3rd place in the GWU SEAS R&D Showcase
Article available at: <http://bit.ly/yVNEXh>
- Media Coverage**, radio interview to **China Radio International** December 2011
Live, hour-long panel discussion on [Robot Revolution](#)
Interview available at: <http://english.cri.cn/8706/2011/12/09/2861s670868.htm>
- Media Coverage**, Television interview for **Voice of America** August 2011
Covered ongoing research activities in the Robotics and Mechatronics Lab
Video and article available at: <http://bit.ly/uHXKPz>
- Media Coverage**, Featured Video and Article at **Loudoun Times** April 2011
Robotics Workshop for GW's Science, Technology and Engineering Day
Article and video available at: <http://bit.ly/e94yNk>
- Media Coverage**, Featured Article at **Leesburg Today** April 2011
Robotics Workshop for Loudon county high school students as part of GW's Science, Technology and Engineering Day at the Virginia Science and Technology Campus

Article available at: <http://bit.ly/odlyXJ>

Media Coverage, radio interview on the show *Today on Beyond Beijing*
Panel discussion featuring international experts on the future of robotics
Interview available at: <http://english.cri.cn/8706/2011/01/07/481s613923.htm>

January 2011

Featured in GW's Newspaper published by **GW Today**
Article titled "[The Robot Revolution](#)"
Article available at: <http://gwtoday.gwu.edu/robot-revolution>

August 2010

Featured in 2010 issue of SEAS **Synergy Magazine** (pg. 6) showcasing my
research activities at the GW Robotics and Mechatronics Lab

July 2010

Featured in the [SEAS Video](#) highlighting my research in the
Robotics & Mechatronics Lab in SEAS
http://www.rmlab.org/bentzvi_GW_video.php

May 2010

* Video used as a media content for various audiences including graduate and undergraduate
recruiting, raising funds for SEAS from prospective donors and keeping alumni engaged

Featured photos of the Robotics and Mechatronics Lab
SEC (Science and Engineering Hall) Brochure highlighting students'
research work in robotics and mechatronics

April 2010

Student Supervision

Graduated Ph.D. Students (10)

Dates	Degree	Candidate	Dissertation Title	Current Position
Aug. 2017 – May 2022	Ph.D.	Yujiong Liu	Novel Legged Robots with a Serpentine Robotic Tail: Modeling, Control, and Implementations	Robotic System Engineer, Cornerstone medical USA Inc.
May 2017 – Dec. 2021	Ph.D.	Shumin Feng	Design, Analysis, Planning, and Control of a Novel Modular Self-Reconfigurable Robotic System	Staff Robotics Engineer, DIMAAG-AI
Jan. 2018 – Dec. 2020	Ph.D.	Taylor Njaka	Design, Simulation, and Experimental Validation of a Novel High-Speed Omnidirectional Underwater Propulsion Mechanism	Postdoctoral Researcher at Virginia Tech
Sep. 2016 – Mar. 2020	Ph.D.	Hailin Ren	Human-Robot Interaction with Pose Estimation and Dual-Arm Manipulation Using Artificial Intelligence	Senior Software Engineer, MathWorks
Jan. 2016 – Sep. 2019	Ph.D.	Bijo Sebastian	Traversability Estimation Techniques for Improved Navigation of Tracked Mobile Robots	Assistant Professor, Indian Institute of Technology, Madras
Sep. 2012 – Mar. 2018	Ph.D.	Wael Saab	Design and Implementation of Articulated Robotic Tails to Augment the Performance of Reduced Degree-of-Freedom Legged Robots	Senior Research and Development Engineer, SoftWear Automation
Jan. 2012 – Feb. 2018	Ph.D.	Anil Kumar	Estimation and Mapping of Ship Airwake Using RC Helicopters as a Sensing Platform	Senior Systems Integration Engineer, GM Cruise
Sep. 2010 – Dec. 2017	Ph.D.	William S. Rone	Hyperredundant Dynamic Robotic Tails for Stabilizing and Maneuvering Control of Legged Robots	Mechanical Engineer, US Airforce Nuclear Weapons Center

Sep. 2009 – May 2013	Ph.D.	Paul M. Moubarak	A Mobile Robot with Modular and Reconfigurable Mobility and Manipulation	Research Engineer, Ford Motor Company
Jan. 2010 – Dec. 2014	Ph.D.	Zhou Ma	Sensing and Force-Feedback Exoskeleton (SAFE) Robotic Glove Mechanism and Its Applications	Senior Robotics Engineer, US Medical Innovations Company

Graduated M.S. Students (20)

Dates	Degree	Candidate	Thesis Title
Aug. 2020 – May 2022 (VT)	M.S.	Isaac Pressgrove	A Systematic Design Methodology for Articulated Serpentine Robotic Tails to Assist Agile Robot Behaviors
Aug. 2019 – July 2021 (VT)	M.S.	Sarthak Pradhan	Design and Control of an Exoskeleton Glove Using a Neural Network Based Controller for Grasping Objects
Aug. 2019 – Dec. 2020 (VT)	M.S.	Yunfei Guo	Personalized Voice Activated Grasping System for a Robotic Exoskeleton Glove
Jan. 2019 – May 2020 (VT)	M.S.	Xiaoxue Han	Autonomous Cricothyroid Membrane Detection and Manipulation using Neural Networks and a Robotic Arm for First-Aid Airway Management
Aug. 2017 – July 2019 (VT)	M.S.	Teja Vanteddu	Grasp Stability with a Robotic Exoskeleton Glove
Aug. 2017 – May 2019 (VT)	M.S.	Shubhdildeep Singh Sohal	A Hybrid Tracking Approach for Autonomous Docking in Self-Reconfigurable Robotic Modules
Aug. 2017 – Dec. 2018 (VT)	M.S.	Jiteng Yang	A Two-DOF Bipedal Robot Utilizing the Reuleaux Triangle Drive Mechanism
May 2017 – Dec. 2018 (VT)	M.S.	Shumin Feng	Mobile Robot Obstacle Avoidance Based on Deep Reinforcement Learning
Sep. 2016 – May 2018 (VT)	M.S.	Adam Williams	A Robotic Head Stabilization Device for Post-Trauma Transport
Sep. 2016 – May 2018 (VT)	M.S.	Brielle Junghee Lee	Development of Intelligent Exoskeleton Grasping Through Sensor Fusion and Slip Detection
Jan. 2016 – Dec. 2017 (VT)	M.S.	Vinaykarthik Kamidi	Design and Integration of Novel Single Degree of Freedom Leg For Fast Locomotion
Jan. 2016 – Dec. 2017 (VT)	M.S.	Peter Racioppo	Design and Control of a Modular, Cable-Driven Snake Robot
Jan. 2016 – Dec. 2017 (VT)	M.S. (ECE)	Eric Refour	Design and Integration of a Form-Fitting General Purpose Robotic Hand Exoskeleton
Sep. 2012 –	M.S.	Jeffrey Phillips	Exoskeleton robotic arms for rehabilitation

May 2014 (GW)			applications
Sep. 2012 – May 2014 (GW)	M.S.	Bohua Zhang	Robotic wrist exoskeleton device for debilitated patients
Sep. 2012 – May 2014 (GW)	M.S.	Yue Sun	Modeling and simulation of micro-droplet precision devices
Sep. 2010 – May 2012 (GW)	M.S.	Chad Gilman	Medical robotics – human wrist joint assist robot
Sep. 2013 – Aug. 2015 (GW)	M.S.	Xiaofan Liu	Non-Thesis
Sep. 2013 – Aug. 2015 (GW)	M.S.	Teng Long	Non-Thesis
Sep. 2012 – May 2015 (GW)	M.S.	Olugbenga Idowu	Non-Thesis

Current PhD and MS Students

Dates	Degree	Candidate	Research Topic
Dec. 2020 – Present (VT) (VT)	Ph.D.	Yunfei Guo (ECE)	Voice activation Control of Robotic Exoskeleton Gloves
Aug. 2019 – Present (VT)	Ph.D.	Wenda Xu	Machine Learning Algorithms for Autonomous Grasping with a Reduced-DOF Exoskeleton Glove for Brachial Plexus Injuries
Aug. 2020 – Present (VT)	Ph.D.	Jingyuan Qi (CS) Co-advised with Prof. Feng	Machine learning application in human robot interaction and UAV

Visiting PhD Students

Date	Candidate	Originating Institution	Topic
09/01/2019 – 10/31/2020	Xiaoyun Lei	Nanjing University of Science and Technology	Dual-arm Cooperation Manipulation with Distance Constrains using Deep Reinforcement Learning

Postdoctoral Scientists

Employed	Student	Degree and Institution	Research Topic	Employment
May 2014– Apr. 2017	Dr. Lawrence Wong	Ph.D., University of Waterloo	Micromachined Ultrasonic Transducers for Non-destructive Testing Applications	Advanced Research Engineer at Thalmic Labs
Jan. 2012– Jan. 2013	Dr. Radu Robotin	Ph.D., Technical University of Cluj-Napoca	Vision Guided Autonomous Robotic Locomotion and	Cloud Systems Engineer at National Cancer

			Manipulation	Institute (NCI)
Feb 2010– Feb. 2011	Dr. Xianxin Ke	Ph.D., Shanghai University	Dynamic Mobility of an Omni-wheel Robots	Associate Professor at Shanghai Univ.
Nov 2009– Jan. 2011	Dr. Samer Charifa	Ph.D., North Carolina Agricultural and Technical State Univ.	Volumetric Environment Mapping Using Multi-sensor Fusion for Robotic Vision	Research Scientist at Intelligent Automation, Inc.

Visiting Professors

Date	Candidate	Originating Institution	Topic
Sep. 2010 – Sep. 2012	Prof. Jae Weon Choi	Pusan National Univ., S. Korea	Navigation, Guidance, and Control for Autonomous Vehicles

Visiting Scholars Advising

Date	Candidate	Topic
Jul. 2010 – Sep 2011	Prof. Arif Ankarali	ANFIS* Inverse Kinematics and Precise Trajectory Tracking of a Dual Arm Robot (* <i>Adaptive Neuro Fuzzy Inference System</i>)
Oct. 2009 – Jan. 2010	Dr. Getachew Befekadu	Decentralized control and optimization of interconnected systems with applications to multiple robots coordination

Undergraduate Students Research Thesis/Projects Advising

Date	Candidate	Department	Research Topic
Aug. 2022 – Present	Renrui Liu	ME/VT	Exoskeleton Robotic Glove Design for Hand Rehabilitation
May 2020 – Present	Alex Broz	ME/VT	Design of a two-section robotic tail based on the Rigitail
May 2020 – Present	Ruichang Chen	ECE/VT	Simulation environment development of modular and reconfigurable robots in V-Rep
Aug. 2019 – Dec 2020	Logan Stevenson	ME/VT	Upper extremity exoskeletons for robot control and rehabilitation therapy
Feb. 2019 – Dec 2020	Jonah Fike	AOE/VT	Omni-Direction Propulsion Mechanism for Underwater Vehicles
May 2019 – Dec 2020	Marco Brizzolara	Physics /VT	Omni-Direction Propulsion Mechanism for Underwater Vehicles
May 2019 – Dec 2020	Abdalla Diraz	ME/VT	Robotic Exoskeleton Glove Mechanism for Autonomous Grasping
Jan. 2019 – Dec 2020	Jingyuan Qi	Physics/VT	Machine learning application in human robot interaction and UAV
Sep. 2018 – Dec 2020	Samatar Jama	ME/VT	Semi-autonomous Robot Motion Planning
Sep. 2018 – Dec. 2018	Alex Rhee	ECE/VT	Design of Rotary SEA for Robotic Glove Exoskeleton Applications
May 2018 –	Alina Voelker	ME/VT	Vision Based Localization Techniques for

Dec. 2018			Ground Robots
Jan 2018 – May 2019	Kefan Li	ME/VT	Autonomous Grasping with a Robotic Exoskeleton
Nov 2017 – May 2018	Zhoubao Pang	ME/VT	Design and Integration of a Single-DOF Biped with a Rigid Robotic Tail
Nov 2017 – May 2018	Hongxu (Howard) Guo	ME/VT	Controller Design for a Single-DOF Biped Locomotion with a Robotic Tail
Jan 2017 – Dec. 2018	Nicole Gouhin	ME/VT	Review of Bio-inspired Robotic Tails
Jan 2017 – Dec. 2018	Xinran Wang	ME/VT	Suspension Design for a Search and Rescue Mobile Ground Robot
May 2017 – Aug 2017	Youssef Haridy	ME/VT	Docking Mechanisms for Modular Robotic Modules
Jan 2016 – May 2017	David Evans	CEC/VT	Design of Embedded Controllers for Reconfigurable Robotic Modules
Jan 2016 – May 2017	Brock Davis	ME/VT	Modeling and Controls of a Robotic Exoskeleton Mechanism for Rehabilitation
Jan 2016 – Dec 2016	Tommy Hutcheson	ME/VT	Design and Simulation of a 2-finger Robotic Exoskeleton Mechanism for Rehabilitation
Jan 2015 – Aug 2015	Timothy Wetzel	MAE/GWU	Simulation of Robotic Tails for Maneuvering Quadruped Robots
May 2013 – Aug 2015	Cyndi-Leigh Pine	MAE/GWU	Rehabilitation robotics and computer-aided design
Jan 2014 – May 2014	Robert Forcha	MAE/GWU	Simulation of Fingers Position for Hand Rehabilitation Application
May 2011 – May 2013	Eric Alvarez	MAE/GWU	Design of docking interface for reconfigurable mobile robotic system
Sep 2011 – May 2013	Jeff Birenbaum	MAE/GWU	Synergistic Piezo Actuation
Sep 2011 – Sep 2012	Jeffrey Phillips	MAE/GWU	Continuum Robotics for Rehabilitation
Jan – May 2012	Allison Hogarth & David Perry	MAE/GWU	Moving Side View Mirror for Blind Spot Detection
Sep 2011 – Dec 2011	Jimmy Gomez	MAE/GWU	Robotic exoskeleton device for augmenting wrist movement in debilitated patients
Sep. 2010 – Sep. 2012	Danielle Barsky	MAE/GWU	Modeling and Simulation of MEMS tilt sensor
May 2011 – Sep 2011	Gabriel Yessin	ECE/GWU	Optimization of algorithms for remote control operation of a mobile robot
Sep. 2009 – Jan. 2011	Michael Shick	CS/GWU	Algorithms for mobile robot autonomous functions
May 2009 – Aug. 2010	Will Rone	MAE/GWU	Piez-actuated dispensing system for micro-drops generation in microarray applications
May–Sep 2009	Sarah Beaver	MAE/GWU	Electroactive polymers applied toward biomimetic robots
May–Dec 2009	Tim Perkins	MAE/GWU	Smart materials for the development of biomimetic micro-robots
Dec. 2009 –	Marcus	MAE/GWU	Mechanical and electrical design layout for a

June 2010	Hendricks		mobile robot remote controller
Mar. 2010 – April 2011	Hannah Stuart	MAE/GWU	Development of a operating control unit for a mobile robot
Mar. 2010 – April 2011	Micah Foster	MAE/GWU	Development of a operating control unit for a mobile robot
Mar. 2010 – Dec 2010	Nicholas Blanton	MAE/GWU	Detailed design layout of a operating control unit components
June – Sep 2010	Brandon Fix	MAE/GWU	Perform design layouts of mechanical parts using SolidWorks

Undergraduate Interns Supervision

Date	Candidate	Originating Institution	Topic
Oct – Dec. 2010	Gustavo Ruiz, B.Sc.	Polytechnic University of Chiapas, Mexico	Hardware-in-the-loop (HIL) simulations of dual arm mobile robotic system (<i>Funded by the Mexican government under the Governors' Internship Program</i>)
Jan–Apr. 2010	Mikhail Zhuk, MechE Senior	University of California, Irvine	Modeling and simulation of robotic systems using ADAMS and ATV ToolKit
Jun–Aug. 2010	Ari Schifftan, MechE Junior	University of Miami, FL	Modeling and analysis of mechanical parts for a hybrid mobile robot using ABAQUS FEA SW

Ph.D. Dissertation External Examiner

Student Name	Thesis Title	Defense date	Institution
So-Ra Chung	MEMS Demodulator Based on Electrostatic Actuator	July 6, 2012	University of Waterloo Dept. of Systems Design Engineering

PhD/MS Thesis Reader / Committee Member/Chair

Student Name	Thesis/Dissertation Title	Level	Defense date	Advisor	Role / Institution
Shumin Feng	Design, Analysis, Planning, and Control of a Novel Modular Self-Reconfigurable Robotic System	Ph.D.	Dec. 2, 2021	Dr. P. Ben-Tzvi	Dissertation Director/ VT*
Michael Molzon	Development of a Mobile Robot System for the Visual Inspection of Railcar Undercarriage Equipment	Ph.D.	June 2022	Dr. Mehdi Ahmadian	Committee Member/ VT*
Sarthak Pradhan	Design and Control of an Exoskeleton Glove Using a Neural Network Based Controller for Grasping Objects	M.S.	July 23, 2021	Dr. P. Ben-Tzvi	Thesis Director/ VT*
Yunfei Guo	Personalized Voice Activated Grasping System for a Robotic Exoskeleton Glove	M.S.	Dec. 10, 2020	Dr. P. Ben-Tzvi	Thesis Director/ VT*
Taylor Njaka	Design, Simulation, and Experimental Validation of a Novel High-Speed Omnidirectional Underwater Propulsion Mechanism	Ph.D.	Dec. 14, 2020	Dr. P. Ben-Tzvi	Dissertation Director/ VT*
Grant Carter	Adaptive Control of the Transition from Vertical to Horizontal Flight Regime of a Quad-Tailsitter UAV	M.S.	May 12, 2021	Dr. Andrea L'Afflitto	Committee Member/ VT*

Alfred Mayalu	Beyond LiDAR for Unmanned Aerial Event-Based Localization in GPS Denied Environments	Ph.D.	May 20, 2021	Dr. K. Kochersberger	Committee Member/ VT*
Kenneth E. Kroeger	Decentralized Task Allocation and Coordination of Heterogeneous UxVs Subjected to Spatiotemporally Evolving Environment	Ph.D.	TBD	Dr. K. Kochersberger	Committee Member/ VT*
Wael Saab	Design and Implementation of Articulated Robotic Tails to Augment the Performance of Reduced Degree-of-Freedom Legged Robots	Ph.D.	March 19, 2018	Dr. P. Ben-Tzvi	Dissertation Director/ VT*
Anil Kumar	Estimation and Mapping of Ship Air Wakes using RC Helicopters as a Sensing Platform	Ph.D.	Feb. 26, 2018	Dr. P. Ben-Tzvi	Dissertation Director/ VT*
William S. Rone	Hyperredundant Dynamic Robotic Tails for Stabilizing and Maneuvering Control of Legged Robots	Ph.D.	Dec. 13, 2017	Dr. P. Ben-Tzvi	Dissertation Director/ VT*
Bijo Sebastian	Traversability Estimation Techniques for Improved Navigation of Tracked Mobile Robots	Ph.D.	Sep. 19, 2019	Dr. P. Ben-Tzvi	Dissertation Director/ VT*
Hailin Ren	Human-Robot Interaction with Pose Estimation and Dual-Arm Manipulation Using Artificial Intelligence	Ph.D.	March 23, 2020	Dr. P. Ben-Tzvi	Dissertation Director/ VT*
Shumin Feng	Path Planning Algorithms and Control of Modular Mobile Robots	Ph.D.	TBD	Dr. P. Ben-Tzvi	Dissertation Director/ VT*
Yujiong Liu	Dynamics Modeling and Control of Hybrid Robotic Tail-Bipedal Systems	Ph.D.	TBD	Dr. P. Ben-Tzvi	Dissertation Director/ VT*
Negin Nikafrooz	Design, fabrication, and control of an assistive glove for farmers with mobility limitations	Ph.D.	Spring 2021	Dr. A. Leonessa	Committee Member/ VT*
Murat Ambarkutuk	Development of a Non-Line-of-Sight Perception Technique with high-frequency short range RADAR for Deformation Measurements	Ph.D.	Fall 2020	Dr. T. Furukawa	Committee Member/ VT*
Murtaza Rangwala	Control and coordination of multi-agent systems/robots using deep reinforcement learning	Ph.D.	TBD	Dr. Ryan Williams	Committee Member/ VT*
Jiteng Yang	A Two-DOF Bipedal Robot Utilizing the Reuleaux Triangle Drive Mechanism	M.S.	Nov. 16, 2018	Dr. P. Ben-Tzvi	Thesis Director/ VT*
Shumin Feng	Mobile Robot Obstacle Avoidance Based on Deep Reinforcement Learning	M.S.	Dec. 12, 2018	Dr. P. Ben-Tzvi	Thesis Director/ VT*
Adam Williams	A Robotic Head Stabilization Device for Post-Trauma Transport	M.S.	May 9, 2018	Dr. P. Ben-Tzvi	Thesis Director/ VT*

Brielle Junghee Lee	Development of Intelligent Exoskeleton Grasping Through Sensor Fusion and Slip Detection	M.S.	May 9, 2018	Dr. P. Ben-Tzvi	Thesis Director/ VT*
Peter Racioppo	Design and Integration of a Form-Fitting General Purpose Robotic Hand Exoskeleton	M.S.	Dec. 11, 2017	Dr. P. Ben-Tzvi	Thesis Director/ VT*
Vinaykarthik Kamidi	Design and Integration of Novel Single Degree of Freedom Leg For Fast Locomotion	M.S.	Dec. 19, 2017	Dr. P. Ben-Tzvi	Thesis Director / VT*
Eric Refour	Design and Integration of a Form-Fitting General Purpose Robotic Hand Exoskeleton	M.S.	Sep. 29, 2017	Dr. P. Ben-Tzvi	Thesis Director/ VT*
Teja Vanteddu	Grasp Stability with a Robotic Exoskeleton Glove	M.S.	July 24, 2019	Dr. P. Ben-Tzvi	Thesis Director/ VT*
Shubhdildeep Singh Sohal	A Hybrid Tracking Approach for Autonomous Docking in Self-Reconfigurable Robotic Modules	M.S.	May 9, 2019	Dr. P. Ben-Tzvi	Thesis Director/ VT*
Gordon Christie	Collaborative Unmanned Air and Ground Vehicle Perception for Scene Understanding, Planning and GPS-denied Localization	Ph.D.	Nov. 7, 2016	Dr. K. Kochersberger	Committee Member/ VT*
Hubert Kim	Joint Torque Feedback for Motion Training with an Elbow Exoskeleton	Ph.D.	Sep. 14, 2021	Dr. A. Asbeck	Committee Member/ VT*
Sebastien Corner	Modeling, Sensitivity Analysis, and Optimization of Hybrid, Constrained Mechanical Systems	Ph.D.	Feb. 14, 2018	Dr. Corina Sandu	Committee Member/ VT*
Adam Lowery	Enhanced Portability and Anti-Frosting Functionality of Cryostats for Synchrotron-Based X-ray Imaging	Ph.D.	June 21, 2022	Dr. Jonathan Boreyko	Committee Member/ VT*
Cong Chen	Robust Motion Tracking and Post Estimation of Combined Camera and Lidar 3D Shape	Ph.D.	TBD	Dr. T. Furukawa	Committee Member/ VT*
Mengyu Song	Specular Micro-texture Photometry for Circumferential Three-Dimensional Profiling	Ph.D.	May 19, 2020	Dr. T. Furukawa	Committee Member/ VT*
John Seminatore	Design of a Series Elastic Humanoid for the DARPA Robotics Challenge	M.S.	August 3, 2016	Dr. Al Wicks	Committee Member / VT*
Tom Ehrenzeller	Visual Servoing Using a Two Armed Robot	M.S.	TBD	Dr. T. Furukawa	Committee Member/ VT*
Chen Tang	Design of a Gravity Compensation Actuator for Arm Assistance	M.S.	Dec. 18, 2017	Dr. Alan Asbeck	Committee Member/ VT*
Yi Tian	Self-Powered Intelligent Traffic Monitoring Using IR Lidar and Camera	M.S.	Dec. 8, 2016	Dr. T. Furukawa	Committee Member/ VT*
Murat Ambarkutuk	A Grid-based Radiolocation Technique Based on Spatially Coherent Path Loss Model	M.S.	Sep. 1, 2017	Dr. T. Furukawa	Committee Member/ VT*
Bryan Todd	Comparison of the Role of Beamwidth in Biological and Engineered Sonar	M.S.	Sep. 29, 2017	Dr. R. Mueller	Committee Member/ VT*

Zhou Ma	Sensing and Force-Feedback Exoskeleton Robotic (SAFER) Glove Mechanism for Rehabilitation	Ph.D.	Dec. 15, 2014	Dr. P. Ben-Tzvi	Dissertation Director/ GWU**
Paul M. Moubarak	A Mobile Robot with Modular and Reconfigurable Mobility and Manipulation	Ph.D.	March 15, 2013	Dr. P. Ben-Tzvi	Dissertation Director/ GWU**
Robert Cortesi	Modeling and Control of Joint-Actuated Buoys	Ph.D.	Feb. 15, 2012	Dr. D. Chichka	Committee Member/ GWU**
Kenan Cole	Design, Analysis, and Optimization of an Interferometer for Extreme Ultraviolet Interference Lithography	M.S.	Nov. 10, 2010	Dr. R. Ryan Vallance	Committee Member/ GWU**
Jaime Alba-Bohorquez	Design of a Robust Altitude-Hold Controller for UAVs Using Neural Networks	M.S.	Nov. 21, 2008	Dr. D. Chichka	Committee Member/ GWU**

* VT – Virginia Tech; ** GWU – George Washington University

High School Students Mentoring

Date	Candidate	School Name	Topic
Summer 2022	Phillipe Charalanis	Blacksburg Middle School	Camera System for Human Motion Detection and Tracking
May 2019 – Dec. 2020	Kye Gonino	James River High School	Omni-Direction Propulsion Mechanism for Underwater Vehicles
Sep 2013 – May 2015	Daniel Dulaney	School Without Walls (SWW)	Omni-directional mobile robots locomotion

Teaching

Courses Taught

Virginia Tech - Department of Mechanical Engineering

Controls Engineering I (ME 3534)	Spring 2022
Advanced Robotics and Automation (ME 5704/ECE 5704)	Fall 2021
Robotics & Mechatronics Seminar (ME 4734)	Fall 2021
Controls Engineering I (ME 3534)	Spring 2021
Engineering Design and Project II (ME4016)	Spring 2021
Mechanical Vibrations (ME 3524)	Fall 2020
Engineering Design and Project I (ME4015)	Fall 2020
Advanced Robotics and Automation (ME 5704/ECE 5704)	Spring 2020
Robotics Laboratory (ME 4584/ECE 4584)	Spring 2020
Robotics and Automation (ME 4524)	Spring 2020
Principles of Robotics Systems (ECE 4704)	Spring 2020
Advanced Robotics and Automation (ME 5704/ECE 5704)	Spring 2019
Robotics Laboratory (ME 4584/ECE 4584)	Spring 2019
Robotics and Automation (ME 4524)	Spring 2019

Principles of Robotics Systems (ECE 4704)	Spring 2019
Advanced Robotics and Automation (ME5704/ECE 5704)	Spring 2018
Robotics Laboratory (ME 4584/ECE 4584)	Spring 2018
Robotics and Automation (ME 4524)	Spring 2018
Principles of Robotics Systems (ECE 4704)	Spring 2018
Engineering Design and Project I (ME4015)	Fall 2017
Robotics and Automation (ME 4524)	Spring 2017
Principles of Robotics Systems (ECE 4704)	Spring 2017
Robotics and Automation (ME 4524)	Spring 2016
Principles of Robotics Systems (ECE 4704)	Spring 2016
Engineering Design and Project II (ME4016)	Spring 2016
System Dynamics (ME 3514)	Fall 2015
Engineering Design and Project I (ME4015)	Fall 2015

George Washington University - Department of Mechanical & Aerospace Engineering

Robotic Systems (MAE 6245)	Spring 2015
Mechatronics Design (MAE 4194)	Spring 2015
Electromechanical Control System Design (MAE 4182)	Fall 2014
Robotic Systems (MAE 6245)	Spring 2014
Mechatronics Design (MAE 4194)	Spring 2014
Analysis and Synthesis of Mechanisms (MAE 3190)	Fall 2013
Robotic Systems (MAE 6245)	Spring 2013
Mechatronics Design (MAE 4194)	Spring 2013
Analysis and Synthesis of Mechanisms (MAE 3190)	Fall 2012
Robotic Systems (MAE 6245)	Spring 2012
Mechatronics Design (MAE 4194)	Spring 2012
Electromechanical Control System Design (MAE 4182)	Fall 2011
Robotic Systems (MAE 6245)	Spring 2011
Mechatronics Design (MAE 4194)	Spring 2011
Electromechanical Control System Design (MAE 4182)	Fall 2010
Mechatronics Design (MAE 4194)	Spring 2010
Introduction to Vibration Analysis (MAE 3134)	Spring 2010
Electromechanical Control System Design (MAE 4182)	Fall 2009
Introduction to Vibration Analysis (MAE 3134)	Spring 2009

University of Toronto – Department of Mechanical & Industrial Engineering

Computer Aided Design (MIE441)	Winter 2006, 2007, 2008
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Introduction to Computer Aided Design (Short Course)	Winter, Spring, Fall 2007, Winter 2008
Control Systems (MIE372) Co-Instructor (with Prof. A.A. Goldenberg)	Fall 2003, 2004
<u>University of Toronto – Faculty of Applied Science and Engineering</u>	
Artificial Intelligence and Robotics	Fall 2006
Mechatronics and Artificial Intelligence	Summer 2005
Mechatronics Design and Operation	Fall 2004
Mechatronics	Summer 2004
<u>Technion - Israel Institute of Technology</u>	
Instructor, Physics Courses – Mechanics	July 1999–July 2000
<u>Israeli Air Force Academy</u>	
Senior Instructor, Engineering Courses Courses taught: Control Systems, Mechanics and Control Lab, Mechanical Machining Lab, Hydraulics Lab, Pneumatics Lab, CNC Lab, Engineering Drafting, Computer Aided Design Lab	May 1993–April 1996

Teaching Expertise & Interests

The following is a selected list of my teaching experiences and interests:

System Dynamics and Control

- Analysis & Design of Feedback Control Systems
- Automatic Control Systems
- Linear & Nonlinear Control Systems
- Modeling and Simulation of Dynamic Systems

Mechatronics

- Mechatronic Systems Design
- Mechatronics Principles
- Microcontroller-based Systems Design
- Sensors, Actuators & Measurement

Core Courses

- Statics
- Dynamics and Vibrations
- Electrical Circuits

Robotics and Automation

- Industrial Automation Systems Design
- Robotic Systems Design
- Robot Kinematics, Dynamics & Control
- Design of Electromechanical Mobile Robots

Design and Manufacturing

- Precision Mechanism Analysis & Synthesis
- Electromechanical Machine Design
- Computer Aided Design (CAD)
- System Design & Analysis (FEA)

Service to Profession and Field

A. Professional Service

A1. Workshops Organized (in my role as Program Director at NSF)

- [1] *NSF EPSCoR Workshop on Quantum Computing, Information, Science, and Engineering*, National Science Foundation (NSF), Alexandria, VA, March 23-24, 2023.

A2. Conference General Chair

General Chair, IEEE International Symposium on Robotic and Sensors Environments – IEEE ROSE 2013, Washington, DC, 21-23 October 2013.

A3. Conference Technical Program Committees – Chair / Co-Chair

- **Chair** of the Technical Program Committee for the 44th Mechanisms and Robotics Conference at the 2020 ASME International Design Engineering Technical Conferences (IDETC/CIE), August 2020, St. Louis, MO, USA.
- **Co-Chair** of the Technical Program Committee for the 43rd Mechanisms and Robotics Conference at the 2019 ASME International Design Engineering Technical Conferences (IDETC/CIE), August 2019, Anaheim, CA, USA.
- **Chair** for Workshops, Tutorials and Special Sessions for the 2017 ASME Dynamic Systems and Control Conference – DSCC 2017, Tysons Corner, VA, 11-13 Oct. 2017.
- **Co-Chair** of the Technical Program Committee for the 10th IEEE International Symposium on Robotic and Sensors Environments – ROSE 2012, Magdeburg, Germany, 16-18 Nov. 2012.
- **Co-Chair** of the Technical Program Committee for the 7th IEEE International Workshop on Robotic and Sensors Environments – ROSE 2009, Lecco, Italy, 6-7 November 2009.

A4. Symposium Chair / Co-Chair

Symposium Co-Chair, Mobile Robotics Symposium, 42nd Mechanisms and Robotics Conference at the 2018 ASME International Design Engineering Technical Conferences (IDETC/CIE), August 26-29, 2018, Quebec City, Canada.

A5. Conference Technical Program Committees – Member

- **Member** of the Technical Program Committee for the 2019 IEEE International Conference on Mechatronics and Automation - IEEE ICMA 2019, Tianjin, China, 4-7 Aug. 2019.
- **Member** of the Technical Program Committee for the 2019 IEEE International Workshop on Robotic and Sensors Environments - ROSE 2019, Ottawa, Canada, 17-18 June 2019.
- **Member** of the Organizing Committee for the 2018 International Conference on Mechatronics Systems and Control Engineering – ICMSCE 2018, Amsterdam, Netherlands, 21-23 Feb. 2018.
- **Member** of the Technical Program Committee for the 2017 IEEE International Conference on Robotics and Biomimetics – ROBIO 2017, Macau SAR, China, 5-8 Dec. 2017.
- **Member** of the Technical Program Committee for the 2017 IEEE International Conference on Mechatronics and Automation - IEEE ICMA 2017, Takamatsu, Japan, 6-9 Aug. 2017.
- **Member** of the Organizing Committee for the 2017 International Conference on Mechatronics Systems and Control Engineering – ICMSCE 2017, Kayseri, Turkey, 2-4 Feb. 2017.
- **Member** of the Technical Program Committee for the 2016 IEEE International Conference on Robotics and Biomimetics – ROBIO 2016, Qingdao, China, 3-7 Dec. 2016.

- **Member** of the Technical Program Committee for the 2016 IEEE International Conference on Mechatronics and Automation - IEEE ICMA 2016, Harbin, China, 7-10 Aug. 2016.
- **Member** of the Technical Editorial Board for the 2016 CSME (Canadian Society for Mechanical Engineering) International Congress – Symposium on Control and Robotics, Kelowna, BC, Canada, 26-29 June 2016.
- **Member** of the Technical Program Committee for the 2015 IEEE International Conference on Robotics and Biomimetics – ROBIO 2015, Zhuhai, China, 6-9 Dec. 2015.
- **Member** of the Technical Program Committee for the 2014 IEEE International Conference on Robotics and Biomimetics – ROBIO 2014, Bali, Indonesia, 5-10 Dec. 2014.
- **Member** of the Technical Program Committee for the 12th IEEE International Symposium on Robotic and Sensors Environments – ROSE 2014, Timisoara, Romania, 16-18 Oct. 2014.
- **Member** of the Technical Program Committee for the 2014 IEEE International Conference on Mechatronics and Automation - IEEE ICMA 2014, Takamatsu, Tianjin, China, 3-6 Aug. 2014.
- **Member** of the Technical Program Committee for the 2014 Robotics Science and Systems Conference – RSS 2014, Berkeley, CA, USA, July 12–16, 2014.
- **Member** of the Technical Program Committee for the 2013 IEEE International Conference on Mechatronics and Automation - IEEE ICMA 2013, Takamatsu, Kagawa, Japan, 4-7 Aug. 2013.
- **Member** of the Technical Program Committee for the 2012 IEEE International Conference on Mechatronics and Automation - IEEE ICMA 2012, Chengdu, Sichuan, China, 5-8 Aug. 2012.
- **Member** of the Technical Program Committee for the 9th IEEE International Symposium on Robotic and Sensors Environments – ROSE 2011, Montréal, Québec, Canada, 17-18 Sep. 2011.
- **Member** of the Technical Program Committee for the 7th ASME/IEEE Int. Conf. on Mechatronics & Embedded Systems & Applications – MESA 2011, Washington, DC, August 28-31, 2011
- **Member** of the Technical Program Committee for the 2011 IEEE International Conference on Mechatronics and Automation - IEEE ICMA 2011, Beijing, China, 7-10 August 2011.
- **Member** of the Technical Program Committee for the 8th IEEE International Workshop on Robotic and Sensors Environments - ROSE 2010, Phoenix, Arizona, 15-16 October 2010.
- **Member** of the Technical Program Committee for the 6th IEEE International Workshop on Robotic and Sensors Environments - ROSE 2008, Ottawa, Canada, 17-18 October 2008.

A6. Expert Panels Chair/Reviewer and Proposal Reviewer

- | | |
|---|------|
| ➤ Proposal Reviewer , Czech Science Foundation, Czech Republic | 2022 |
| ➤ Panelist at a Study Section , National Institutes of Health (NIH)
SRO, Bioengineering, Technology, and Surgical Sciences (BTSS) Study Section
Surgical Sciences, Biomedical Imaging and Bioengineering IRG | 2021 |
| ➤ Reviewer , Mitacs, Canadian Network of Centres of Excellence, Canada | 2019 |
| ➤ Proposal Reviewer , National Research Foundation, Prime Minister's Office, Singapore | 2019 |
| ➤ Proposal Reviewer , Natural Sciences & Eng Research Council of Canada (NSERC) | 2018 |

- **Proposal Reviewer**, Israeli Ministry of Science and Technology August 2018
Topic: Robotics, Medical Devices and Big Data
- **Panelist**, IIHCC Industry Roundtable – Virginia Tech Applied Research Corp. Nov. 2017
Intelligent Infrastructure for Human-Centered Communities (IIHCC)
- **Panelist**, Red Teaming Round Table – Virginia Tech Applied Research Corp. Nov. 2016
Fully-Autonomous Drone Swarms; Office of the Deputy Assistant Secretary of the Army R&T
- **Expert Reviewer**, Canada Foundation for Innovation (CFI) Jul – Oct 2016
2015 Innovation Fund (IF) Competition
- **Panelist**, National Science Foundation – National Robotics Initiative (NRI) June 2016
Division for Electrical, Communications and Cyber Systems (ECCS)
- **Panelist**, National Science Foundation – CISE/IIS/Robust Intelligence (NRI) May 2015
Division of Information and Intelligent Systems
- **Proposal Reviewer**, Canadian Institutes of Health Research (CIHR) December 2014
- **Panelist**, NSF CAREER – CMMI / Sensors, Dynamics & Control Programs Sep 2014
- **Chair of Expert Committee**, Canada Foundation for Innovation (CFI) Jul – Oct 2014
2015 Innovation Fund (IF) Competition
- **Panelist**, National Science Foundation – CMMI / Dynamical Systems May 2014
- **Proposal Reviewer**, National Science Foundation – CISE/Robust Intelligence Feb 2014
- **Proposal Reviewer**, Natural Sciences & Eng Research Council of Canada (NSERC) 2012-2014
- **Panelist**, U.S. Army Medical Robotics Product Line Review (PLR) Expert Panel October 2012
U.S. Army Telemedicine & Advanced Technology Research Center (TATRC)
- **Panelist**, National Science Foundation – National Robotics Initiative (NSF-NRI) June 2012
- **Panel Chair**, National Defense Science & Eng. Graduate (NDSEG) Fellowship Feb 2012
- **Panelist**, Air Force Summer Faculty Fellowship Program (AF SFFP) Jan 2010, 2011
- **Panelist**, NSF Graduate Research Fellowship Program (GRFP) Feb 2010, 2011, 2012, 2013
- **Panelist**, National Defense Science & Eng. Graduate (NDSEG) Fell. 2010, 2011, 2012, 2015
- **Panelist**, ONR Summer Faculty Research Program (ONR SFRP) Feb 2011, 2012
- **Panelist**, DOD Science, Mathematics & Research for Transformation 2011, 2012, 2015, 2016
(SMART) Defense Scholarship for Service Program
- **Panelist**, NASA Aeronautics Scholarship Program (NASA ASP) Feb 2011, 2012, 2013
- **Panelist**, NSF East Asia and Pacific Summer Institutes (EAPSI) Jan 2010
- **Proposal Reviewer**, *India Science & Technology Partnership (INSTP)* April 2009
Invited by the Smithsonian Institution, INDO-US Science & Technology Forum, Washington, DC

A7. Technical Editorial and Reviewer

Associate Editor - Journal May 2021 – Aug. 2022
Robotics

Technical Editor - Journal July 2016 – April 2021
IEEE/ASME Transactions on Mechatronics

Guest Editor - Journal June 2020 – April 2021
ASME Journal of Mechanisms and Robotics (special issue)

Guest Editor - Journal June 2019 – April 2020
ASME Journal of Mechanisms and Robotics (special issue)

Associate Editor - Journal Jan. 2018 – Jan. 2021
ASME Journal of Mechanisms and Robotics

Associate Editor - Journal Oct. 2017 – Dec. 2021
IEEE Robotics and Automation Magazine

Associate Editor - Journal Jan. 2011 – Jan. 2021
International Journal of Control, Automation and Systems

Associate Editor – Conference

IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2022)	2021–2022
IEEE International Conference on Robotics and Automation (ICRA 2018)	2017–2018
IEEE International Conference on Robotics and Automation (ICRA 2017)	2016–2017
ASME Dynamic Systems and Control Conference (DSCC 2017)	2017
IEEE International Conference on Robotics and Automation (ICRA 2016)	2015–2016
IEEE International Conference on Robotics and Automation (ICRA 2014)	2013–2014
IEEE International Conference on Robotics and Automation (ICRA 2013)	2012–2013

Journal Reviewer (2007 – current):

- IEEE Transactions on Robotics
- IEEE Robotics and Automation Letters
- IEEE/ASME Transactions on Mechatronics
- Transactions of the ASME, Journal of Mechanical Design
- Transactions of the ASME, Journal of Mechanisms and Robotics
- Transactions of the ASME, Journal of Dynamic Systems, Measurement and Control
- Journal of Field Robotics
- Journal of Robotics and Autonomous Systems
- Journal of Intelligent and Robotic Systems
- Robotica Journal
- Mechatronics Journal
- IEEE Sensors Journal
- IEEE Transactions on Systems, Man, and Cybernetics – Part A: Systems & Humans
- IEEE Transactions on Nanotechnology
- Journal of Intelligent Service Robots (ISR)

- Autonomous Robots
- Journal of Biomedical Microdevices

Conference Proceedings Reviewer (2004 – current):

- IEEE International Conference on Robotics and Automation (ICRA)
- IEEE International Conference on Intelligent Robots and Systems (IROS)
- IEEE International Workshop on Robotic and Sensors Environments (ROSE)
- IEEE International Conference on Mechatronics and Automation (ICMA)
- ASME International Mechanical Engineering Congress and Exposition (IMECE)
- Dynamic Systems and Control Conference (DSCC)
- IEEE Conference on Automation Science and Engineering (CASE)
- IEEE Conference on Decision and Control (CDC)
- IEEE RAS/EMBS Int. Conference on Biomedical Robotics and Biomechanics (BioRob)
- IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM)
- American Control Conference
- ASME International Design Engineering Technical Conferences (IDETC/CIE)
- ASME/IFTOMM International Conference on Reconfigurable Mechanisms and Robots
- IASTED Conference on Robotics and Applications

Book Proposals Reviewer

- Fundamentals and Applications of Nanopositioning Technologies Mar. 2014
Publisher: Springer; Edited by: Changhai Ru, Xinyu Liu, and Yu Su

A8. Professional Meetings, Workshops, Etc. Chaired or Organized

- **Session Chair**, Technical Session: “Prosthetics, exoskeletons and Rehabilitation”, *Proc. of the 2023 IEEE International Conference on Robotics and Automation (ICRA2023)*, London, UK, May 29-June 2, 2023.
- **Session Chair**, Technical Session: “Novel Mechanisms, Robots, and Applications”, Topic: TBD1”; *ASME IDETC/CIE 2021, 46th Mechanisms & Robotics Conference*, St. Louis, Missouri, Aug. 14-17, 2022.
- **Session Chair**, Technical Session: “Novel Mechanisms, Robots, and Applications”, Topic: TBD2”; *ASME IDETC/CIE 2021, 46th Mechanisms & Robotics Conference*, St. Louis, Missouri, Aug. 14-17, 2022.
- **Session Chair**, Technical Session: “Motion Planning”, Topic: “Dynamics, and Control of Robots”; *ASME IDETC/CIE 2021, 45th Mechanisms & Robotics Conference*, Virtual Conference, Aug. 17-19, 2021.
- **Session Chair**, Technical Session: “Ions, Hydrogels, LC Elastomers, and Coiled Artificial Muscle Heat Pumping”, *2020 SPIE Smart Structures and Nondestructive Evaluation (EAPAD 2020) Conference*, Anaheim, CA, April 26-30, 2020.
- **Session Chair**, Technical Session: “Autonomous Vehicle Navigation II”, *2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Macau, China, November 4-8, 2019.

- **Session Organizer**, Technical Session: “Humanlike Robots - The Ultimate Challenge to Biomimetics”, *ASME IDETC/CIE 2018, 43rd Mechanisms & Robotics Conference*, Anaheim, CA, Aug. 18-21, 2019.
- **Session Chair**, Technical Session: “Motion Planning”, Topic: “Mobile Robotics”; *ASME IDETC/CIE 2018, 42nd Mechanisms & Robotics Conference*, Quebec City, Canada, Aug. 26-29, 2018.
- **Session Co-Chair**, Technical Session: “Upper Extremity”, Topic: “Medical & Rehabilitation Robotics”; *ASME IDETC/CIE 2018, 42nd Mechanisms & Robotics Conference*, Quebec City, Canada, Aug. 26-29, 2018.
- **Session Chair**, Technical Session: “Robot Design and Development”, *2018 International Conference on Mechatronics Systems and Control Engineering – ICMSCE 2018*, Amsterdam, Netherlands, 21-23 Feb. 2018.
- **Session Co-Organizer**, Technical Session: “Design and Control of Robots, Mechanisms and Structures I”, Track: “Dynamics, Vibration, and Control”; Topic: “Design and Control of Robots, Mechanisms and Structures”; *ASME International Mechanical Engineering Congress and Exposition – IMECE 2017*, Tampa, FL, 3-9 Nov. 2017.
- **Session Co-Chair**, Technical Session: “Unmanned, Ground and Surface Robotics I”, 2017 ASME Dynamic Systems and Control Conference – DSCC 2017, Tysons Corner, VA, 11-13 Oct. 2017.
- **Session Co-Chair**, Technical Session: “Unmanned, Ground and Surface Robotics III”, 2017 ASME Dynamic Systems and Control Conference – DSCC 2017, Tysons Corner, VA, 11-13 Oct. 2017.
- **Session Chair**, Technical Session: “Mobile Robots”, *2017 IEEE Conference on Control Technology and Applications*, Kohala Coast, Hawai'i, Aug. 27–30, 2017
- **Session Co-Chair**, Technical Session: “Assistive Devices”, Topic: “Medical & Rehabilitation Robotics”; *ASME IDETC/CIE 2017, 41st Mechanisms & Robotics Conference*, Cleveland, OH, Aug. 6-9, 2017.
- **Session Chair**, Technical Session: “Mobile Robots”, Topic: “Novel Mechanisms, Robots and Applications”; *ASME IDETC/CIE 2016, 40th Mechanisms & Robotics Conference*, Charlotte, NC, Aug. 21-24, 2016.
- **Session Organizer**, Technical Session: “Mobile Robots”, Topic: “Novel Mechanisms, Robots and Applications”; *ASME IDETC/CIE 2016, 40th Mechanisms & Robotics Conference*, Charlotte, NC, Aug. 21-24, 2016.
- **Session Co-Organizer**, Technical Session: “Modeling, Analysis, and Estimation”, Topic: “Mobile Robots, Motion Planning, Dynamics and Control”; *ASME IDETC/CIE 2016, 40th Mechanisms & Robotics Conference*, Charlotte, NC, Aug. 21-24, 2016.
- **Session Chair**, Technical Session: “Modeling and Control of Mobile Robots”, Topic: “Mobile Robots and Cable-Driven Systems”; *ASME IDETC/CIE 2015, 39th Mechanisms & Robotics Conference*, Boston, MA, Aug. 2-5, 2015.
- **Session Chair**, Technical Session: “Developments in sUAV: From Payload to Safety”, Topic: “Small Unmanned Aerial Vehicle Technologies and Applications”; *ASME IDETC/CIE 2015*,

ASME/IEEE International Conference on Mechatronics and Embedded Systems and Applications (MESA), Boston, MA, Aug. 2-5, 2015.

- **Session Chair**, Technical Session: “Bioinspired Mechanisms and Robots II”, Topic: “Symposium on Biologically Inspired and Health Motivated Mechanisms and Robotics”; *ASME IDETC/CIE 2014, 38th Mechanisms & Robotics Conference*, Buffalo, NY, Aug. 17-20, 2014.
- **Session Co-Chair**, Technical Session: “Surgical and Rehabilitation Robotics”, Topic: “Symposium on Biologically Inspired and Health Motivated Mechanisms and Robotics”; *ASME IDETC/CIE 2014, 38th Mechanisms & Robotics Conf.*, Buffalo, NY, Aug. 17-20, 2014.
- **Session Chair**, Technical Session: “Collaborative Robotics & Distributed Sensing”, *IEEE International Symposium on Robotic & Sensors Environments – ROSE 2013*, Washington, DC, Oct. 21-23, 2013.
- **Session Chair**, Technical Session: “Robotic Dynamics”, Track: “Dynamic Systems and Control”; Topic: “Dynamics and Control of Mechanisms and Robots”; *ASME International Mechanical Engineering Congress & Exposition – IMECE 2011*, Denver, CO, 11-17 Nov. 2011.
- **Session Organizer**, Technical Session: “Biomedical Mechatronics”, Track: “Mechatronics & Intelligent Machines”; Topic: “Symposium on Biomedical Mechatronics”; *ASME International Mechanical Engineering Congress and Exposition – IMECE 2011*, Denver, CO, 11-17 Nov. 2011.
- **Session Organizer**, Technical Session: “Robotics, Actuators and Sensors V”, Track: “Mechatronics & Intelligent Machines”; Topic: “Symposium on Robotics, Actuators and Sensors”; *ASME Int’l Mechanical Eng. Congress & Expo. – IMECE 2011*, Denver, CO, 11-17 Nov. 2011.
- **Session Chair**, Technical Session: “Localization Systems”, *IEEE International Symposium on Robotic & Sensors Environments – ROSE 2011*, Montreal, Quebec, Canada, Sep. 17-18, 2011.
- **Session Chair**, Technical Session: “Robot Control”, Track: “Dynamic Systems and Control”; Topic: “Symposium on Dynamics and Control of Mechanisms and Robots”; *ASME International Mechanical Engineering Congress and Exposition – IMECE 2010*, Vancouver, BC, 12-18 November 2010.
- **Session Co-Chair**, Technical Session: “Robot Control II”, Track: “Dynamic Systems and Control”; Topic: “Symposium on Dynamics and Control of Mechanisms and Robots”; *ASME International Mechanical Engineering Congress and Exposition – IMECE 2010*, Vancouver, BC, 12-18 November 2010.
- **Session Chair**, Technical Session: “Wireless and Distributed Sensing Networks”, *IEEE International Workshop on Robotic and Sensors Environments – ROSE 2010*, Phoenix, Arizona, 15-16 October 2010.
- **Session Co-Chair**, Technical Session: “Vibration and Control of Mechanical Systems”, *ASME International Mechanical Engineering Congress and Exposition – IMECE 2009*, Lake Buena Vista, FL, 13-19 November 2009.

A9. Advisory/Technical Committee Memberships

- **Member**, IEEE Robotics and Automation Society, Mechanisms and Design Technical Committee (TC) 2017–Present
- **Elected Voting Member**, ASME Design Engineering Division, 2018–2022

Mechanisms and Robotics Technical Committee (TC)

- **Program Advisory Committee**, Robotics & Mechatronics Systems Eng. Program 2011–
Present University of Detroit, Mercy

A10. Professional Memberships

- American Society of Mechanical Engineers (ASME) 2002 – Present
- Institute of Electrical & Electronics Engineers (IEEE) 2002 – Present
- IEEE Robotics and Automation Society (RAS) 2009 – Present
- Association for Unmanned Vehicle Systems International (AUVSI) 2008 – Present
- Society of Automotive Engineers (SAE) 2008 – Present
- The Israeli Robotics Association (IROB) 2018 – Present
- Robotics Technology Consortium (RTC) 2009 – 2014

B. Departmental Service and Administrative Assignments

Virginia Tech

- **Member**, RADS Major Subcommittee 2022 – 2022
Robotics, Autonomous, and Dynamical Systems (RADS)
Mechanical Engineering Department
- **Member**, Graduate Program Committee 2015 – 2022
Mechanical Engineering Department
- **Chair**, Faculty Search Committee (Dynamic Systems and Control) 2017 – 2018
Mechanical Engineering Department
- **Chair**, Faculty Search Committee (Robotics Perception) 2017 – 2018
Mechanical Engineering Department
- **Member**, Ad Hoc (P&T and TAC) Committee 2017 – 2019
Mechanical Engineering Department
- **Coordinator**, Thrust Area Committee (TAC) 2017 – 2018
Robotics, Autonomous, and Dynamical Systems (RADS)
Mechanical Engineering Department
- **Mentor for Junior Faculty** 2018 – 2019
Mechanical Engineering Department
- **Representative Member**, Thrust Area Committee (TAC) 2016 – 2019
Robotics, Autonomous, and Dynamical Systems (RADS)
Mechanical Engineering Department
- **Member**, Faculty Search Committee (Dynamic Systems & Control - Perception) 2016 – 2017
Mechanical Engineering Department
- **Member**, Faculty Search Committee (Energy Area) 2015 – 2016
Mechanical Engineering Department

George Washington University

- Member, Sub-Committee for the Undergraduate Design Curriculum 2009 – 2015
- ABET Design Subcommittee 2010 – 2015
- Member, Academic Standards Committee 2009 – 2015
- Member, Laboratory Committee 2009 – 2015
- Member, Steering Committee
Center for Biomimetics & Bioinspired Engineering (COBRE) 2009 – 2015
- Member, Faculty Search Committee
Dept. of Mechanical & Aerospace Engineering, GWU 2010 – 2011
- Member, Faculty Search Committee
Dept. of Computer Science, GWU 2009 – 2010
- Departmental Secretary, MAE Faculty Meetings 2009 – 2010

C. School/College Service and Administrative AssignmentsVirginia Tech

- Faculty Judge, 2022 Senior Design Competition Expo April 2022
- Faculty Judge, 2021 Senior Design Competition Expo April 2021
- Faculty Judge, Torgersen Graduate Research Award Competition May 2019
- Faculty Judge, 2019 Senior Design Competition Expo May 2018
- Faculty Judge, 2018 Senior Design Competition Expo May 2018
- Faculty Judge, 2017 Senior Design Competition Expo May 2017
- Faculty Judge, 2016 Senior Design Competition Expo May 2016

George Washington University

- Faculty Judge, 2015 R&D SEAS Showcase Feb 2015
- Faculty Judge, The Pelton Award for Outstanding Senior Project May 16, 2012
- Faculty Judge, 2012 R&D SEAS Showcase Feb 27, 2012
- Faculty Panelist, SEAS New Faculty Orientation August 24, 2011
- Faculty Panelist, SEAS New Faculty Orientation August 25, 2010
- Member, SEAS Biomedical Engineering (BME) Interest Group 2009 – 2015
- Member, Science and Engineering Hall (SEH) Planning Committee 2009 – 2015

- Member, SEAS Educational Initiatives (SEI) Committee Spring 2009
Undergraduate Programs in Robotics, and Energy & Sustainability
- Affiliate Member, GW Institute for Nanotechnology (GWIN) 2013 – 2015
- Affiliate Member, GW Institute for Biomedical Engineering (GWIBE) 2009 – 2015
- Participated in various School of Engineering & Applied Science recruiting events and orientations for Graduate and Undergraduate students, including:
 - Graduate / Undergraduate Open Houses
 - Undergraduate recruiting events and orientations

As part of those activities, students tour the Robotics & Mechatronics Lab (RML) and I give talks about educational and research opportunities in SEAS through various demonstrations of research ongoing in RML.

D. University Service and Administrative Assignments

George Washington University

- Member, Faculty Governance Working Group on Appointment, Promotion & Tenure 2014–2015
- Member, Faculty Senate Committee on Professional Ethics & Academic Freedom 2012–2015
- Judging Team Member, GWU Research Day Apr 2014
- Judging Team Captain, GWU Research Day Apr 2013
- Reviewer, George Washington University Facilitating Fund UFF/Dilthey Award Jan. 2012, 2013
- Organizer, Robotics Workshops at the Science, Apr 2011, 2012, 2013, 2014
Technology & Engineering Day
Virginia Science and Technology Campus, GWU
Workshop title: “Greater than the Sum of its Parts: Integrating a Robotic System”

Dr. Pinhas Ben-Tzvi, journal articles, books, patents

PEER-REVIEWED JOURNAL PUBLICATIONS:

- [76] Liu, Y., Ben-Tzvi, P., “How a Serpentine Tail Assists Agile Motions of Kangaroo Rats: A Dynamics and Control Approach”, *Nonlinear Dynamics*, Accepted, February 2023. <https://doi.org/10.21203/rs.3.rs-1315822/v1>
- [75] Xu, W., Guo, Y., Bravo, C.J., Ben-Tzvi, P., “Design, Control, and Experimental Evaluation of a Novel Robotic Glove System for Patients with Brachial Plexus Injuries”, *IEEE Transactions on Robotics*, Vol. 39, Issue 2, pp. 1637-1652, April 2023. DOI: 10.1109/TRO.2022.3220973
- [74] Han, X., Ren, H., Qi, J., Ben-Tzvi, P., “Autonomous Cricothyroid Membrane Detection and Manipulation using Neural Networks and Robot Arm for First-Aid Airway Management”, *Journal of Medical Devices, Transactions of the ASME*, Vol. 17, Issue 1, pp. 014502: 1-9, March 2023. DOI: <https://doi.org/10.1115/1.4056505>
- [73] Guo, Y., Xu, W., Pradhan, S., Bravo, C.J., Ben-Tzvi, P., “Personalized Voice Activated Grasping System for a Robotic Exoskeleton Glove”, *Mechatronics Journal*, Vol. 83, pp. 102745:1-12, May 2022. DOI: 10.1016/j.mechatronics.2022.102745
- [72] Sohal, S.S., Sebastian, B., Ben-Tzvi, P., “Autonomous Docking of Hybrid-Wheeled Modular Robots With an Integrated Active Genderless Docking Mechanism”, *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 14, Issue 1, pp. 011010: 1-15, February 2022. DOI: doi.org/10.1115/1.4051519
- [71] Njaka, T., Brizzolara, S., Ben-Tzvi, P., “Design and Experimental Validation of a Novel High-Speed Omnidirectional Underwater Propulsion Mechanism”, *IEEE/ASME Transactions on Mechatronics*, Vol. 26, Issue 5, pp. 2339-2349, October 2021. DOI: 10.1109/TMECH.2020.3037887
- [70] Guo, Y., Xu, W., Pradhan, S., Bravo, C.J., Ben-Tzvi, P., “Data Driven Calibration and Control for Compact Lightweight Series Elastic Actuators for Robotic Exoskeleton Gloves”, *IEEE Sensors Journal*, Vol. 21, Issue 19, pp. 21120-21130, October 2021. DOI:10.1109/JSEN.2021.3101143 * Selected as a featured article
- [69] Yang, J., Saab, W., Liu, Y., Ben-Tzvi, P., “Reuleaux Triangle Based Two Degrees of Freedom Bipedal Robot”, *Robotics Journal*, Vol. 10, Issue 4, pp. 1-15, October 2021. DOI: 10.3390/robotics10040114
- [68] Liu, Y., Ben-Tzvi, P., “Dynamic Modeling, Analysis, and Design Synthesis of a Reduced Complexity Quadruped with a Serpentine Robotic Tail”, *Integrative and Comparative Biology*, Vol. 61, Issue 2, pp. 464-477, August 2021. DOI: 10.1093/icb/icab083

- [67] Liu, Y., Ben-Tzvi, P., "A New Extensible Continuum Manipulator Using Flexible Parallel Mechanism and Rigid Motion Transmission", *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 13, Issue 3, pp. 031112: 1-7, June 2021.
DOI: doi.org/10.1115/1.4050097

- [66] Feng, S., Sebastian, B., Ben-Tzvi, P., "A Collision Avoidance Method Based on Deep Reinforcement Learning", *Robotics Journal*, Vol. 10, Issue 2, pp. 1-19, May 2021.

- [65] Ren, H., Qi, J., Ben-Tzvi, P., "Learning Flatness-Based Controller Using Neural Networks", *ASME Letters in Dynamic Systems and Control*, Vol. 1, Issue 2, pp. 021003: 1-6, April 2021.
DOI: 10.1115/1.4046776

- [64] Wang, J., Liu, Y., Ben-Tzvi, P., "Robust Adaptive Input-Output Control for a Class of Modular Robotic Systems via Inverse Optimality Theory", *International Journal of Control*, Vol. 95, Issue 7, pp. 1898-1912, July 2022.
DOI:10.1080/00207179.2021.1885741

- [63] Liu, Y., Ben-Tzvi, P., "Dynamic Modeling, Analysis, and Comparative Study of A Quadruped With Bio-Inspired Robotic Tails", *Multibody System Dynamics*, Vol. 51, Issue 2, pp. 195-219, February 2021. DOI: 10.1007/s11044-020-09764-8

- [62] Vanteddu, T., Ben-Tzvi, P., "Stable Grasp Control with a Robotic Exoskeleton Glove", *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 12, Issue 6, pp. 061015: 1-14, December 2020.

- [61] Wang, X., Ren, H., Kumar, A., Ben-Tzvi, P., "Design and Analysis of a Variable Inertia Spatial Robotic Tail for Dynamic Stabilization", *Biomimetics*, Vol. 5, Issue 4, pp. 1-16, November 2020. DOI: 10.3390/biomimetics5040055

- [60] Liu, Y., Ben-Tzvi, P., "An Articulated Closed Kinematic Chain Planar Robotic Leg for High Speed Locomotion", *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 12, Issue 4, pp. 041003: 1-15, August 2020. DOI: 10.1115/1.4045689

- [59] Liu, Y., Ben-Tzvi, P., "Design, Analysis and Integration of a New Two-DOF Articulated Multi-link Robotic Tail Mechanism", *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 12, Issue 2, pp. 021101: 1-9, April 2020. DOI: 10.1115/1.4045842

- [58] Ren, H., Ben-Tzvi, P., "Advising Reinforcement Learning Towards Scaling Agents in Continuous Control Environments with Sparse Rewards", *Journal to Engineering Applications of Artificial Intelligence*, Vol. 90, pp. 103515: 1-12, April 2020.
DOI: 10.1016/j.engappai.2020.103515

- [57] Ren, H., Ben-Tzvi, P., "Learning Inverse Kinematics and Dynamics of a Robotic Manipulator using Generative Adversarial Networks", *Robotics and Autonomous Systems*, Vol. 124, pp. 103386: 1-12, February 2020. DOI: 10.1016/j.robot.2019.103386
- [56] Chauhan, R., Sebastian, B., Ben-Tzvi, P., "Grasp Prediction Towards Naturalistic Exoskeleton Glove Control", *IEEE Transaction on Human-Machine Systems*, Vol. 50, Issue 1, pp. 22-31, February 2020. DOI: 10.1109/THMS.2019.2938139
- [55] Refour, E., Sebastian, B., Chauhan, R., Ben-Tzvi, P., "A General Purpose Robotic Hand Exoskeleton with Series Elastic Actuators", *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 11, Issue 6, pp. 060902: 1-9, December 2019.
- [54] Williams, A., Sebastian, B., Ben-Tzvi, P., "Review and Analysis of Search, Extraction, Evacuation, and Medical Treatment Field Robots", *Journal of Intelligent and Robotic Systems*, Vol. 96, Issue 3, pp. 401-418, December 2019.
- [53] Budolak, D., Ben-Tzvi, P., "Series Elastic Actuation for Improved Transparency in Time Delayed Haptic Teleoperation", *Mechatronics Journal*, Vol. 63, pp. 102278:1-8, November 2019. DOI: 10.1016/j.mechatronics.2019.102278
- [52] Sebastian, B., Ben-Tzvi, P., "Support Vector Machine Based Real-time Terrain Estimation for Tracked Robots", *Mechatronics Journal*, Vol. 62, pp. 102260: 1-10, October 2019.
- [51] Liu, Y., Wang, J., Ben-Tzvi, P., "A Cable Length Invariant Robotic Tail Using a Circular Shape Universal Joint Mechanism", *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 11, Issue 5, pp. 051005: 1-14, October 2019.
- [50] Kumar, P., Ben-Tzvi, P., "Estimation of Wind Conditions Utilizing RC Helicopter Dynamics", *IEEE/ASME Transactions on Mechatronics*, Vol. 24, Issue 5, pp. 2293-2303, October 2019.
- [49] Ben-Tzvi, P., Saab, W., "A Hybrid Tracked-Wheeled Multi-Directional Mobile Robot", *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 11, Issue 4, pp. 041008: 1-10, August 2019.
- [48] Rone, W., Saab, W., Kumar, A., Ben-Tzvi, P., "Controller Design, Analysis and Experimental Validation of a Robotic Serpentine Tail to Maneuver and Stabilize a Quadrupedal Robot", *Journal of Dynamic Systems, Measurement and Control, Transactions of the ASME*, Vol. 141, Issue 8, pp. 081002: 1-9, August 2019.

- [47] Sebastian, B., Ben-Tzvi, P., "Physics Based Path Planning for Autonomous Tracked Vehicle in Challenging Terrain", *Journal of Intelligent and Robotic Systems*, Vol. 95, Issue 2, pp. 511-526, August 2019.
- [46] Racioppo, P., Ben-Tzvi, P., "Design and Control of an Articulated Cable-Driven Modular Snake Robot", *IEEE/ASME Transactions on Mechatronics*, Vol. 24, Issue 3, pp. 893-901, June 2019.
- [45] Ren, H., Kumar, A., Ben-Tzvi, P., "LOSA-X: Expandable 3D Motion Tracking System", *IEEE Sensors Journal*, Vol. 19, Issue 9, pp. 3288-3295, May 2019.
- [44] Saab, W., Rone, W., Kumar, A., Ben-Tzvi, P., "Design and Integration of a Novel Spatial Articulated Robotic Tail", *IEEE/ASME Transactions on Mechatronics*, Vol. 24, Issue 2, pp. 434-446, April 2019.
- [43] Sebastian, B., Ben-Tzvi, P., "Active Disturbance Rejection Control for Handling Slip in Tracked Vehicle Locomotion", *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 11, Issue 2, pp. 021003: 1-12, April 2019.
- [42] Williams, A., Sebastian, B., Ben-Tzvi, P., "A Robotic Head Stabilization Mechanism for Medical Transport", *Robotics Journal*, Vol. 8, Issue 1, pp. 1-16, March 2019.
- [41] Saab, W., Racioppo, P., Kumar, A., Ben-Tzvi, P., "Design of a Miniature Modular Inchworm Robot with an Anisotropic Friction Skin", *Robotica Journal*, Vol. 37, Issue 3, pp. 521-538, March 2019.
- [40] Saab, W., Racioppo, P., Ben-Tzvi, P., "A Review of Coupling Mechanism Designs for Modular Reconfigurable Robots", *Robotica Journal*, Vol. 37, Issue 2, pp. 378-403, February 2019.
- [39] Rone, W., Liu, Y., Ben-Tzvi, P., "Maneuvering and Stabilization Control of a Bipedal Robot with a Universal-Spatial Robotic Tail", *Bioinspiration and Biomimetics Journal*, Vol. 14, Issue 1, pp. 016014: 1-16, January 2019.
- [38] Liu, Y., Kong, M., Wan, N., Ben-Tzvi, P., "A Geometric Approach to Obtain the Closed-Form Forward Kinematics of H4 Parallel Robot", *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 10, Issue 5, pp. 051013: 1-9, October 2018.
- [37] Saab, W., Rone, W., Ben-Tzvi, P., "Robotic Tails: A State-of-The-Art Review", *Robotica Journal*, Vol. 36, Issue 9, pp. 1263-1277, September 2018.
- [36] Lee, J., Williams, A., Ben-Tzvi, P., "Intelligent Object Grasping with Sensor Fusion for Rehabilitation and Assistive Applications", *IEEE Transactions on Neural Systems & Rehabilitation Engineering*, Vol. 26, Issue 8, pp. 1556-1565, August 2018.

- [35] Rone, W., Saab, W., Ben-Tzvi, P., "Design, Modeling and Integration of a Flexible Universal Spatial Robotic Tail", *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 10, Issue 4, pp. 041001: 1-14, August 2018.
- [34] Saab, W., Rone, W., Ben-Tzvi, P., "Discrete Modular Serpentine Robotic Tail: Design, Analysis and Experimentation", *Robotica Journal*, Vol. 36, Issue 7, pp. 994-1018, July 2018.
- [33] Kumar, A., Ben-Tzvi, P., "Novel Wireless Sensing Platform for Experimental Mapping and Validation of Ship Air Wake", *Mechatronics Journal*, Vol. 52, pp. 58-69, June 2018.
- [32] Refour, E., Sebastian, B., Ben-Tzvi, P., "Two-Digit Robotic Exoskeleton Glove Mechanism: Design and Integration", *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 10, Issue 2, pp. 025002: 1-9, April 2018.
- [31] Yanga, Y., Ren, H., Yang, X., Ben-Tzvi, P., He, Z., "Optimal Interval of Periodic Polarity Reversal for Maximizing Hydrogen Production in Microbial Electrolysis Cells", *International Journal of Hydrogen Energy*, Vol. 42, Issue 31, pp. 20260–20268, Aug. 2017.
- [30] Saab, W., Rone, W., Ben-Tzvi, P., "Robotic Modular Leg: Design, Analysis and Experimentation", *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 9, Issue 2, pp. 024501: 1-6, April 2017.
- [29] Saab, W., Ben-Tzvi, P., "A Genderless Coupling Mechanism with 6-DOF Misalignment Capability for Modular Self-Reconfigurable Robots", *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 8, Issue 6, pp. 061014: 1-9, December 2016.
- [28] Ma, Z., Ben-Tzvi, P., Danoff, J., "Hand Rehabilitation Learning System with an Exoskeleton Robotic Glove", *IEEE Transactions on Neural Systems & Rehabilitation Engineering*, Vol. 24, Issue 12, pp.1323–1332, December 2016.
- [27] Zhao, H., Ben-Tzvi, P., "Synchronous Position Control Strategy for Bi-Cylinder Electro-pneumatic Systems", *International Journal of Control, Automation and Systems*, Vol. 14, Issue 6, pp. 1501-1510, December 2016.
- [26] Kumar, A., Ben-Tzvi, P., "Spatial Object Tracking System Based on Linear Optical Sensor Arrays", *IEEE Sensors Journal*, Vol. 16, Issue 22, pp. 7933-7940, November 2016.
- [25] Ben-Tzvi, P., Danoff, J., Ma, Z., "The Design Evolution of a Sensing and Force-Feedback Exoskeleton Robotic (SAFER) Glove for Hand Rehabilitation Application", *Journal of*

Mechanisms and Robotics, Transactions of the ASME, Vol. 8, Issue 5, pp. 051019: 1-9, October 2016.

- [24] Rone, W., Ben-Tzvi, P., "Dynamic Modeling and Simulation of a Yaw-Angle Quadraped Maneuvering with a Robotic Tail", Journal of Dynamic Systems, Measurement and Control, Transactions of the ASME, Vol. 138, Issue 8, pp. 084502: 1-7, August 2016.
- [23] Kumar, A., Ben-Tzvi, P., Saab, W., Snyder, M.R., "Wireless Telemetry System for Real-time Estimation of Ship Air Wake with UAVs", Mechatronics Journal, Vol. 36, pp. 18-26, June 2016.
- [22] Ben-Tzvi, P., Ma, Z., "Sensing and Force-Feedback Exoskeleton (SAFE) Robotic Glove", IEEE Transactions on Neural Systems & Rehabilitation Engineering, Vol. 23, Issue 6, pp. 992-1002, November 2015.
- [21] Ma, Z., Ben-Tzvi, P., "Design and Optimization of a Five-Finger Haptic Glove Mechanism", Journal of Mechanisms and Robotics, Transactions of the ASME, Vol. 7, Issue 4, pp. 041008: 1-8, November 2015.
- [20] Ma, Z., Ben-Tzvi, P., "RML Glove – An Exoskeleton Glove Mechanism with Haptics Feedback", IEEE/ASME Transactions on Mechatronics, Vol. 20, Issue 2, pp. 641-652, April 2015.
- [19] Rone, W., Ben-Tzvi, P., "Mechanics Modeling of Multi-Segment Rod-Driven Continuum Robots", Journal of Mechanisms and Robotics, Transactions of the ASME, Vol. 6, Issue 4, pp. 041006: 1-12, November 2014.
- [18] Moubarak, P., Ben-Tzvi, P., "A Tristate Rigid Reversible and Non-Back-Drivable Active Docking Mechanism for Modular Robotics", IEEE/ASME Transactions on Mechatronics, Vol. 19, Issue 3, pp. 840-851, June 2014.
- [17] Rone, W., Ben-Tzvi, P., "Continuum Robot Dynamics Utilizing the Principle of Virtual Power", IEEE Transactions on Robotics, Vol. 30, Issue 1, pp. 275-287, February 2014.
- [16] Moubarak, P., Ben-Tzvi, P., "A Globally Converging Algorithm for Adaptive Manipulation and Trajectory Following for Mobile Robots with Serial Redundant Arms", Robotica Journal, Vol. 31, Issue 8, pp. 1299-1312, December 2013.
- [15] Rone, W., Ben-Tzvi, P., "Design and FE Analysis of Integrated Sensing using Gas Compressibility for Microdroplet Generation", Mechatronics Journal, Vol. 23, Issue 4, pp. 397-408, June 2013.

- [14] Moubarak, P., Ben-Tzvi, P., "On the Dual-Rod Slider Rocker Mechanism and its Applications to Tri-State Rigid Active Docking", *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 5, Issue 1, pp. 011010: 1–10, February 2013.
- [13] Rone, W., Ben-Tzvi, P., "Mapping, Localization and Motion Planning in Mobile Multi-Robotic Systems", *Robotica Journal*, Vol. 31, Issue 1, pp. 1-24, January 2013.
- [12] Moubarak, P., Ben-Tzvi, P., "Modular and Reconfigurable Mobile Robotics", *Journal of Robotics and Autonomous Systems*, Vol. 60, Issue 12, pp. 1648-1663, December 2012.
- [11] Moubarak, P., Ben-Tzvi, P., Zaghloul, M.E., "A Self-Calibrating Mathematical Model for the Direct Piezoelectric Effect of a new MEMS Tilt Sensor", *IEEE Sensors Journal*, Vol. 12, Issue 5, pp. 1033-1042, May 2012.
- [10] Ben-Tzvi, P., Bai, S., Zhou, Q., Huang, X., "Fuzzy Sliding Mode Control of Rigid-Flexible Multi-Body Systems with Bounded Inputs", *Journal of Dynamic Systems, Measurement and Control, Transactions of the ASME*, Vol. 133, Issue 6, pp. 061012: 1–8, November 2011.
- [9] Bai, S., Ben-Tzvi, P., Zhou, Q., Huang, X., "Variable Structure Controller Design for Linear Systems with Bounded Inputs", *International Journal of Control, Automation and Systems*, Vol. 9, Issue 2, pp. 228–236, April 2011.
- [8] Ben-Tzvi, P., Goldenberg, A.A., Zu, J.W., "Articulated Hybrid Mobile Robot Mechanism with Compounded Mobility and Manipulation and On-Board Wireless Sensor/Actuator Control Interfaces", *Mechatronics Journal*, Vol. 20, Issue 6, pp. 627–639, September 2010.
- [7] Ben-Tzvi, P., "Experimental Validation and Field Performance Metrics of a Hybrid Mobile Robot Mechanism", *Journal of Field Robotics*, Vol. 27, Issue 3, pp. 250–267, May 2010.
- [6] Ben-Tzvi, P., Rone, W., "Microdroplet Generation in Gaseous and Liquid Environments", *Microsystem Technologies Journal*, Vol. 16, Issue 3, pp. 333–356, March 2010.
- [5] Ben-Tzvi, P., Ito, S., Goldenberg, A.A., "A Mobile Robot with Autonomous Climbing and Descending of Stairs", *Robotica Journal*, Vol. 27, Issue 02, pp. 171–188, Feb. 2009.
- [4] Zhou, Q., Ben-Tzvi, P., Fan, D., "Design and Analysis of a Fast Steering Mirror for Precision Laser Beams Steering", *Sensors & Transducers Journal*, Vol. 5, Issue 3, pp. 104-118, March 2009. *** Listed in the Top 25 List of Most Downloaded Articles in June 2011**

- [3] Bai, S., Ben-Tzvi, P., Zhou, Q., Huang, X., “A Study on Dynamic Stiffening of a Rotating Beam with a Tip Mass”, *Sensors & Transducers Journal*, Vol. 5, Issue 3, pp. 53-68, 2009.
- [2] Ben-Tzvi, P., Goldenberg, A.A., Zu, J.W., “Design and Analysis of a Hybrid Mobile Robot Mechanism with Compounded Locomotion and Manipulation Capability”, *Journal of Mechanical Design*, *Transactions of the ASME*, Vol. 130, Issue 7, pp. 1–13, July 2008.
- [1] Ben-Tzvi, P., Ben Mrad, R., Goldenberg, A.A., “A Conceptual Design and FE Analysis of a Piezoceramic Actuated Dispensing System for Microdrops Generation in Microarray Applications”, *Mechatronics Journal*, Vol. 17, Issue 1, pp. 1-13, February 2007.

PEER-REVIEWED CONFERENCE PUBLICATIONS (FULL ARTICLES WITH FULL REVIEW)

- [99] Guo, Y., Xu, W., Bravo, C., Ben-Tzvi, P., “Voice-based Human Machine Interface for Rehabilitation Exoskeleton Robotic Glove with Speaker Verification Feature Using One-shot Learning”, *Proceedings of the 2023 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2023)*, Detroit, Michigan, October 1-5, 2023.
- [98] Xu, W., Guo, Y., Ben-Tzvi, P., “Robotic Exoskeleton Glove System Design and Simulation for Patients with Brachial Plexus Injuries”, *Proceedings of the 2023 ASME IDETC/CIE, 47th Mechanisms & Robotics Conference*, Boston, MA, August 20-23, 2023. Accepted.
- [97] Xu, W., Guo, Y., Bravo, C.J., Ben-Tzvi, P., “Design, Control, and Experimental Evaluation of a Novel Robotic Glove System for Patients with Brachial Plexus Injuries”, *Proc. of the 2023 IEEE International Conference on Robotics and Automation (ICRA2023)*, London, UK, May 2-June 2, 2023.
- [96] Xu, W., Guo, Y., Bravo, C., Ben-Tzvi, P., “Development and Experimental Evaluation of a Novel Portable Haptic Robotic Exoskeleton Glove System for Patients with Brachial Plexus Injuries”, *Proceedings of the 2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2022)*, Kyoto, Japan, October 23-27, 2022.
- [95] Xu, W., Liu, Y., Ben-Tzvi, P., “Development of a Novel Low-profile Robotic Exoskeleton Glove for Patients with Brachial Plexus Injuries”, *Proceedings of the 2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2022)*, Kyoto, Japan, October 23-27, 2022.
- [94] Xu, W., Liu, Y., Ben-Tzvi, P., “Design, Analysis, and Prototyping of a Novel Single DOF Index Finger Exoskeleton Mechanism”, *Proceedings of the 2022 ASME IDETC/CIE, 46th Mechanisms & Robotics Conference*, St. Louis, Missouri, August 14-17, 2022.

- [93] Pressgrove, I., Liu, Y., Ben-Tzvi, P., "Design and Implementation of a Power-Dense, Modular, and Compact Serpentine Articulated Robotic Tail", Proceedings of the 2022 ASME IDETC/CIE, 46th Mechanisms & Robotics Conference, St. Louis, Missouri, Aug 14-17, 2022.
- [92] Liu, Y., Ben-Tzvi, P., "Systematic Development of a Novel, Dynamic, Reduced Complexity Quadruped Robot Platform for Robotic Tail Research", Proc. of the 2022 IEEE International Conference on Robotics and Automation (ICRA2022), Philadelphia, PA, pp. 4664-4670, May 23-27, 2022.
- [91] Liu, Y., Ben-Tzvi, P., "Feedback Control of the Locomotion of a Tailed Quadruped Robot", Proceedings of the 2021 ASME IDETC/CIE, 45th Mechanisms & Robotics Conference, Virtual, Online, Aug. 17-20, 2021.
- [90] Guo, Y., Xu, W., Pradhan, S., Bravo, C.J., Ben-Tzvi, P., "Integrated and Configurable Voice Activation and Speaker Verification System for a Robotic Exoskeleton Glove", Proceedings of the 2020 ASME IDETC/CIE, 44th Mechanisms & Robotics Conference, St. Louis, MO, Aug. 16-19, 2020.
- [89] Xu, W., Pradhan, S., Guo, Y., Bravo, C.J., Ben-Tzvi, P., "A Novel Design of a Robotic Glove System for Patients with Brachial Plexus Injuries", Proceedings of the 2020 ASME IDETC/CIE, 44th Mechanisms & Robotics Conference, St. Louis, MO, Aug. 16-19, 2020.
- [88] Han, X., Ren, H., Ben-Tzvi, P., "Autonomous Cricothyroid Membrane Detection Using Neural Networks for First-Aid Surgical Airway Management", Proceedings of the 2020 ASME IDETC/CIE, 44th Mechanisms & Robotics Conference, St. Louis, MO, Aug. 16-19, 2020.
- [87] Liu, Y., Ben-Tzvi, P., "A New Extensible Continuum Manipulator Using Flexible Parallel Mechanism and Rigid Motion Transmission", Proceedings of the 2020 ASME IDETC/CIE, 44th Mechanisms & Robotics Conference, St. Louis, MO, Aug. 16-19, 2020.
- [86] Sohal, S.S., Ben-Tzvi, P., "Sensor Based Target Tracking with Application to Autonomous Docking and Self-Reconfigurability", Proceedings of the 2020 ASME IDETC/CIE, 44th Mechanisms & Robotics Conference, St. Louis, MO, Aug. 16-19, 2020.
- [85] Liu, Y., Ben-Tzvi, P., "Maneuvering and Stabilization of Reduced Complexity Legged Robots Using Bioinspired Robotic Tails", 2019 Do Good Robotics Symposium (DGRS), University of Maryland, College Park, MD, Oct. 3-4, 2019.
- [84] Chauhan, R., Ben-Tzvi, P., "A Series Elastic Actuator Design and Control in a Linkage Based Hand Exoskeleton", Proceedings of the ASME 2019 Dynamic Systems and Control Conf. (DSCC 2019), Park City, Utah, Oct. 8-11, 2019.

- [83] Ren, H., Qi, J., Ben-Tzvi, P., "Learning Flatness-Based Controller Using Neural Networks", Proceedings of the ASME 2019 Dynamic Systems and Control Conf. (DSCC 2019), Park City, Utah, Oct. 8-11, 2019.
- [82] Liu, Y., Ben-Tzvi, P., "A New Approach to Model the Constant Curvature Continuum Robot Dynamics", Proceedings of the ASME 2019 Dynamic Systems and Control Conf. (DSCC 2019), Park City, Utah, Oct. 8-11, 2019.
- [81] Yang, J., Saab, W., Ben-Tzvi, P., "A Two-DOF Bipedal Robot Utilizing the Reuleaux Triangle Drive Mechanism", Proceedings of the 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2019), Macau, China, pp. 4660-4665, Nov. 3-8, 2019.
- [80] Sebastian, B., Ren, H., Ben-Tzvi, P., "Neural Network Based Heterogeneous Sensor Fusion for Robot Motion Planning", Proceedings of the 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2019), Macau, China, pp. 2899-2904, Nov. 3-8, 2019.
- [79] Budolak, D., Chauhan, R., Ben-Tzvi, P., "Semi-Autonomous Teleoperation, Guidance, and Obstacle Avoidance with Path Adherence", Proceedings of the 2019 ASME IDETC/CIE, 43rd Mechanisms & Robotics Conference, Anaheim, CA, Aug. 18-21, 2019.
- [78] Sohal, S.S., Ben-Tzvi, P., "Image-Based Motion Analysis for Self-Reconfigurable Mobile Robots with Integrated Docking", Proceedings of the 2019 ASME IDETC/CIE, 43rd Mechanisms & Robotics Conference, Anaheim, CA, Aug. 18-21, 2019.
- [77] Njaka, T., Brizzolara, S., Ben-Tzvi, P., "Design and Simulation of a Novel High-Speed Omnidirectional Fully-Actuated Underwater Propulsion Mechanism", Proceedings of the 2019 ASME IDETC/CIE, 43rd Mechanisms & Robotics Conference, Anaheim, CA, Aug. 18-21, 2019.
- [76] Feng, S., Ren, H., Wang, X., Ben-Tzvi, P., "Mobile Robot Obstacle Avoidance Based on Deep Reinforcement Learning", Proceedings of the 2019 ASME IDETC/CIE, 43rd Mechanisms & Robotics Conference, Anaheim, CA, Aug. 18-21, 2019.
- [75] Liu, Y., Ben-Tzvi, P., "Design, Analysis, and Optimization of a New Two-DOF Articulated Multi-link Robotic Tail", Proceedings of the 2019 ASME IDETC/CIE, 43rd Mechanisms & Robotics Conference, Anaheim, CA, Aug. 18-21, 2019.
- [74] Kamidi, V., Williams, A., Ben-Tzvi, P., "A Framework for Modeling Closed Kinematic Chains with a Focus on Legged Robots", Proceedings of the 2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2018), Madrid, Spain, pp. 2733-2738, Oct. 1-5, 2018.

- [73] Saab, W., Yang, J., Ben-Tzvi, P., “Modeling and Control of an Articulated Tail for Maneuvering a Reduced Degree of Freedom Legged Robot”, Proceedings of the 2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2018), Madrid, Spain, pp. 2695-2700, Oct. 1–5, 2018.
- [72] Vanteddu, T., Sebastian, B., Ben-Tzvi, P., “Design Optimization of RML Glove for Improved Grasp Performance”, Proceedings of the ASME 2018 Dynamic Systems and Control Conf. (DSCC 2018), Atlanta, GA, Sep. 30 – Oct. 3, 2018.
- [71] Ren, H., Kumar, A., Wang, X., Ben-Tzvi, P., “Parallel Deep Learning Ensembles for Human Pose Estimation”, Proceedings of the ASME 2018 Dynamic Systems and Control Conf. (DSCC 2018), Atlanta, GA, Sep. 30 – Oct. 3, 2018.
- [70] Wang, J., Kamidi, V., Ben-Tzvi, P., “A Multibody Toolbox for Hybrid Dynamic System Modeling Based on Nonholonomic Symbolic Formalism”, Proceedings of the ASME 2018 Dynamic Systems and Control Conf. (DSCC 2018), Atlanta, GA, Sep. 30 – Oct. 3, 2018.
- [69] Chauhan, R., Ben-Tzvi, P., “Latent Variable Grasp Prediction for Exoskeletal Glove Control”, Proceedings of the ASME 2018 Dynamic Systems and Control Conf. (DSCC 2018), Atlanta, GA, Sep. 30 – Oct. 3, 2018.
- [68] Refour, E., Sebastian, B., Ben-Tzvi, P., “Design and Implementation of an Exoskeleton Glove for Infant Medical Rehabilitation”, Proceedings of the 2018 ASME IDETC/CIE, 42nd Mechanisms & Robotics Conference, Quebec City, Canada, Aug. 26-29, 2018.
- [67] Sohal, S.S., Saab, W., Ben-Tzvi, P., “Improved Alignment Estimation for Autonomous Docking of Mobile robots”, Proceedings of the 2018 ASME IDETC/CIE, 42nd Mechanisms & Robotics Conference, Quebec City, Canada, Aug. 26-29, 2018.
- [66] Liu, Y., Ben-Tzvi, P., “Dynamic Modeling of a Quadruped with a Robotic Tail Using Virtual Work Principle”, Proceedings of the 2018 ASME IDETC/CIE, 42nd Mechanisms & Robotics Conference, Quebec City, Canada, Aug. 26-29, 2018.
- [65] Sebastian, B., Williams, A., Ben-Tzvi, P., “Gaussian Kernel Controller for Path Tracking in Mobile Robots”, Proceedings of the 2018 ASME IDETC/CIE, 42nd Mechanisms & Robotics Conference, Quebec City, Canada, Aug. 26-29, 2018.
- [64] Lee, J., Ben-Tzvi, P., “Design of a Wearable 3-DOF Forearm Exoskeleton for Rehabilitation and Assistive Purposes”, Proceedings of the 2017 ASME International Mechanical Engineering Congress and Exposition (IMECE 2017), Tampa, Florida, Nov. 3–9, 2017.

- [63] Sebastian, B., Williams, A., Ben-Tzvi, P., “Control of a Head Stabilization System for Use in Robotic Disaster Response”, Proceedings of the 2017 ASME International Mechanical Engineering Congress and Exposition (IMECE 2017), Tampa, Florida, Nov. 3–9, 2017.
- [62] Rone, W., Ben-Tzvi, P., “Design, Modeling and Optimization of the Universal-Spatial Robotic Tail”, Proceedings of the 2017 ASME International Mechanical Engineering Congress and Exposition (IMECE 2017), Tampa, Florida, Nov. 3–9, 2017.
- [61] Kumar, A., Ben-Tzvi, P., “An Inertial Sensor to Measure Wind Turbulence with RC Helicopters”, Proceedings of the ASME 2017 Dynamic Systems and Control Conf. (DSCC 2017), Tysons Corner, VA, Oct 11-13, 2017.
- [60] Saab, W., Ben-Tzvi, P., “Maneuverability and Heading Control of a Quadruped Robot Utilizing Tail Dynamics”, Proceedings of the ASME 2017 Dynamic Systems and Control Conf. (DSCC 2017), Tysons Corner, VA, Oct 11-13, 2017.
- [59] Kumar, A., Ren, H., Ben-Tzvi, P., “Obstacle Identification for Vision Assisted Control Architecture of a Hybrid Mechanism Mobile Robot”, Proceedings of the ASME 2017 Dynamic Systems and Control Conf. (DSCC 2017), Tysons Corner, VA, Oct 11-13, 2017.
- [58] Kamidi, V., Saab, W., Ben-Tzvi, P., “Design And Analysis of a Novel Planar Robotic Leg For High-Speed Locomotion”, Proceedings of the 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2017), Vancouver, Canada, pp. 6343–6348, Sep. 24–28, 2017.
- [57] Rone, W., Ben-Tzvi, P., “Maneuvering and Stabilizing Control of a Quadrupedal Robot using a Serpentine Robotic Tail”, 2017 IEEE Conference on Control Technology and Applications, Kohala Coast, Hawai'i, pp. 1763–1768, Aug. 27–30, 2017.
- [56] Racioppo, P., Ben-Tzvi, P., “Modeling and Control of a Cable Driven Modular Snake Robot”, 2017 IEEE Conference on Control Technology and Applications, Kohala Coast, Hawai'i, pp. 468–473, Aug. 27–30, 2017.
- [55] Williams, A., Saab, W., Ben-Tzvi, P., “Analysis of Differential Mechanisms for a Robotic Head Stabilization System”, Proceedings of the 2017 ASME IDETC/CIE, 41st Mechanisms & Robotics Conference, Cleveland, Ohio, Aug. 6-9, 2017.
- [54] Refour, E., Sebastian, B., Ben-Tzvi, P., “Design and Integration of a Two-Digit Exoskeleton Glove”, Proceedings of the 2017 ASME IDETC/CIE, 41st Mechanisms & Robotics Conference, Cleveland, Ohio, Aug. 6-9, 2017.

- [53] Racioppo, P., Saab, W., Ben-Tzvi, P., "Design and Analysis of Reduced Degree-of-Freedom Modular Snake Robot", Proceedings of the 2017 ASME IDETC/CIE, 41st Mechanisms & Robotics Conference, Cleveland, Ohio, Aug. 6-9, 2017.
- [52] Kumar, P., Saab, W., Ben-Tzvi, P., "Design of a Multi-Directional Hybrid-Locomotion Modular Robot with Feedforward Stability Control", Proceedings of the 2017 ASME IDETC/CIE, 41st Mechanisms & Robotics Conference, Cleveland, Ohio, Aug. 6-9, 2017.
- [51] Burns, C., Francom, M., Repisky, P., Kinney, A., Medina, B., Tello, E., Ben-Tzvi, P., "Development of Autonomous Robotic Cataract Surgery Device", Proceedings of the 2016 ASME IDETC/CIE, 40th Mechanisms & Robotics Conference, Charlotte, North Carolina, Aug. 21-24, 2016.
- [50] Saab, W., Ben-Tzvi, P., "Design and Analysis of a Miniature Modular Inchworm Robot", Proceedings of the 2016 ASME IDETC/CIE, 40th Mechanisms & Robotics Conference, Charlotte, North Carolina, Aug. 21-24, 2016.
- [49] Saab, W., Ben-Tzvi, P., "Design and Analysis of a Discrete Modular Robotic Tail for Improved Performance of Mobile Robots", Proceedings of the 2016 ASME IDETC/CIE, 40th Mechanisms & Robotics Conference, Charlotte, North Carolina, Aug. 21-24, 2016.
- [48] Saab, W., Ben-Tzvi, P., "Design and Analysis of a Robotic Modular Leg Mechanism", Proceedings of the 2016 ASME IDETC/CIE, 40th Mechanisms & Robotics Conference, Charlotte, North Carolina, Aug. 21-24, 2016.
- [47] Kumar, A., Ben-Tzvi, P., "Extraction of Impact of Wind Turbulence on RC Helicopters using Machine Learning", Proceedings of the 2016 ASME IDETC/CIE, 40th Mechanisms & Robotics Conference, Charlotte, North Carolina, Aug. 21-24, 2016.
- [46] Saab, W., Ben-Tzvi, P., "Development of a Novel Coupling Mechanism for Modular Self-Reconfigurable Mobile Robots", Proceedings of the 2015 ASME IDETC/CIE, 39th Mechanisms & Robotics Conference, Boston, MA, Aug. 2-5, 2015.
- [45] Rone, W., Ben-Tzvi, P., "Static Modeling of a Multi-Segment Serpentine Robotic Tail", Proceedings of the 2015 ASME IDETC/CIE, 39th Mechanisms & Robotics Conference, Boston, MA, Aug. 2-5, 2015.
- [44] Ma, Z., Ben-Tzvi, P., Danoff, J., "Sensing and Force-Feedback Exoskeleton Robotic (SAFER) Glove Mechanism for Hand Rehabilitation", Proceedings of the 2015 ASME IDETC/CIE, 39th Mechanisms & Robotics Conference, Boston, MA, Aug. 2-5, 2015.

- [43] Kumar, A., Ben-Tzvi, P., Snyder, M.R., "UAV-based Wireless Telemetry System for the Estimation of Ship Air Wake Patterns", Proc. of the 2015 ASME IDETC/CIE, 2015 ASME/IEEE International Conference on Mechatronic and Embedded Systems and Applications, Boston, MA, Aug. 2–5, 2015.
- [42] Ma, Z., Ben-Tzvi, P., "Modeling Human Hand and Sensing Hand Motions with the Five-Fingered Haptic Glove Mechanism", Proc. of the 2014 ASME Int'l Design Engineering Technical Conferences & Computers and Information in Engineering Conf. (IDETC/CIE 2014), 38th Mechanisms & Robotics Conference, Buffalo, NY, Aug. 17–20, 2014.
- [41] Rone, W., Ben-Tzvi, P., "Continuum Robotic Tail Loading Analysis for Mobile Robot Stabilization and Maneuvering", Proceedings of the 2014 ASME Int'l Design Engineering Technical Conferences & Computers and Information in Engineering Conf. (IDETC/CIE 2014), 38th Mechanisms & Robotics Conference, Buffalo, NY, Aug. 17–20, 2014.
- [40] Snyder, M.R., Kumar, A., Ben-Tzvi, P., "Off Ship Measurement of Ship Air Wakes Using Instrumented Unmanned Aerial Vehicles", 32nd AIAA Applied Aerodynamics Conference, AIAA Aviation and Aeronautics Forum and Exposition 2014, AIAA Paper 2014-3100, Atlanta, GA, 16-20 June 2014.
- [39] Rone, W., Ben-Tzvi, P., "Multi-Segment Continuum Robot Shape Estimation Using Passive Cable Displacements", Proceedings of the 2013 IEEE International Symposium on Robotic and Sensors Environments (ROSE 2013), Washington, DC, pp. 37–42, Oct. 21-23, 2013.
- [38] Ma, Z., Ben-Tzvi, P., "Tendon Transmission Efficiency of A Two-finger Haptic Glove", Proceedings of the 2013 IEEE International Symposium on Robotic and Sensors Environments (ROSE 2013), Washington, DC, pp. 13–18, Oct. 21-23, 2013.
- [37] Kumar, A., Ben-Tzvi, P., Snyder, M.R., Saab, W., "Instrumentation System for Ship Airwake Measurement", Proceedings of the 2013 IEEE Int'l Symposium on Robotic and Sensors Environments (ROSE 2013), Washington, DC, pp. 118–123, Oct. 21-23, 2013.
- [36] Moubarak, P., Alvarez, E., Ben-Tzvi, P., "Reconfiguring a Modular Robot into a Humanoid Formation: A Multi-Body Dynamic Perspective on Motion Scheduling for Modules and their Assemblies", Proc. of the 2013 IEEE International Conference on Automation Science and Engineering (CASE2013), Madison, Wisconsin, pp. 687–692, Aug. 17-21, 2013.
- [35] Moubarak, P., Ben-Tzvi, P., "Globally Converging MIMO Optimal Controller for Adaptive

- Manipulation of Mobile Robots with Redundant Arms”, Proceedings of the 2013 American Control Conference, Washington, DC, pp. 5729–5734, June 17–19, 2013.
- [34] Moubarak, P., Ben-Tzvi, P., Ma, Z., Alvarez, E., “An Active Coupling Mechanism with Three Modes of Operation for Modular Mobile Robotics”, Proc. of the 2013 IEEE International Conference on Robotics and Automation (ICRA2013), Karlsruhe, Germany, pp. 5469–5474, May 6-10, 2013.
 - [33] Snyder, M.R., Kumar, A., Ben-Tzvi, P., Kang, H.S., “Validation of Computational Ship Air Wakes for a Naval Research Vessel”, American Institute of Aeronautics and Astronautics (AIAA) 51st Aerospace Sciences Meeting, AIAA Paper 2013-0959, Grapevine, Texas, January 7-10, 2013. DOI: 10.2514/6.2013-959
 - [32] Rone, W., Ben-Tzvi, P., “Continuum Manipulator Statics Based on the Principle of Virtual Work”, Proceedings of the 2012 ASME International Mechanical Engineering Congress and Exposition (IMECE 2012), Houston, TX, pp. 321-328, November 9–15, 2012.
 - [31] Moubarak, P., Ben-Tzvi, P., Ma, Z., Alvarez, E., “Kinematic Synthesis and Dynamic Analysis of the Dual-Rod Slider Crank Mechanism: An Application to Modular Robotics”, Proceedings of the 2012 ASME IDETC/CIE, 36th Mechanisms & Robotics Conference, Chicago, IL, pp. 1073-1078, Aug. 12–15, 2012.
 - [30] Ma, Z., Ben-Tzvi, P., “An Admittance Glove Mechanism for Controlling a Mobile Robot”, Proceedings of the 2012 ASME IDETC/CIE, 36th Mechanisms & Robotics Conference, Chicago, IL, pp. 1109-1114, Aug. 12–15, 2012.
 - [29] Moubarak, P., Barsky, D., Ben-Tzvi, P., Zaghoul, M., “A Self-Calibrating Temperature Independent Model of a Bi-Axial Piezoelectric MEMS Tilt Sensor,” Proceedings of SPIE - Defense, Security, and Sensing, Micro- and Nanotechnology Sensors, Systems, and Applications IV Conference, Vol. 8373, 83732L-1, Baltimore, MD, April 23-27, 2012.
 - [28] Gilman, C., Ben-Tzvi, P., Yessin, G., Danoff, J., “A Robotic Wrist Exoskeleton Device for Augmenting Wrist Movement and Grip Function in Debilitated Patients”, Proceedings of the 2011 ASME International Mechanical Engineering Congress and Exposition (IMECE 2011), Denver, CO, pp. 1041-1050, November 11–17, 2011.
 - [27] Ma, Z., Ben-Tzvi, P., “An Admittance Type Haptic Device: RML Glove”, Proceedings of the 2011 ASME International Mechanical Engineering Congress and Exposition (IMECE 2011), Denver, CO, pp. 1219-1226, November 11–17, 2011.
 - [26] Gilani, O., Ben-Tzvi, P., “Bioinspired Jumping Mobility Concepts for Rough Terrain Mobile Robots”, Proceedings of the 2011 ASME International Mechanical Engineering Congress and Exposition (IMECE 2011), Denver, CO, pp. 207-214, November 11–17,

2011.

- [25] Gilani, O., Ben-Tzvi, P., "The Application of Bipinspired Jumping Locomotion Principles to Mobile Robots: Modeling and Analysis", Proceedings of the 2011 ASME Annual Dynamic Systems and Control Conf. (DSCC 2011), Arlington, VA, pp. 427-434, Oct 31–Nov 2, 2011.
- [24] Rone, W., Ben-Tzvi, P., "MEMS-Based Microdroplet Generation with Integrated Sensing", COMSOL Conference, Boston, MA, October 13-15, 2011.
*** Winner of the Best Paper Award ***
- [23] Moubarak, P., Ben-Tzvi, P., "Design and Analysis of a New Piezoelectric MEMS Tilt Sensor", Proceedings of the 2011 IEEE International Symposium on Robotic and Sensors Environments (ROSE 2011), Montreal, Quebec, Canada, pp. 83–88, Sep. 17-18, 2011.
- [22] Moubarak, P., Ben-Tzvi, P., "Adaptive Manipulation of a Hybrid Mechanism Mobile Robot", Proceedings of the 2011 IEEE International Symposium on Robotic and Sensors Environments (ROSE 2011), Montreal, Quebec, Canada, pp. 113–118, Sep. 17-18, 2011.
- [21] Rone, W., Ben-Tzvi, P., "Finite Element Modeling of a Microdroplet Generator with Integrated Sensing", Proceedings of the 2011 ASME International Design Engineering Technical Conferences & Computers and Information in Engineering Conference (IDETC/CIE 2011), 2011 ASME/IEEE International Conference on Mechatronic and Embedded Systems and Applications (MESA2011), Washington, DC, Aug. 28–31, 2011.
- [20] Moubarak, P., Ben-Tzvi, P., Ma, Z., Dumas, M., "A Mobile Robotic Platform for Autonomous Navigation and Dexterous Manipulation in Unstructured Environments", Proceedings of the 2010 ASME International Mechanical Engineering Congress and Exposition (IMECE 2010), Vancouver, British Columbia, Canada, November 12–18, 2010.
- [19] Ben-Tzvi, P., Zhuk, M., "Real-time Dynamic Modeling and Virtual Prototype Simulation of Mechanical systems", Proceedings of the 2010 ASME International Mechanical Engineering Congress and Exposition (IMECE 2010), Vancouver, British Columbia, Canada, November 12–18, 2010.
- [18] Charifa, S., Ben-Tzvi, P., "Using Backpropagation Neural Network in Object Recognition for Hybrid Mechanism Mobile Robot", Proceedings of the 2010 ASME International Mechanical Engineering Congress and Exposition (IMECE 2010), Vancouver, British Columbia, Canada, November 12–18, 2010.

- [17] Moubarak, P., Ben-Tzvi, P., and Ma, Z., "A Generic Configuration of a Compact Dexterous and Self-Contained End-Effector for Mobile Robotic Platforms", Proceedings of the 2010 IEEE International Workshop on Robotic and Sensors Environments (ROSE 2010), Phoenix, Arizona, pp. 116–121, October 15-16, 2010.
- [16] Ben-Tzvi, P., Xu, X., "An Embedded Feature-Based Stereo Vision System for Autonomous Mobile Robots", Proceedings of the 2010 IEEE International Workshop on Robotic and Sensors Environments (ROSE 2010), Phoenix, Arizona, pp. 176–181, October 15-16, 2010.
- [15] Ben-Tzvi, P., Charifa, S., Shick, M., "Extraction of 3D Images Using Pitch-Actuated 2D Laser Range Finder for Robotic Vision", Proceedings of the 2010 IEEE International Workshop on Robotic and Sensors Environments (ROSE 2010), Phoenix, Arizona, pp. 140–145, October 15-16, 2010.
- [14] Zhou, Q., Ben-Tzvi, P., Iqbal, A., Fan, D., "Design, Analysis and Optimization of Magnetic Microactuators", Proceedings of the 2009 ASME Int'l Mechanical Engineering Congress and Exposition (IMECE 2009), Lake Buena Vista, Florida, pp. 503-512, Nov. 13-19, 2009.
- [13] Bai, S., Ben-Tzvi, P., Zhou, Q., Huang, X., "Fuzzy Sliding Mode Control of Flexible Spacecraft with Input Saturation", Proceedings of the 2009 ASME International Mechanical Engineering Congress and Exposition (IMECE 2009), Lake Buena Vista, Florida, pp. 1055-1061, November 13-19, 2009.
- [12] Ben-Tzvi, P., "Experimental Validation of a Hybrid Mobile Robot Mechanism with Interchangeable Locomotion and Manipulation", Proceedings of the 2009 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2009), St. Louis, Missouri, pp. 420–421, October 11–15, 2009.
- [11] Ben-Tzvi, P., "Wireless Modular Control Hardware Architecture for Hybrid Mechanism Mobile Robot", Proceedings of the 2009 ASME International Design Engineering Technical Conferences & Computers and Information in Engineering Conf. (IDETC/CIE 2009), 33rd Mechanisms & Robotics Conference, San Diego, CA, pp. 675–680, Aug. 30–Sep. 2, 2009.
- [10] Zhao, H., Ben-Tzvi, P., Tingqi Lin, T., Goldenberg, A.A., "Two-layer Sliding Mode Control of Pneumatic Position Synchro System with Feedback Linearization Based on Friction Compensation", Proceedings of the 2008 IEEE International Workshop on Robotic and Sensors Environments (ROSE 2008), Ottawa, ON, Canada, pp. 41–45, Oct 17–18, 2008.
- [9] Zhou, Q., Ben-Tzvi, P., Fan, D., Goldenberg, A.A., "Design of Fast Steering Mirror Systems for Precision Laser Beams Steering", Proceedings of the 2008 IEEE

International Workshop on Robotic and Sensors Environments (ROSE 2008), Ottawa, Ontario, Canada, pp. 144–149, October 17–18, 2008.

- [8] Bai, S., Ben-Tzvi, P., Zhou, Q., Huang, X., “Dynamic Modeling of a Rotating Beam Having a Tip Mass”, Proceedings of the 2008 IEEE International Workshop on Robotic and Sensors Environments (ROSE 2008), Ottawa, Ontario, Canada, pp. 52–57, October 17–18, 2008.
- [7] Ben-Tzvi, P., Goldenberg, A.A., and Zu, J.W., “Design, Simulations and Optimization of a Tracked Mobile Robot Manipulator with Hybrid Locomotion and Manipulation Capabilities”, Proceedings of the 2008 IEEE International Conference on Robotics and Automation (ICRA2008), Pasadena, California, pp. 2307–2312, May 19–23, 2008.
- [6] Ben-Tzvi, P., Goldenberg, A.A., “Mobile Robots for Hazardous Environments: New Technology for Mobility”, ANS 2nd Int. Joint Topical Meeting on Emergency Preparedness & Response and Robotic & Remote Systems (12th Robotics & Remote Systems for Hazardous Environments), Albuquerque, NM, Mar 9–12, 2008.
- [5] Raoufi, C., Ben-Tzvi, P., Goldenberg, A.A., and Kucharczyk, W., “A MR-Compatible Tele-Robotic System for MRI-Guided Intervention: System Overview and Mechanical Design”, Proceedings of the 2007 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2007), San Diego, California, pp. 1975–1800, October 29 – Nov 2, 2007.
- [4] Ben-Tzvi, P., Goldenberg, A.A., and Zu, J.W., “Implementation of Sensors and Control Paradigm for a Hybrid Mobile Robot Manipulator for Search and Rescue Operations”, Proceedings of the 2007 IEEE International Workshop on Robotic and Sensors Environments (ROSE 2007), Ottawa, Ontario, Canada, pp. 92–97, October 12–13, 2007.
 *** Winner of the Best Student Paper Award ***
- [3] Ben-Tzvi, P., Ito, S., and Goldenberg, A.A., “Autonomous Stair Climbing with Reconfigurable Tracked Mobile Robot”, Proceedings of the 2007 IEEE International Workshop on Robotic and Sensors Environments (ROSE 2007), Ottawa, Canada, pp. 104–109, October 12–13, 2007.
- [2] Ben-Tzvi, P., Raoufi, C., Goldenberg, A.A., Zu, J.W., “Virtual Prototype Development and Simulations of a Tracked Hybrid Mobile Robot”, Proceedings of MSC Software 2007 Virtual Product Development Conference, Detroit, Michigan, October 10–12, 2007.
- [1] Ben-Tzvi, P., Goldenberg, A.A., Zu, J.W., “A Novel Control Architecture and Design of Hybrid Locomotion and Manipulation Tracked Mobile Robot”, Proceedings of the

2007 IEEE International Conference on Mechatronics and Automation (ICMA 2007), Harbin, China, pp. 1374–1381, August 5–8, 2007.

BOOKS

[B1] Kurdila, A.J., Ben-Tzvi, P., Dynamics and Control of Robotic Systems. Wiley & Sons, Inc., December 2019, ISBN: 978-1-119-52483-0. (520 pages)

MONOGRAPHS

[2] Ben-Tzvi, P., Hybrid Mobile Robot Systems: Symbiosis of Locomotion and Manipulation. Germany: LAP LAMBERT Academic Publishing, 2010 (ISBN-13: 978-3-8433-6890-2)

[1] Ben-Tzvi, P., A Dispensing System for Microdrops Generation in Medical Applications. Germany: LAP LAMBERT Academic Publishing, 2010 (ISBN-13: 978-3-8383-6000-3)

BOOK CHAPTERS

[1] Ben-Tzvi, P., Moubarak, P., "A Mechatronic Perspective on Robotic Arms and End-Effectors" in Intelligent Mechatronics. Vienna, Austria: InTech Open Access Publisher, 28 Feb. 2011, pp. 3–20. (ISBN-13: 978-953-307-300-2, DOI: 10.5772/16234)

PATENTS

- [20] Ben-Tzvi, P., Kamidi, V., “An Articulated Closed Kinematic Chain Planar Monopod”, U.S. Patent Application No. 17/813,772, Filed July 20, 2022. Published online November 24, 2022
- [19] Ben-Tzvi, P., Liu, Y., Rone, W.S., Saab, W., “Articulated Multi-Link Robotic Tail Systems and Methods”, U.S. Patent Application No. 17/697,353, Published June 30, 2022.
- [18] Ben-Tzvi, P., Njaka, T., Brizzolara, S., “High-Speed Omnidirectional Underwater Propulsion Mechanism”, U.S. Patent Application No. 17/531,007, Published December 8, 2022.
- [17] Ben-Tzvi, P., Refour, E., Sebastian, B., Xu, W., Guo, Y., Pradhan, S., “Robotic Exoskeleton Glove System”, U.S. Patent Application No. 16/888,993, Filed June 1, 2020.
- [16] Ben-Tzvi, P., Liu, Y., “Extensible Continuum Manipulator”, U.S. PCT Patent Application No. PCT/US2021/034564, Filed May 27, 2021.
- [15] Ben-Tzvi, P., Kamidi, V., “Articulated Closed Kinematic Chain Planar Monopod”, U.S. Patent No. 11,413,475, Issued August 16, 2022.
- [14] Ben-Tzvi, P., Liu, Y., Rone, W.S., Saab, W., “Articulated Multi-Link Robotic Tail Systems and Methods”, U.S. Patent 11,305,420, Issued April 19, 2022.
- [13] Ben-Tzvi, P., Kumar, A., “Linear Optical Sensor Arrays (LOSA) Tracking System for Active Marker Based 3D Motion Tracking”, U.S. Patent 10,295,651, Issued May 21, 2019.
- [12] Ben-Tzvi, P., Moubarak, P., “Active Docking Mechanism for Modular and Reconfigurable Robots”, U.S. Patent 9,616,948, Issued April 11, 2017.
- [11] Ben-Tzvi, P., Goldenberg, A.A., and Zu, J.W., “Hybrid Mobile Robot”, Canadian Patent No. CA2631116, Issued, September 2016.
- [10] Ben-Tzvi, P., Moubarak, P., “A mobile Robot with Hybrid Traction and Mobility Mechanism”, U.S. Patent 9,004,200, Issued April 14, 2015.
- [9] Ben-Tzvi, P., “A Mobile Robot with Symbiosis of Locomotion and Manipulation”, U.S. Patent 8,225,892, Issued July 24, 2012.
- [8] Ben-Tzvi, P., Goldenberg, A.A., and Zu, J.W., “Hybrid Mobile Robot”, U.S. Patent 7,874,386, Issued January 25, 2011.

- [7] Ben-Tzvi, P., Yang, J., Saab, W., “Robotic Modular Leg V2 Utilizing the Reuleaux Triangle Drive Mechanism to Build Legged Mobile Robots”, U.S. Provisional Patent Application No. 62/855,968, June 1, 2019. (abandoned)
- [6] Ben-Tzvi, P., Williams, A., Sebastian, B., Kumar, A., Saab, W., “Semi-Autonomous Victim Extraction Robot (SAVER)”, U.S. Provisional Patent Application No. 62/836,915, April 22, 2019. (abandoned)
- [5] Ben-Tzvi, P., Kumar, A., “An Expandable 6D Motion Tracking System Using Linear Optical Sensors Arrays (LOSA-X)”, U.S. Patent Application No. 16/356,568, Filed March 18, 2019. (abandoned)
- [4] Ben-Tzvi, P., Saab, W., “Discrete Modular Serpentine Robotic Tail Mechanism for Mobile Legged Robots”, U.S. Provisional Patent Application No.62/340,140, May 23, 2016. (abandoned)
- [3] Ben-Tzvi, P., Saab, W., “Robotic Modular Leg Mechanism for Legged Mobile Robots”, U.S. Provisional Patent Application No.62/340,136, May 23, 2016. (abandoned)
- [2] Ben-Tzvi, P., “A Hybrid Suspension and Tension Mechanism for Mobile Robots”, U.S. Patent Application No. 13/507,180, June 12, 2012. (abandoned)
- [1] Ben-Tzvi, P., “Mobile Robot with Symbiosis of Locomotion and Manipulation”, U.S. Patent Application No. 12/925,145, October 14, 2010. (abandoned)

EXHIBIT 2

DR. PINHAS BEN-TZVI, PH.D., P.E., FASME, SMIEEE

5503 Chestermill Ct

Fairfax, VA 22030

Tel: 202-641-8011

pinhas.bentzvi@gmail.com

Expert Testimony List

United States District Court, Southern District of Mississippi, Eastern Division

Caspa Solutions LLC (Plaintiff)* v. Howard Industries, Inc. (Defendant), Civil Action No. 2:22-cv-00065-HSO-BWR, Patent Infringement Case Pertaining to US Patents 7,594,668 and 8,215,650

Declaration

United States International Trade Commission (ITC)

In the Matter of Certain Electronic Candle Products and Components Thereof (Investigation No. 337-TA-1195)

L&L Candle Company LLC and Sotera Tschetter, Inc. (Complainants) v. Sterno Products *et al.* (Defendants)*

Provide expert opinion on patentability/obviousness

United States District Court, District of Nebraska

Hartford Fire Insurance Company (Plaintiff)* v. McLeod Software Corporation (Defendant), Hartford Insurance Claim # CP0017674514, Court suit not yet filed

Technical Report

United States District Court, District of New Jersey

IOTTIE INC. and HSM CO., LTD., (Plaintiffs)* v. MERKURY INNOVATIONS (Defendant), Civil Action No. 2:15-cv-06597-KM-JBC (D.N.J.) Pertaining to US Patent 8,627,953

Declaration, Deposition

United States Patent and Trademark Office, Before the Patent Trial and Appeal Board

Wagner Spray Tech (Plaintiff)* v. Graco Inc. (MN) (Defendant); Not yet filed

Patent No. at Issue: 9,675,982

Declaration, Provide expert opinion on patentability/obviousness

In the Court of Queen's Bench of Alberta, Canada

DFI Corporation (Plaintiff)* v. Sauer Danfoss, Inc. and Norcan Fluid Power Limited (Defendant), Court File Number 0903-16237

Site Inspection/Field Investigation, Expert Report

United States International Trade Commission (ITC)

In the Matter of Certain Hospital Beds and Components Thereof (Investigation No. 337-TA-987)

Stryker (Complainant)* v. Umano Medical Inc. and Umano Medical World Inc. (Defendants)

Two Declarations, Deposition

United States Patent and Trademark Office, Before the Patent Trial and Appeal Board (IPR)

SATA GmbH & CO. KG (Petitioner)* v. ANEST IWATA CORPORATION (Patent Owner),

Case No. IPR2013-00111 (Patent 6,494,387)

Declaration, Deposition

In the Superior Court of the State of Delaware, In and For Sussex County

Patrick Black (Plaintiff) v. Chromascape, Inc. dba Amerimulch; Lenze Americas Corp., Southtech Industries, Inc. (Defendant)*, Civil Case No. S13C-04-018 RFS

Site Inspection/Field Investigation, Expert Report

EXHIBIT 3

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APPLICATIONS

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RESOURCES

What are the main types of linear actuators?

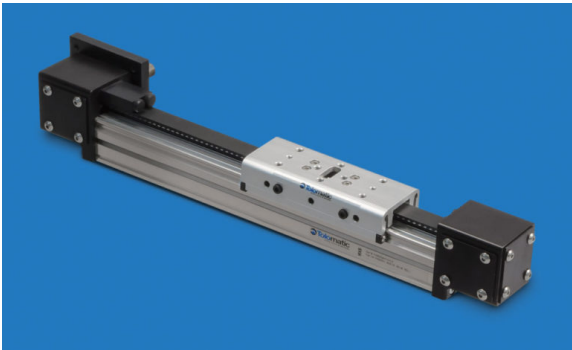
MARCH 3, 2016 BY DANIELLE COLLINS — 2 COMMENTS

f t in +

Updated August 2017 || Linear actuators come in myriad configurations to suit almost any application, environment or industry. They're primarily categorized by their drive mechanism; then manufacturers use other features such as the type of guide and housing to further differentiate them. Below is an explanation of the most common linear actuator categories.

Belt-driven and screw-driven actuators

Although belt and screw drives are different technologies, it makes sense to put them in the same category because they are the two most common types of electromechanical actuators. Most manufacturers of linear actuators offer both belt and screw-driven options.



This Tolomatic MXB-S belt-driven actuator has a solid bearing design to boost performance in harsh environments — with load-carrying capacities up to 520 lb.

Belt driven actuators can use a variety of guide mechanisms, with plain bearings, cam-roller guides, and recirculating bearings (riding on a profiled rail or round shaft) being the most common. Because their strengths are high speeds and long strokes, belt-driven systems are often housed in an aluminum extrusion or in an open configuration with no protective housing.

Within the screw driven category, there are two sub-categories — ball screw driven and lead screw driven. While ball screw actuators have higher repeatability and thrust forces than lead screw actuators, both provide inherent gearing through the lead (pitch) of the screw.



Ball screw drive actuator
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guided by plain bearings. Because screw driven actuators require end bearings that must be rigidly mounted, they are often enclosed in an aluminum extrusion. However, when high travel accuracy is required, ball screw types are commonly offered with a machined steel housing.

Corp.

One design that you won't find is a ball screw actuator with cam rollers as the guide mechanism. This is because the strength of cam roller guides is high speed, whereas ball screw actuators are primarily used for high repeatability and high thrust force, with limited speed capabilities. Using cam roller guides in a ball screw driven actuator would be comparable to putting racing slicks on a Hummer. It can be done, but it wouldn't make much sense.

Pneumatically driven actuators

Although they're not electromechanical devices like the other actuator types, their prevalence in automated equipment makes pneumatic driven versions an important category of linear actuators. Pneumatic actuators can be further divided into two sub-categories: slider-type and rod-type.



Pneumatic rod-type actuators |
Image credit: PHD Inc.

In slider-type actuators, the motion is contained within the limits of a housing and the load is mounted to a slider (also referred to as a carriage, saddle, or table).

In rod-type actuators, the motion is produced by a rod that extends and retracts from a housing. The load may be mounted to the end of the rod, or the rod can be used to push the load. (Think of pressing or stamping a label onto a carton, or pushing defective products to a diverter lane along a conveyor.)

Slider-type pneumatic actuators can be guided by recirculating or plain bearings, depending on the load they're designed for.

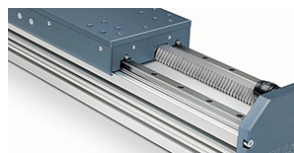
Rod-style versions are not typically designed for radial (downward/upward/side) loads, and use simple plain bearings to provide guidance to the rod, without significantly contributing to load-carrying capacity.

Note: Ball screw driven actuators are also offered in both slider- and rod-types, making the actuator family tree even more complex.

Rack-and-pinion driven actuators

For extremely long lengths and robustness against contamination, rack and pinion drives are often the best choice. However, these characteristics make finding a suitable guide system difficult in some applications.

For extremely long lengths, joined profiled rails are sometimes used, but when contamination is a significant concern, metal wheels are usually preferred. A unique



Rack and pinion drive actuator
Image credit: Rollon

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feature of rack and pinion types is their ability to drive multiple carriages independently. A common application for rack and pinion actuators is the overhead gantry, often found in automotive production.

Linear motor driven actuators



Linear motor drive actuator

Image credit: Parker Hannifin Corp.

Linear motor actuators are also capable of long travel lengths with multiple carriages, but they're primarily used for high-precision, highly dynamic motion.

To complement the strengths of the linear motor, these actuators use high precision profiled rails, crossed roller guides, or even air bearings as their guidance system.

Linear motor types can be mounted in an extruded housing or on a machined aluminum plate, but in order to meet the highest travel accuracy specifications, they can also be mounted on a machined steel plate or granite base.

While there are very few "standards" in the linear actuator industry, one thing that manufacturers have done a good job of adhering to is the distinction between actuators and stages. When the mounting surface is a machined steel or granite base, the term "stage" is used. The performance difference between stages and actuators has primarily to do with travel accuracy. Stages hold much higher travel accuracies than actuators and use linear motors or very high precision ball screws for extremely smooth, precise positioning.

With so many options, choosing the best linear actuator is a complex task, and there's not one "right" way to make a selection. The best place to start, however, is usually with a manufacturer's sizing software or selection program. Still, the results often include several choices, which can be narrowed down by looking at non-quantitative criteria, such as ease of maintenance, integration with existing components or systems, and space constraints.



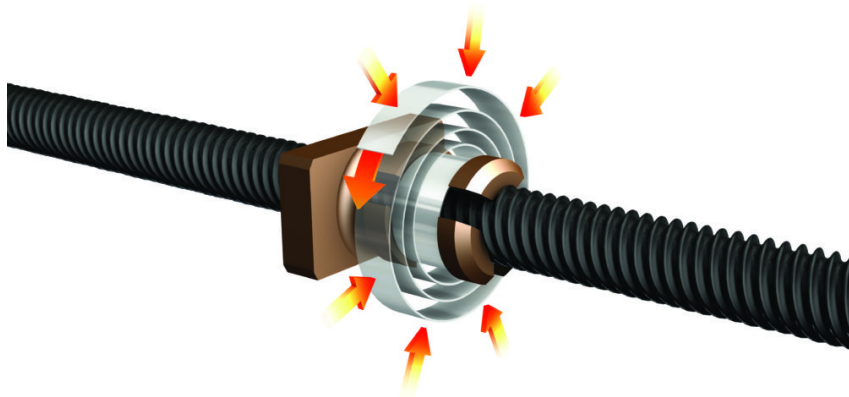
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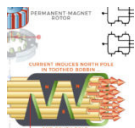
Electric rod-style actuators as those shown here deliver more performance, control, and efficiency than fluid-power (pneumatic and hydraulic) counterparts. Electric actuators meet motion-control needs ranging from low-cost to high-performance for myriad industries — from food and beverage processing and production to high-force timber processing. Design tip: Fully analyze the linear-motion application and determine the project's exact parameters (such as loads, forces, application footprint and environment) before specifying an actuator. Careful upfront analysis reduces overall costs and makes for automation systems with higher reliability, better performance, lower energy expenditures, and less maintenance. Courtesy Tolomatic Inc.



PBC Linear offers integrated motor and screw technology. The actuator shown here includes the manufacturer's Constant Force Technology (CFT) including a constant-force spring to apply uniform pressure to the nut even over variable motion profiles.

Feature image credit: Tolomatic, Inc.

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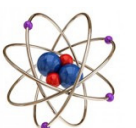
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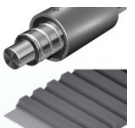
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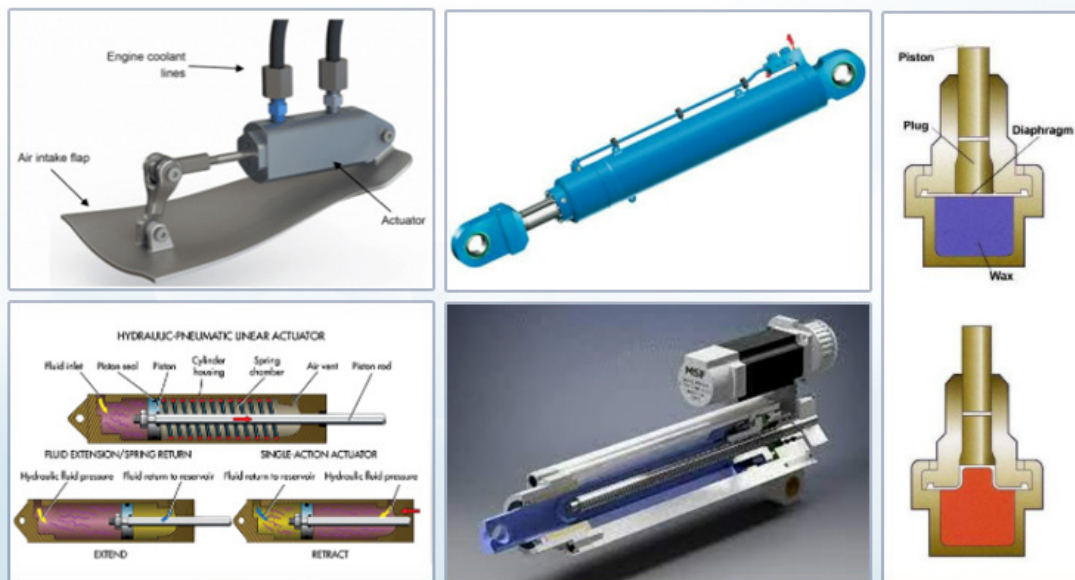
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Different Types of Actuators (/articles/types-of-actuators)

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Complete Guide to Actuators



Complete Guide to Actuators

Actuators are machines capable of converting a form of energy into physical force or mechanical motions. In easier language, actuators are components that enable motion in a machine or in an object. To perform the motion, actuators need a control signal and a source of energy. The energy can be in the form of electrical energy, hydraulic fluid pressure, pneumatic pressure, etc. The block diagram below shows a simplified action of actuators.



Different Types of Actuators

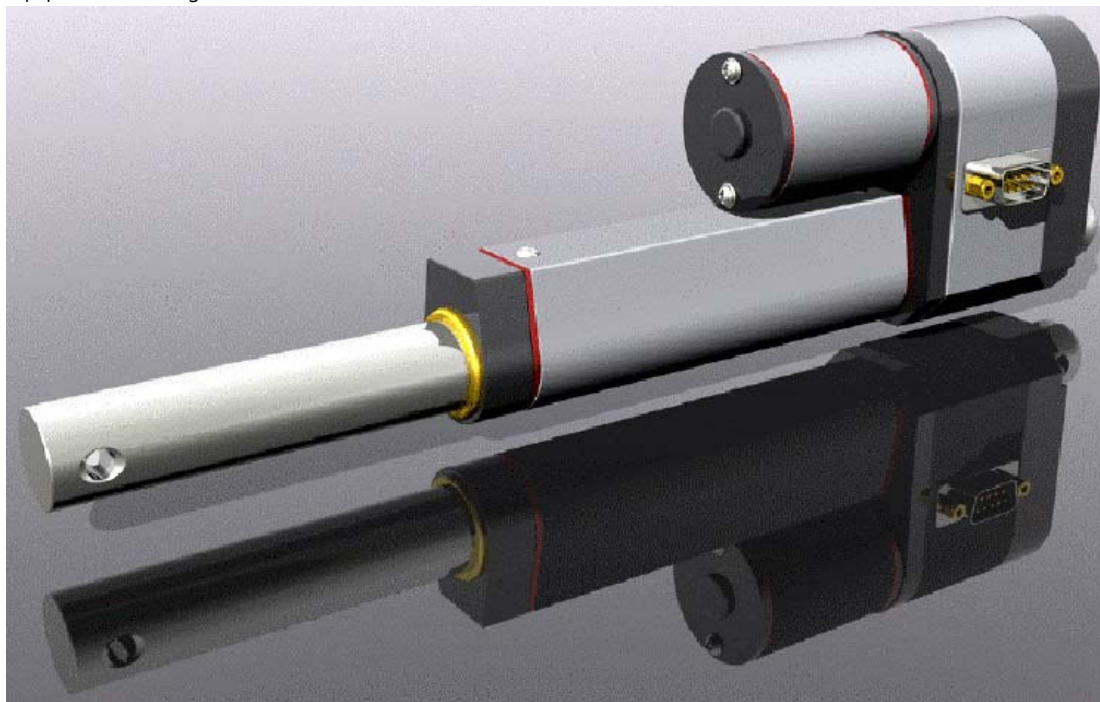
Actuators can be categorized into 2 types, based on their motion and based on their driving method. In this article, I will be categorizing the actuators on the basis of the input energy required for actuation.

Actuators based on Motion

Based on the motion, actuators can be classified as **Linear Actuators** or **Rotary Actuators**.

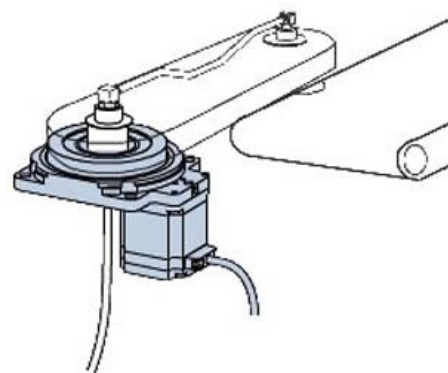
Linear Actuators

Linear Actuators are machines that provide mechanical force linearly or in simpler words they provide mechanical forces in a straight line, they only have a **push and pull motion**. The most commonly used linear actuators are push-pull solenoids and hydraulic cylinders which are used in construction equipment. The image below shows a linear electric actuator.



Rotary Actuators

Rotary actuators are able to provide mechanical torque around a point. One of the most common types of rotary actuators is electrical motors. The image below shows a rotary actuator in action.



Actuators based on their Input Energy

Actuators are most commonly classified on the basis of input energy. **Hydraulic, pneumatic, and electrical actuators** are the most common types of actuators present in the market. Hydraulic actuators are the oldest kind of actuators still used while electrical actuators are becoming the most used type. There are new kinds of actuators which are operated by a change in pH level of body or with interaction with certain chemicals, these have their application in the field of **Bio-medical** and **Bio-surgeries** which are used

Electrical Actuator

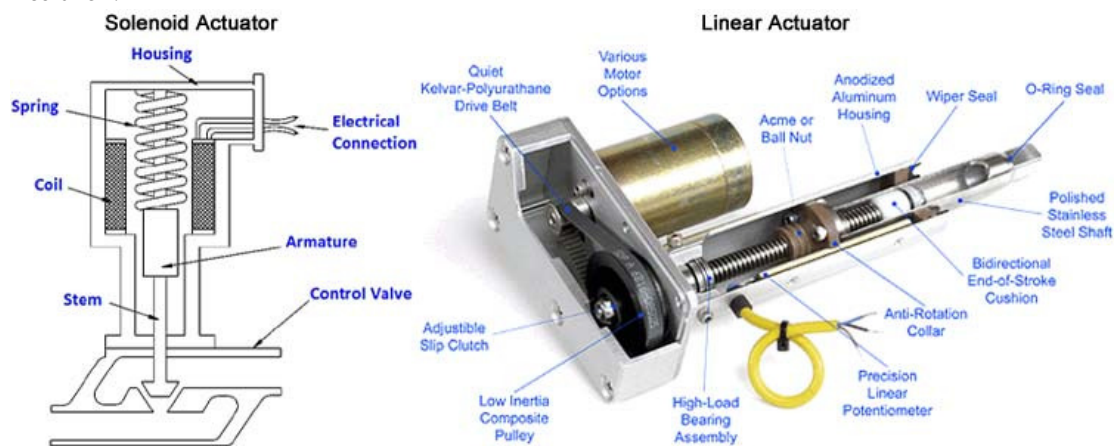
Electric actuators are devices that take electrical energy both AC or DC as an input to provide a mechanical torque or linear motion. Electric motors are becoming one of the most commonly used actuators due to their easier control, longer life spans, and high efficiency. Servo motors and other DC and AC types of motors provide a rotational output. **Rotational actuators** are the most efficient type of electrical actuator, they have higher power to weight ratio and lower moving parts compared to most linear actuators. The below image shows a rotary actuator used as a valve in a cross-section area of a pipeline.



Electric Linear Actuators

These devices convert electrical energy into linear motion. There are 2 types of linear actuators, one is a solenoid actuator, which provides a linear motion and the second type has a rotary motion with a mechanical system to convert rotary motion into linear motion. These have a motor providing rotating motion and the output shaft is connected to a set of gears and drive mechanism to convert the rotary motion into a linear motion, the output shaft of the linear actuator is connected with the linear guides which ensure proper movement of the output shaft. The second type of linear actuator is most commonly used among the 2 as they have much higher load capacity.

In the image shown below, the left diagram is depicting a solenoid actuator whereas the right figure shows the internals of a linear actuator and its driving mechanism.



Where are Electrical Linear Actuators used?

Electrical linear actuators are extensively used in industrial applications, they are also commonly used for controlling valves, pumps, etc in power plants, oil and gas plants, etc. In our houses, these are commonly used for solenoid-actuated bell mechanisms, automatic door mechanisms in houses, and find application in electronically operated power windows in cars.

Advantages of Electric Linear Actuators

- Electric actuators offer the highest precision among all types of actuators.
- They are highly modular and scalable for different purposes and force requirements.
- Electric actuators are capable of working in extreme conditions.
- Easy to construct and repair.
- Lack of oil and other fluids make them much more durable for a given weight.

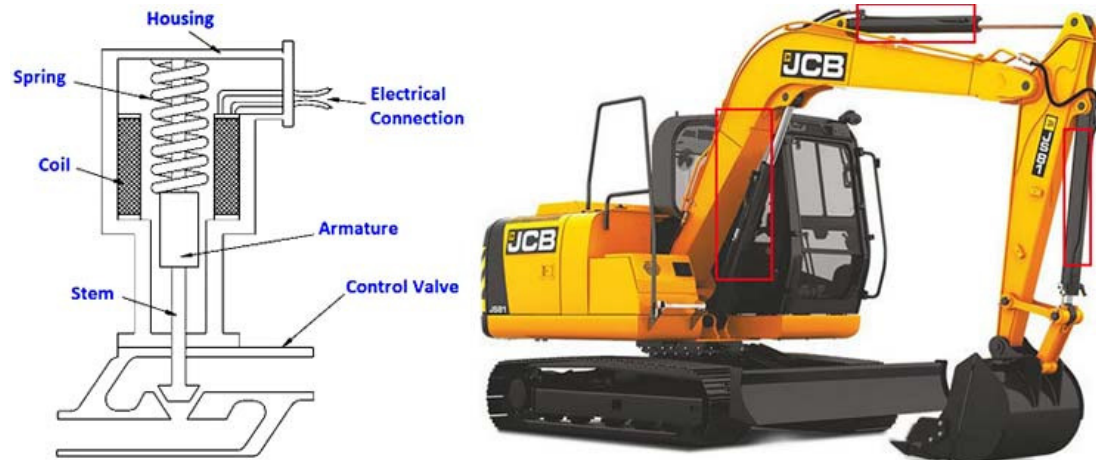
- They produce less sound than hydraulic and pneumatic actuators.

Disadvantages of Electric Linear Actuators

- Higher initial cost for higher powered applications.
- Control mechanism is more complex
- Requires highly skilled people for maintenance and repair.
- These are unsuitable for hazardous and flammable areas.
- Electric motors require a gear mechanism, thus higher maintainability.

Hydraulic Actuator

The hydraulic actuators consist of a cylinder or **fluid-based motor** which utilizes the power of hydraulics to create mechanical actions. Hydraulic actuators are capable of providing linear as well as rotary motions. They utilize incompressible fluids such as oils from a pump that fills the cylinder to apply power to either one or both sides of the pistons. The speed and force can be adjusted by increasing the pressure of the fluid inside the cylinder. These are the oldest types of actuators known to us. The below image shows a cross-section of the hydraulic actuator. In the image of a JCB machine, we can see 3 hydraulic actuators used to control its arm.



Advantage of Hydraulic Actuators

- They are capable of producing high speed and high power
- Hydraulic actuators can hold constant force even without a pump consuming extra energy for supplying fluids to the cylinder as they utilize incompressible fluids.

Disadvantages of Hydraulic Actuators

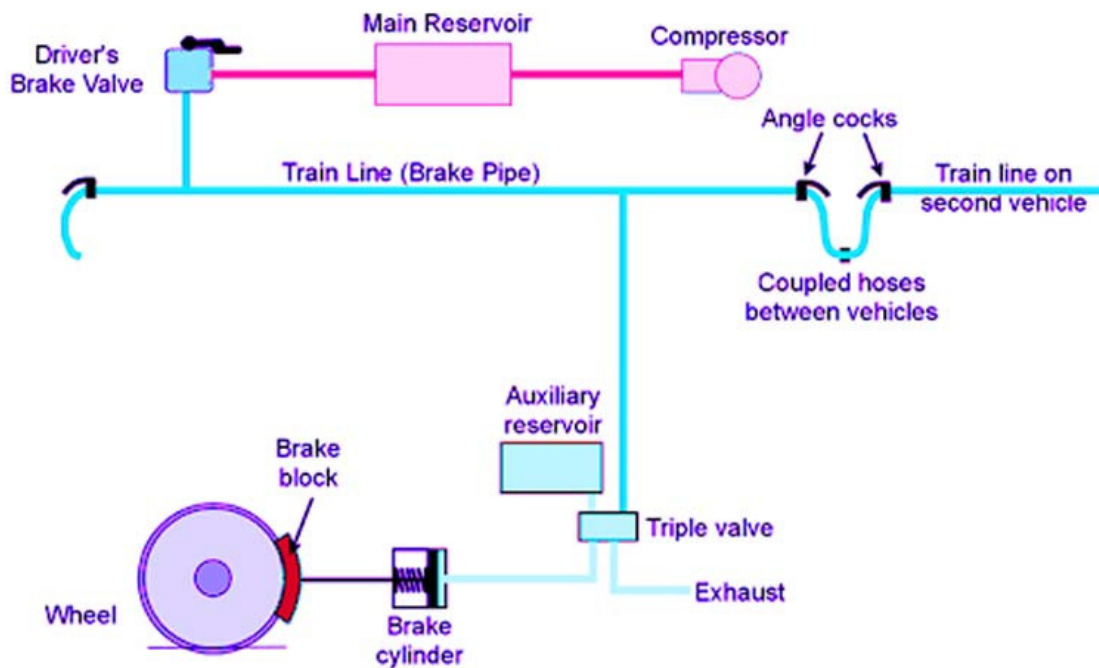
- They require higher maintenance cost
- Leaks in the fluid may result in loss of efficiency, the fluids can also impact the environment adversely.
- They are not suitable for extreme temperatures as the fluid property may vary depending on temperatures.
- Hydraulic Actuators have a lot of components such as reservoirs, pumps, release valves, heat exchangers, etc, which can result in lower reliability and higher resources for monitoring, thus increasing the cost of operations.

Where are Hydraulic Actuators used?

Hydraulic actuators are extensively used in industrial applications, they are also used in construction equipment such as JCB machines, diggers, etc for operating their equipment such as plunger or diggers. They are commonly used in brakes of our vehicles or suspension systems etc.

Pneumatic Actuator

Pneumatic Actuators are similar to hydraulic actuators. The difference is the fluid used for driving the pistons is gaseous in nature. The energy is from either a high-pressured compressed air or vacuum is used to get a linear or rotary mechanical motion. Similar to hydraulic actuators, they convert pressure into force. A diagram of air brakes used in trains is shown below



Advantages of Pneumatic Actuators

- Very fast response rate
- High forces can be produced with small pressure changes
- Cheaper to construct and operate than electrical and hydraulic actuators.
- Pneumatic actuators produce higher power than electric or hydraulic actuators.
- It can be used in extreme temperatures and hazardous conditions as it is safer to operate air in hazardous places than chemicals or electricity.

Disadvantages of Pneumatic Actuators

- Even if no movement is required a compressor must operate continuously since pressure losses and compressibility of air make pneumatic actuators loose power.
- Small leaks are difficult to identify than in hydraulic actuators.
- If the air in reservoir gets contaminated by oil, lubrication, or other gases, the power output is changed which leads to downtime and maintenance.

Where are Pneumatic Actuators used?

Pneumatic actuators find applications in a lot of different types of industries, they are used as **Rack and Pinion** actuators for valve controls operations. They are also used in Pneumatic brakes in vehicles as they are very responsive to small pressure changes applied by the driver.

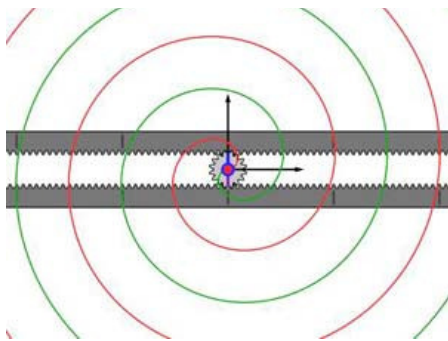
Magnetic Actuators

Magnetic actuation is based on the **Principle of Lorentz Forces**, which states that the magnetic field produced by a current-carrying conductor placed in a static magnetic field interacts with the static field to produce a force. This force can be used to cause the displacement of a mechanical structure. These are used for very small applications such as **nano-robots** and have huge potential in the field of **bio-medicals**. Their main advantage is that they require low voltages and have no contact operations. There is another kind of magnetic actuator known as **Magneto Rheological Fluid Actuator**. These fluids solidify in presence of a magnetic field and have applications in hydrodynamic bearings, semi-active clutches, etc.

Example: Magnetostrictive micro walker used in biomedical applications, magneto rheological fluid actuator are used as valves, brakes, and dampers.

Mechanical Actuators

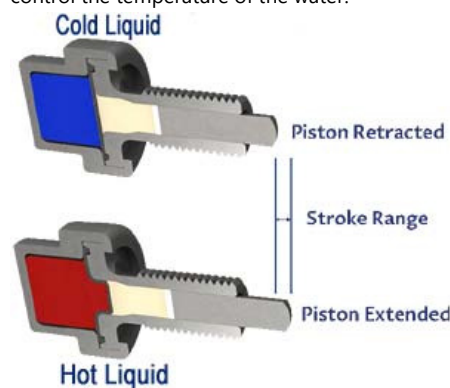
Mechanical actuators convert one form of motion into another, they utilize gears, chains, pulleys, rails, and different contraptions for their operations. They are often combined with another actuator and driving mechanism. They are used for increasing torque or power of the output or even to convert linear motion to rotary or vice versa. The gif shows how two rails providing linear motion to the gear are converted to a rotary motion.



Examples: Rack and pinion mechanism, crankshaft in engines, etc.

Thermal Actuators

Thermal actuators are usually made up of metals or **shape memory alloys**, which can retain a predefined shape when required heat energy is provided. These are thermal-sensitive materials capable of producing linear operations in response to change in heat energy. The main advantages of thermal actuators are compact, light in weight, and easy-to-use devices. The below image shows a thermostatic valve, commonly used in our showers to passively control the temperature of the water.



Examples: Thermal actuators are commonly used as temperature control mechanisms in thermostats, electric iron boxes, and as thermostatic valves in pipelines containing fluids, these are frequently used in passive temperature control applications in industries, homes, automobiles, etc.

Soft Actuators

Soft actuators are **polymer based actuators** designed for very niche operations to perform delicate tasks such as manipulating the internal organs in **biomedicine** or harvesting fruits in agriculture. Their main advantage is that they have low density and are biodegradable. Based on their composition can respond to stimuli such as light, heat, emf, change in pH, etc.

Application of Soft Actuators

These are commonly used in surgeries and in the field of biomedical they also have applications in the aerospace industry.

Conclusion

All the actuator technologies have their specific application and hence place in the industry. But the most common and flexible types of actuators are hydraulic, pneumatic, and electric actuators. Mechanical actuators are usually used in conjunction with other actuators or drive mechanisms to provide the desired mechanical outputs. The soft actuator is being investigated a lot because of its great potential in the field of biomedical and biochemistry.

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- [Motor Encoder Feedback](#)
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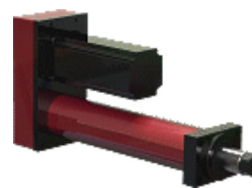
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Linear Actuators Information

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Linear actuators are mechanical devices used to move items through a system. The device uses energy to develop force and motion in a linear manner, as opposed to a rotational motion in an electric motor. Linear actuators offer advantages including a simple design with minimal moving parts. They are self-contained and can achieve high speeds, and the actuator has identical behavior extending and retracting. The disadvantage to using a linear actuator is that it can only achieve a low force of actuation.



Methods

- **Mechanical actuation** is used to covert rotary motion of a screw thread or gear into linear displacement and force. Examples include a car jack, laser positioner, and other positioning instrumentation.
- **Electrical actuation** uses electrically driven motors to drive the actuator.
- **Hydraulic actuation** is performed by hydraulic actuators or cylinders. They use fluid pressure actuated by a linear motion piston within an enclosed cylinders. There are two isolated sides of the hydraulic piston. One side is pressurized or de-pressurized to achieve the linear motion of the piston, causing movement. A common example of a hydraulic actuator is an automotive repair lift.
- **Pneumatic actuation**, also called air actuation, uses air pressure to actuate a piston within a cylinder. Their function is similar to that of a hydraulic actuator except the actuating fluid is air.
- **Electrohydraulic actuation** is done with a self-contained electrically- driven hydraulic pump used to drive cylinders or actuators.

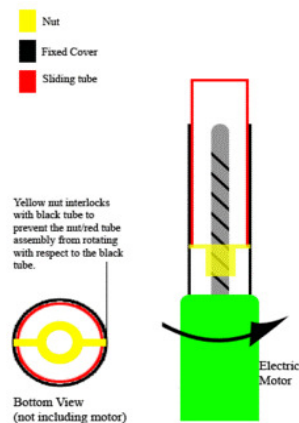
Types

Linear actuators can be divided into three types: screw, belt, and rod type.

Screw Type

Screw type linear actuators generate motion via a turning screw. Types of screws include a motor-driven ball screw, or lead screw. The load is attached to the end of the screw and is unsupported.

Lead screw actuators have a threaded nut which moves with respect to the screw. This generates motion in whichever element is not fixed. This technology is simple, economical, and widely used. All the screws in screw type actuators are made of lead, but term 'lead scrw actuator' is commonly used for this design. The disadvantages of this design include the amount of wear that occurs between the surfaces of the nut and the threads of the screw, which reduces lifetime, efficiency, speed, and performance. Lead screw actuators are best used when performance trade-offs are acceptable and when the application requires a lighter load and duty cycle.



Lead screw linear actuator. The lead screw is gray. Image Credit: Wikipedia

Ball screws are lead screw and ball nut combinations that enable the balls in the nut to circulate when the actuator is in motion. The motion of the nut around the screw is assisted by the ball bearings. This reduces friction, distributes the load, and increases the lifetime predictability over a lead screw design. The advantages of ball screws include the ability to take heavy loads, deliver precision positioning, and higher efficiency and thrust capabilities than a lead screw actuator. The disadvantages associated with ball screws is that they are more expensive, generate more noise, and the bearings

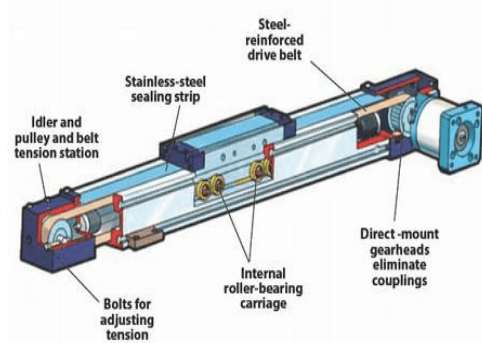
can become contaminated reducing performance or causing failure.

Planetary roller screw uses a planetary arrangement of threaded rollers surrounding the main threaded shaft. This increases the surface area that takes the load and offers the highest possible thrust and lifetime of the screw type actuators. Planetary roller screws are the most expensive type of screw actuator but they have the best performance for demanding applications that require high thrust force.

Belt Type

Electric linear actuators with belt drives, geared drives, and direct drives are also available.

Belt drives connect the motor to the actuator with a belt. This type of actuator is best used when the application is horizontal and requires speed and force. They are generally not used in vertical applications since breakage of the belt could put the load into free-fall. The disadvantage of using a belt drive is that it has a lower repeatability than the alternatives and the belt requires regular tensioning. Belt drives have low noise and complexity.



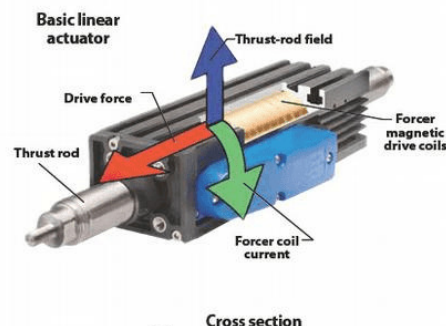
Belt drives. Image Credit: MachineDesign

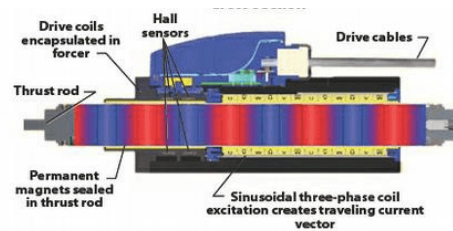
Geared drives connect the motor to the actuator with a set of gears. Gears used in motors are external type gears such as spur, helical, and herringbone designs.

Direct drives connect the motor directly to the electric linear actuator. This method takes the power coming from a motor without any reductions. Direct drives offer increased efficiency, longer lifetime, and less noise; however, direct drives do require a special motor that is best used for application with a relatively high torque at very low speeds and requires a more precise control mechanism.

Rod Type

Rod style actuators are distinguished by the thrust element (rod) moving out of the end of the actuator as the motion takes place. This type of actuator produces more force and excels at applications which require thrust since there is room inside the casing for a larger bearing mechanism. The housing is also sealed from dust and debris that could cause the actuator to wear or fail. Rod style actuators do not provide the support that some loads need since they are only supported by a nut at one end. In this design the mass from the rod can cause sag, compromising rigidity and increasing wear against bearing elements. Rod style is best used when the load does not need to be placed or held in a precise location.





Servo motor, rod type linear actuator. Image Credit: Machine Design

Rodless style actuators have the screw completely encased by the housing and this moves the load on a platform that rides along the top of the actuator. This style supports the load and provides a guidance structure since the device is supported by a nut at both ends. This smaller footprint is also less subject to screw whip, also known as critical speed. Due to the narrow slits that run the length of the actuator, rodless actuators cannot be sealed for wet environments. The narrow slits permit the load bearing platform to couple to and move with the nut.

Specifications

The applications of linear actuators are far reaching. They can be found in agriculture machinery, high-voltage switch gears, train and bus doors, and medical machines, just to name a few. There are many specifications to consider when selecting a linear actuator. Identifying the requirements from the application is the first step. This includes determining how much force the actuator needs in newtons or pounds-force. Also important to consider is how far and in what direction the actuator needs to move. The directions could include pushing, pulling, vertical, or horizontal, while the distance factors in both the stroke and retracted length.



Stroke is the maximum distance that the shaft travels from a fully extended position to a fully retracted position. Standard catalog options denote two inch increments. The longer the stroke, the longer the actuator will be when fully retracted.

Rated force or load is the force required to move the object. The actuator must produce enough force to overcome friction before motion.

System backlash, also known as backlash, is the position error due to directional change.

Rated speed is the maximum actuator speed; this is typically a low or no load amount. The actuator will need to move fast enough for the application. The combination of speed and the rated force required will help determine the mechanical power required by the motor.

Duty cycle- A critical specification is the duty cycle or lifetime of the actuator; it indicates how often an actuator will operate and how much time there is between operations. The life verses load relationship should be evaluated based upon the desired result of application demands. Applications which will have a higher load would be expected to reduce the life of the bearing system and vice versa. Except for high end servo units, most actuators will not be able to run continuously without overheating. To calculate duty cycle, assume an actuator runs for 10 seconds cumulative, up and down, and then doesn't run for another 40 seconds. The duty cycle would be $10 / (40 + 10)$, or 20%. If duty cycle is increased, the load or the speed must be reduced.

Linear Actuator Specifications

Linear actuators vary in terms of motor type, power, and features. A linear motor is very similar to a rotary electric motor. In a

linear motor the rotor and stator (metal ring of insulated wire) components are laid out in a straight line. The magnetic field structures of linear motors are physically repeated across the length of the actuator.

DC Motor Types are powered by direct current such as from a battery or DC power supply. They are able to change rotational direction when the polarity of the input current changes.



- **DC brush motors** feature built-in commutation so that as the motor rotates, mechanical brushes automatically actuate coils on the rotor.
- **Brushless DC motors** use an external power drive that allows commutation of the coils on the stator.
- **DC servomotors** have an output shaft that is positioned when a coded signal is sent to the motor.

AC Motor Types are electric motors powered by alternating current. They convert electrical energy into mechanical energy in order to do work in a system.

- **AC motors** include a wide class of motors including single/ multiphase, universal, induction, synchronous, and gear motors.
- **AC servomotors** are permanent magnet synchronous motors that have low torque-to-inertia ratios for high acceleration ratings.
- **AC stepper motors** use a magnetic field to move a rotor in small angular steps or fractions of steps.

Linear motors generate force only in the direction of travel, and do not utilize a rotary mechanism to transfer power.

Motor specifications

- **Motor voltage** denotes the voltage applied to the motor and includes AC, DC, and stepper type motors.
- **Continuous power**, also known as sustainable power, does not include short-term peak power ratings.

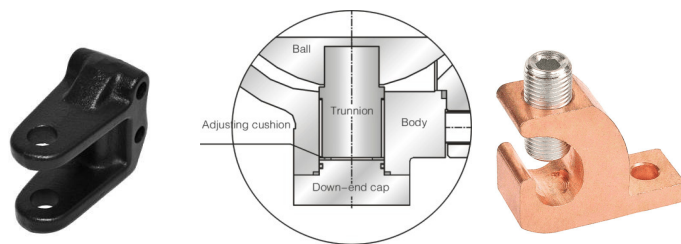
Motor features

- **Motor encoder feedback** provides continuous output position in an analog or digital signal.
- **Linear position feedback** provides continuous output of position in an analog or digital signal.
- **Position switches** have a switch that outputs the limit travel.
- **Integral brakes** hold the current position of the motor.

For more information on motor specifications, read [How to Select DC Motors](#), and [How to Select AC Motors](#).

Actuator Mounting Options

There are several mounting options for electric linear actuators.



Clevis mount. Trunnion mount. Lug mount

Image Credit: UHAUL | FBV Valve | Garvin

- **Clevis** or eye attachment connects the cylinder to the extended end of the piston via threads.
- **Double end** mounts have a nose and rear which contain threaded bosses for nut attachment.
- **Flange** mounts are brackets placed on the cylinder
- **Floating mounts** are for more convenient installation of the cylinder.
- **Foot brackets** are flanges that rest underneath the cylinder.
- **Lugs** are short blocks with holes that attach to the side of the cylinder and allow mounting to another surface.
- **Face mount** have threaded holes on the front face for attachment.
- **Nose mounts** are threaded for mounting through a hole with a nut on the other side.

- **Rear mount** have tapped holes or mounting flange on the rear.
- **Threaded** mounts are designed to mount to bolts via threaded holes in the cylinder head or cap.
- **Trunnion mounts** are specially designed mounting blocks which can be located at the cap, end, or an intermediate location along the cylinder.

Actuator Features

Linear actuators provide many optional features.

- **Adjustable stroke-** Adjustable stroke allows for the end points or the total stroke length to be adjusted.
- **Bumpers and cushions-**Bumpers and cushions are used to soften the impact at the end of the stroke.
- **Closed loop control-** Also known as servo control, the cylinders have external devices that send back a signal to the pump control giving it position information.
- **Holding brakes-** Holding brakes work in conjunction with the self-locking feature to increase holding force.
- **Shock absorbers-** Shock absorbers are used in pneumatic or hydraulic fluid absorption of shock.
- **Double-ended rods-** Double end rods extend from both ends of the cylinder with attachment features such as threads on both ends.
- **Multi-position end-plate-** A multi-position end plate can be actuated to different positions along its stroke, not just the endpoint.
- **Integrated overload slip clutch or torque limiter-** An integral flow control incorporates a flow control valve that limits the amount of air or fluid that enters the cylinder.
- **Protective boot-** Protective boots are a cover that protects moving parts against environment damage.
- **Self-locking-** Self-locking actuators lock in the current position when there is a loss of signal.
- **Integral sensors-** Integral sensors are equipped within the cylinder to monitor position and proximity.
- **Integral flow-** Integral flow control incorporates a flow control valve or device that limits the amount of air or fluid that enters the cylinder.
- **Non-rotating-** Non-rotating denotes multiple rods to prevent the plunger from rotating.
- **Magnetic switches-** Magnetic switches such as Hall Effect sensors indicate if the thruster is in the retracted or extended position.
- **Thermal overload protection-** Thermal overload protection is used to trip a switch when a preset temperature is exceeded.
- **Intrinsically safe-** Intrinsically safe electric linear actuators can be used in hazardous environments such as chemical processing facilities.
- **Water resistant-** Devices are sealed to prevent corrosion due to water or liquid entering the housing.

Typically, body materials consist of aluminum, steel, plastic, or stainless steel.

References

- [Choosing the Right Linear Actuator](#)
- [Linear Actuator Review](#)
- [Selecting a Linear Actuator](#)
- [Making Sense of Manufacturer Specifications](#)
- [What is a Linear Actuator?](#)
- [How to Choose the Right Linear Actuator](#)

Image Credit: Del-Tron | Thomson | AeroTech

[Read user Insights about Linear Actuators](#)

Related Products & Services

Air Cylinders

Air cylinders are pneumatic linear actuators that are driven by a pressure differential in the cylinder's chambers. They may be single-acting (with a spring return) or double-acting.

Hydraulic Cylinders

Hydraulic cylinders are actuation devices that utilize pressurized hydraulic fluid to produce linear motion and force.

Linear Thrusters

Linear thrusters use double-acting pneumatic cylinders or hydraulic cylinders mated to shafts and plates to provide reoccurring linear motion They are used in conveying, inspection systems, and lifting applications, or to apply thrust



load

Rodless Cylinders

Rodless cylinders are linear devices that use pressurized fluid to move a load within many power transfer operations.

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EXHIBIT 6



Tameson's Technical Information Center > Product Information

Pneumatic Cylinders - A Technical Guide

A pneumatic cylinder is a mechanical device that converts compressed air energy into a reciprocating linear motion. A double-acting cylinder uses compressed air to move a piston in and out, while a single-acting cylinder uses compressed air for one-way movement and a return spring for the other.

They have numerous accessories, like **sensors** to detect the position of the piston and **different mounting accessories** to mount the cylinder or add components to the end of the piston.

A wide range of industries requiring linear motion use pneumatic cylinders since they are simple to use and are a cost-efficient solution. They are also referred to as air cylinders.



Figure 1: Pneumatic cylinder

View our online selection of pneumatic cylinders



ISO 15552 pneumatic cylinders



ISO 6432 mini pneumatic cylinders



ISO 21287 compact pneumatic cylinders



Rodless pneumatic cylinders

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Contents

- Pneumatic cylinder parts
- Pneumatic cylinder working principle
- Standards
- Cushioning
- Accessories
- Symbols
- Selection criteria
- Frequently asked questions

Pneumatic cylinder parts

Figure 2 shows the main components of a double-acting pneumatic cylinder. They are cap-end port (A), tie rod (B), rod-end port (C), piston (D), barrel (E), and piston rod (F). A single-acting cylinder will only have either a cap-end port (A) or a rod-end port (C) and utilize a mechanical spring for the secondary motion. The pneumatic cylinder barrel (E) is sealed on both ends with a head cap and end cap. The compressed air (or spring) moves the piston (D) and subsequently the piston rod (F). The stroke length of a pneumatic cylinder is how far the piston rod can extend.

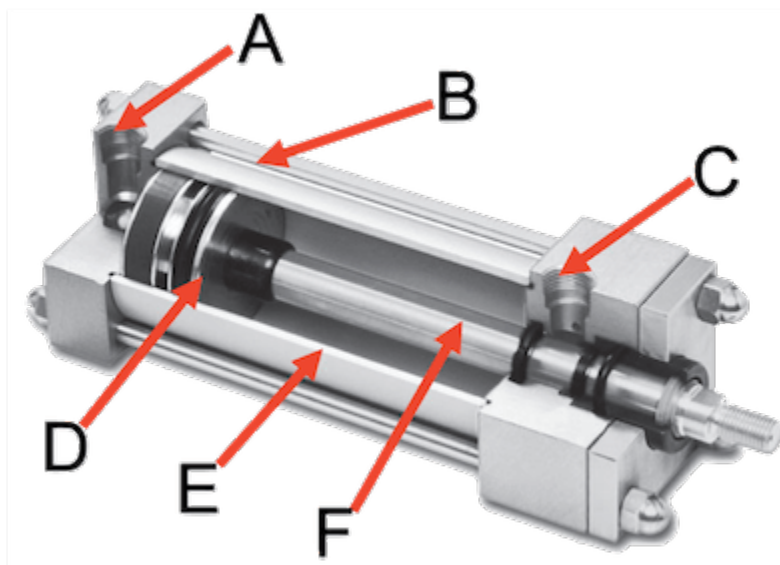


Figure 2: Double-acting pneumatic cylinder parts

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Pneumatic cylinder working principle

Double-acting pneumatic cylinder

Double-acting pneumatic cylinders are the most common type since they give the user complete control of the piston movement. Figure 3 shows how the piston and piston rod move when compressed air enters the cap-end port and the rod-end port. A negative position is when the piston rod is retracted, and a positive position is when the piston rod is extended. When compressed air enters the cap-end port, it pushes the piston forward (positively), extending the piston rod (shown in Figure 3 A). Air is forced out of the rod-end port. To retract the piston rod, compressed air enters the rod-end port, forcing air out of the cap-end port, and forcing the piston to retract to the negative position (shown in Figure 3 B).



Figure 3: Double-acting cylinder working principle with air going in (blue arrow) and air coming out (grey arrow). The left image shows positive movement (A). The right image shows negative movement (B).

Double-acting pneumatic cylinders allow the user full control, longer piston stroke length, and a constant output force through the entire stroke. They can also operate at higher cycling rates. However, a double-acting cylinder should not be used if the application requires a base position during fail-safe scenarios because there is a loss in compressed air. Since they use compressed air for both directions, they also use more energy.



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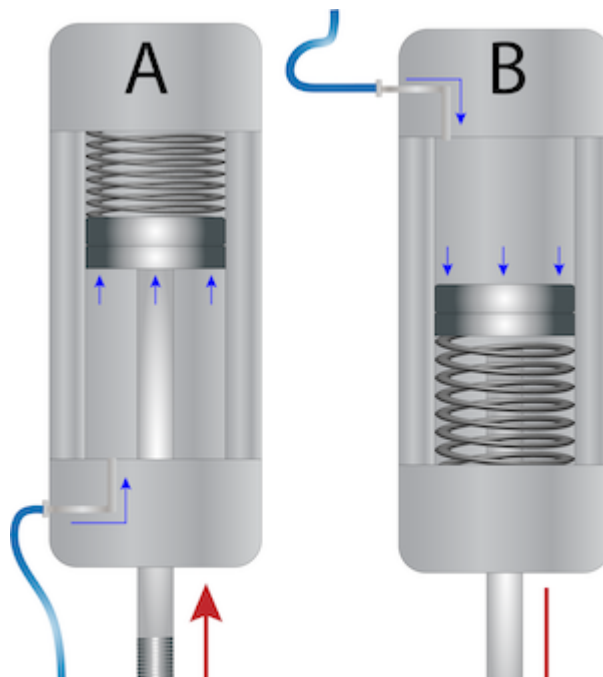


Figure 4: Double-acting cylinders can be used in a wide variety of ways, here we see a vacuum pick and place application that uses a pneumatic cylinder to move the position of the suction cup.

Single-acting pneumatic cylinder

A single-acting pneumatic cylinder only uses compressed air to drive the piston in one direction. A mechanical spring moves the piston in the opposite direction. Figure 4 shows the two design possibilities. Either the spring extends (Figure 4 A) or retracts (Figure 4 B) the piston. Single-acting cylinders are often used for fail-safe applications where it is required that the piston is in a certain position upon compressed air loss. Therefore, single-acting pneumatic cylinders have a "base" position.

Due to the mechanical spring, single-acting pneumatic cylinders do not provide a consistent output force throughout the full piston stroke length due to the opposing spring force. Furthermore, the stroke of single-acting cylinders is limited due to the space of the compressed spring. Therefore, the construction length of single-acting cylinders is longer than the actual stroke length.



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Figure 5: Single-acting pneumatic cylinder working principle. Compressed air is used to move the piston in one direction, and a spring either extends the piston (A) or retracts it (B).

Standards

Pneumatic cylinder designs typically adhere to ISO standards, allowing them to be interchangeable with products of different manufacturers. Therefore, the mounting dimensions, cylinder bore, stroke, piston rod characteristics, and air ports depend on the type/standard and use. However, there are still numerous non-standard cylinders for special applications.

Round ISO 6432 (8-25 mm)

ISO 6432 is a metric ISO standard applicable to single rod pneumatic cylinders with bores from 8 mm to 25 mm and a maximum working pressure of up to 10 bars (1000 k Pa). They are commonly referred to as mini air cylinders or round cylinders. This standard establishes a metric series of mounting dimensions required for the interchangeability of the cylinders. This pneumatic cylinder standard does not have manual damping adjustment. The ISO 6432 is a perfect compact cylinder line suitable for automation systems in diagnostic instrumentation, bottling, automotive and commercial kitchen, and laundry equipment. View our online selection of [ISO 6432 pneumatic cylinders](#).



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ISO 6432 pneumatic mini cylinders | A quick guide

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Profile ISO 15552 (32-320 mm)

ISO 15552 establishes metric mounting dimensions, bore sizes, mounting styles, piston rod characteristics, strokes for single or double rod pneumatic cylinders with a maximum working pressure of up to 10 bar (1000 k Pa), and bore sizes from 32 mm to 320 mm. This standard applies to cylinders with detachable mountings. VDMA 24562 is common in Germany and is for profile and tie-rod cylinders. The ISO 15552 pneumatic cylinder series have adjustable cushioning, which helps to achieve perfect dampening. Therefore, ISO 15552 cylinders are suitable for the efficient movement of large loads. They are generally used in general automation systems in machine and systems constructions, the food and beverage industry, etc. ISO 15552 has replaced the older standards of ISO 6431 and VDMA 24562. View our online selection of [ISO 15552 pneumatic cylinders](#).



ISO 15552 pneumatic cylinders & accessories | A quick guide

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Compact ISO 21287 (20-100 mm)

ISO 21287 applies to single rod compact pneumatic cylinders with a maximum working pressure of up to 10 bar (1000 k Pa) and bore sizes from 20 mm to 100 mm. This pneumatic cylinder

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series is not equipped with adjustable cushioning. However, there are rubber bumpers at both ends for cushioning. The ISO 21287 pneumatic cylinder series are compact and lightweight, thus desirable for applications that have space limitations. View our online selection of [ISO 21287 pneumatic cylinders](#).



Figure 6: ISO 21287 pneumatic cylinders

Rodless cylinders

A rodless cylinder is similar to pneumatic cylinders in that they use compressed air to move a load in a linear path. However, a rodless cylinder moves the load alongside the piston rather than pushing or pulling the load. Therefore, there is no piston rod buckling, same force in both directions, and they are more compact for the same stroke length. Rodless cylinders are commonly used for material handling, loading, lifting, web cutting, etc. Read our [rodless cylinder technical article](#) for more information. View our online selection of [rodless cylinders](#).

Cushioning

The movement of the piston in a pneumatic cylinder can be very fast as the compressed air enters the cylinder. This fast movement can create a hard shock when the piston hits the head or end cap. This shock imposes stress on the air cylinder components, makes a noise, and transmits vibration to the machine structure. To prevent this, cushioning at the caps is used to decelerate the piston. Cushioning can also prevent the piston from rebounding (bouncing) off the

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Most pneumatic cylinders have end-of-stroke cushioning in one of the following

Flexible shock absorbers

For smaller air cylinders where the impact is not that high, a flexible material is used at the cap end/head. This material is often made from elastomers and comes in the form of a ring. These bumpers are either integrated as a part of the piston or at the head and end caps. This type of cushioning is best suited for slow operating speeds, low loads, and shorter strokes.

Adjustable pneumatic cushioning

For larger pneumatic cylinders with higher piston speeds or stronger forces, shock absorption is achieved by trapping a certain air volume in the end position. At the end of the stroke, the air is compressed, generating a braking effect. For this purpose, throttling non-return valves are installed directly on the end ports of the cylinder. This allows for the free inflow of pressurized air and exhaust port to be adjustable with a screw. This method of cushioning is wear-free and offers optimal cushioning performance. Depending on the operating pressure and the cylinder force, the screw settings on the cylinder are adjusted for ideal cushioning. Too much cushioning results in slow strokes and too little cushioning increases the end-of-stroke shock.

Self-adjusting pneumatic cushioning

In this cushioning method, the exhaust air escapes through longitudinal slots on the inside of the cylinder. The cross-section of this exhaust depends on the stroke. This will allow the cushioning to automatically adjust to different energy levels by changing loads and speeds. Therefore, allow for optimal cushioning with no manual intervention.

Accessories

Piston position feedback

Pneumatic cylinder sensors are used to provide piston position feedback to a control system in automated machinery and equipment. It is typically standard that the piston has a magnet inside the cylinders body. Then, a sensor can be mounted onto the pneumatic cylinders body, like Figure 6 shows, to provide the pistons position. Depending on where the sensor is mounted, it can detect extension, retraction, or individual positions along the cylinder body. If multiple position feedback is needed, multiple sensors can be mounted to the cylinders body.

\$5 Off Proximity sensors are the most common type of sensor as they have a long life cycle (over 10 years). They are typically not the first point of failure for high shock or vibration applications. Read more...

million) and are typically not the first point of failure for high shock or vibration applications. Read our [pneumatic cylinder sensor article](#) to learn more about how they work. View our online selection of [pneumatic cylinder sensors](#)..

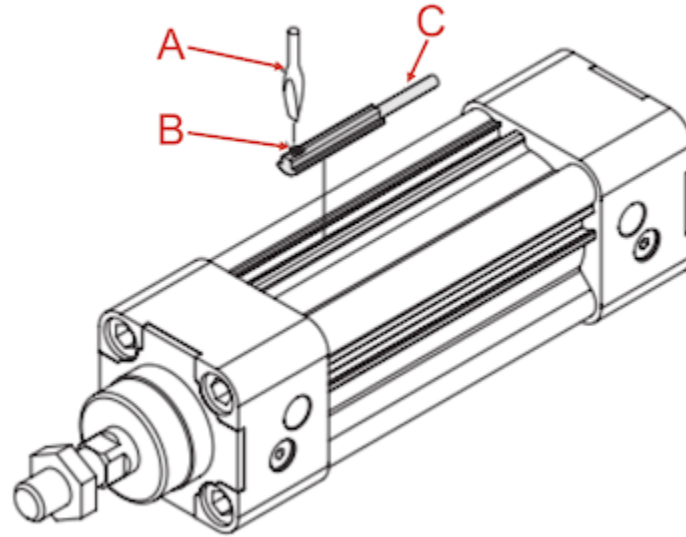


Figure 7: A pneumatic cylinder with a sensor (C) mounted via set screw (B) with a screw driver (A)

Pneumatic grippers

A pneumatic gripper is a [pick-and-place](#) device that uses compressed air to operate gripper jaws, also called fingers. They typically have two or three fingers and have an internal pneumatic cylinder to operate and control them. They are mostly used in automated manufacturing processes to grip a workpiece. Read our [pneumatic gripper article](#) to learn more about how they work. View our online selection of [pneumatic grippers](#).



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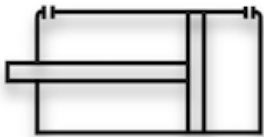
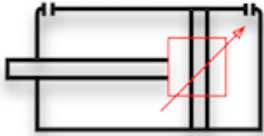
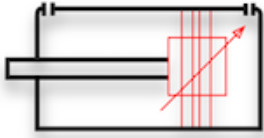
Figure 8: Pneumatic grippers

Mounting accessories

Mounting accessories are used to mount the pneumatic cylinder or for coupling the piston rod to a load. They are typically designed based on the ISO standard of the pneumatic cylinder. Mounting accessories will affect system performance, reliability, and overall design. Flanges, foot mounted, pivots, angle brackets, spherical eye, etc., are just some of the different mounting accessories. Read our [pneumatic cylinder mounting accessories article](#) to learn more about the mounting options. View our online selection of [pneumatic cylinder mounting accessories](#)..

Symbols

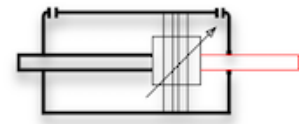
ISO has developed well-defined symbols for pneumatic cylinders to distinguish their function in schematics. These symbols are independent of pneumatic cylinder ISO standards, diameter, or stroke.

Double-acting cylinder	
Double-acting cylinder with magnetic piston	
Double-acting cylinder with adjustable cushioning	
Double-acting cylinder with adjustable cushioning and magnetic piston	

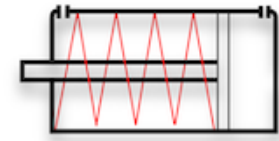
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cylinder with through piston rod, adjustable cushioning and

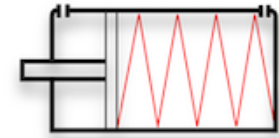
Double-acting cylinder with through piston rod, adjustable cushioning and magnetic piston



Single-acting cylinder (minus)



Single-acting cylinder (plus)



Selection Criteria

1. **Cylinder Diameter:** The diameter of the pneumatic cylinder is directly proportional to the amount of force it can generate from an input air pressure. For single-acting pneumatic cylinders, the opposing spring force should also be taken into consideration.

$$F = (P \times A) - f$$

- **F:** Cylinder's Force (N)
- **P:** Air Pressure (MPa)
- **A:** Piston Area (mm²)
- **f:** Friction Drag (N)

2. **Stroke Length:** Ensure that the piston rod can extend or retract the required length. It is also important to note that longer piston rods puts higher stress on the rod and requires a longer pneumatic cylinder.

3. Mounting Style

4. Position Feedback

5. Cushioning

6. Operating pressure

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ection size

Frequently asked questions

What does a pneumatic cylinder do?

A pneumatic cylinder is a mechanical device that converts compressed air energy into a reciprocating linear motion.

Can pneumatic cylinders stop mid-stroke?

Double-acting cylinders are capable of stopping mid-stroke. For high accuracy applications, special locking cylinders and position feedback should be used.

How do pneumatic cylinders work?

A double-acting pneumatic cylinder uses compressed air to move a piston in and out, while a single-acting pneumatic cylinder uses compressed air for one-way movement and a return spring for the other.

What does stroke mean for pneumatic cylinders?

The stroke is the total distance that the piston rod is capable of moving in one direction.

View our online selection of pneumatic cylinders



ISO 15552 pneumatic cylinders



ISO 6432 mini pneumatic cylinders



ISO 21287 compact pneumatic cylinders



Rodless pneumatic cylinders

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EXHIBIT 7



MECHANICAL & MOTION SYSTEMS

A Guide to Gas Spring Design and Customization

April 29, 2019

Knowing how gas springs work will help you select the right one for a design.

David Rowland



When a design calls for an industrial gas spring, there's a wide range of standard, off-the-shelf products available from various manufacturers. But ordering a gas spring from a catalog comes with a lot of risks. Depending on the application, it's likely that some degree of customization is necessary to ensure just the right gas spring is found.

There is a better way to get the best gas spring: Take an engineering approach to adding gas springs to designs, and use standard industrial gas springs as a starting point.



Gas springs are self-contained, force generating, maintenance-free cylinders. They are used to move and position lids, chairs, table-tops, and host of other assemblies. body is pre-charged with

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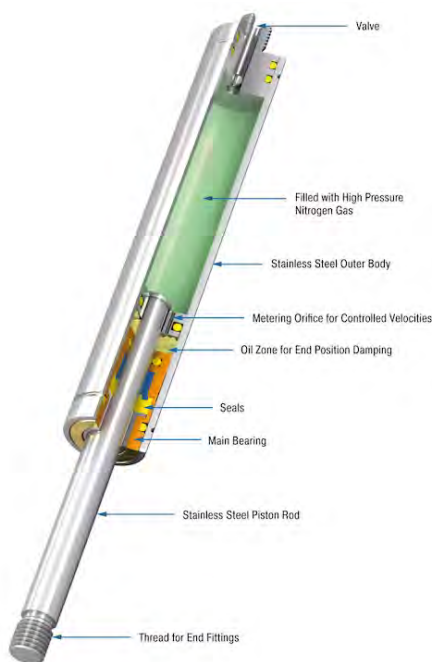
nitrogen gas to provide a specific output force. Pressure is applied to the piston and diameter area, which provides the output force in push-type gas springs.

Standard Gas Springs

Standard gas springs are quick and easy to order. They're also relatively inexpensive, provided they don't need troubleshooting right out of the box to fit the application. However, customers may underestimate how much data they need to specify gas springs. Furthermore, off-the-shelf gas springs commonly offer only one of three choices of output force. Will one of them be exactly right? There's a good chance designers and customers may get unintended results.

If factory-supplied output forces don't work, hoods or lids may open unexpectedly, or the spring might not support the load it needs to move. Another concern with off-the-shelf gas springs: customer drawings fail to allow room in the installation for the spring. Or, the spring comes with the wrong end fittings. These situations often force customers to waste time trying different forces and modifying the assembly, and they still may not get the right gas spring for the job. All this trial-and-error inflates labor costs and the project suffers needless delays.

Unlike most standard gas springs, an engineered spring is, in essence, a custom part the manufacturer typically adjusts to an application's specifications. The added investment usually pays off via saved time and labor costs that come from gas springs working perfectly the first time.



Gas Spring Basics

To understand the important factors to consider when ordering a custom gas spring, engineers should know the basics behind how they work.

Gas springs are self-contained, force generating, maintenance-free cylinders. The body is filled with pressurized nitrogen gas that generates a specific pressure. The pressure pushes on the piston, which provides the output force in push-type gas springs. As the piston rod is pushed and compressed, the piston generates a constant output force and controls its velocity by metering nitrogen

through a hole. A little oil dampens, or cushions, piston movement at the end of travel when the gas spring is mounted with the piston rod facing downward. Some

Drives Stack...

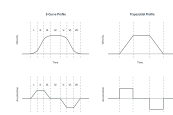


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Primer



Surge
Protection



gas springs have a field-accessible vent valve for venting nitrogen to reduce the spring's force.

Depending on the application, designers can choose from several types of gas springs. Some common gas spring types include:

Push-type to lift and lower loads with easy control and minimal exertion. Push-type gas springs support covers and lids in a broad range of industries.

Pull-type to fit in tight. This type is compact and mounts in any orientation and position. Unlike in standard push-type springs, pressure in the cylinder retracts the piston rod. Pull-types can have low progression rate. Progression is the increase in force exerted by the gas spring over the stroke. Progression rates, which measure the change in progression, can be as low as 11%.

They also can have an adjustment valve to control the traction force. Traction force is the pulling force from the gas pressure that retracts the rod. It can be as low as 11 lb and as high as 1,630 lb, depending on the gas spring. Providing this pulling force is the gas spring's main function as it helps in lifting and holding up all types of heavy objects in many different applications.

Locking to hold a position. Chairs often need to maintain a certain position to support a patient or someone. In an adjustable desk chair, for example, a person adjusts the height by first pressing a button or lever. This opens a piston valve so the seat can be moved up or down to the desired position. Letting go of the button or lever lets the valve closes and locks the piston so the seat remains at that height.

Two custom-made stainless-steel locking gas springs from Ace Controls lets this hygiene and toileting device for children with disabilities be inclined up to 15 deg. forward or aft and be easy to clean.



Two custom-made stainless-steel locking gas springs from Ace Controls lets this hygiene and toileting device for children with disabilities be inclined up to 15 deg. forward or aft and be easy to clean.

To get the best performance from an off-the-shelf gas spring, it's important to identify the following parameters as you begin the selection process. Sometimes

mistakes happen here, but the right gas spring manufacturer can provide the tools and engineering support to help designers get started.

Size and weight: Know the dimensions and weight of the object being moved. For

best results, use a spring scale to determine its weight.

Orientation: The body of the gas spring must fit within the assembly without anything limiting its range of motion.

Pivot point: The pivot point or hinge provide support and is the axis of rotation for hoods and covers and other rotating objects. Is it at the top, middle, or bottom?

Point of lifting: Where will users push or pull to move the load?

Starting angle: The angle of the load before the spring begins its travel.

Finishing angle: The angle of the load when the spring ends its travel.

Hand force: The amount of force users must apply to move the load. An application engineer can help determine the necessary hand force for different angles of movement throughout the load's complete motion.

Extension force: Gas springs apply forces to counterbalance the load or hood being moved. Designers decide how much nitrogen goes inside the spring that pushes the piston head and gives it the force to move the load. Some manufacturers and suppliers have calculators that help customers balance the forces the gas spring needs to apply in relation to its load.

Center of gravity: Understanding how the geometry and weight of the load are all affected by gravity is critical when determining where to mount the gas spring, the force needed to counterbalance the load, and where to make the compromise. When gas springs are mounted with their center of gravity close to the pivot, their operation is easier to predict.

Stroke length: The distance the load must move. Make sure the gas spring can manage the overall force in the installation. Gas spring vendors have product data that show how different forces interact with stroke and how much force a specific stroke length can handle.

Mounting: How the gas spring is mounted determines the load's opening angle and the distance the gas spring needs to move the load, which is commonly known as stroke. For example, linear applications have a straight stroke. You will need to know the load's dimensions and account for any equipment or obstructions nearby that could affect the mounting location.

Materials: Most gas springs are used in benign indoor environments, so they are usually made of carbon steel. However, customers may opt for rust-inhibiting materials or UV coatings if they will be used near saltwater or in food and medical applications. Some vendors offer rust-inhibiting versions of standard models to protect against corrosion in food and hygienically sensitive areas like clean rooms.

ACE Controls, for example, offers standard gas springs with an advanced UV coating or 303 or 316 VA stainless steel outer bodies that can be filled with food-grade oil, conforming to FDA 21 CFR 178.3570, which regulates incidental food contact.

Ambient temperature: This refers to the range of temperatures in the gas spring's proposed operating environment.



Industrial gas springs from Ace Controls make it easy to open and close the doors on this rescue helicopter. The maintenance-free, sealed springs are installed on the access doors of EC 135 helicopters. They let the crew enter and exit the helicopter quickly, enhancing

safety. The GS-19 gas springs provide a defined retraction speed and secure engagement of the door lock. The built-in end-position damper allows for gentle closing of the door which saves wear and tear on the lightweight material.

Mounting Gas Springs

When mounting a gas spring, make sure the spring fits within the device. The general tolerance for fitting a gas spring is ± 0.08 in., but it varies depending on spring's size and extension force. So check with the manufacturer to get the correct tolerance. If the application demands durability and stability, do not combine a small diameter body with a long stroke length and high forces in your gas spring.

Proper alignment is also crucial for preventing side loads that can damage a gas spring's seal and piston rod. Consider end fittings with a swivel eyelet or angle ball joint, as these help mitigate minor sideloads. An application engineer can recommend the best mounting strategy and end fittings to alleviate side-load risks.

Finally, gas springs should be installed with the piston rod downwards. As a gas spring nears full extension and the piston rod reaches the bottom, it travels through a small oil chamber which provides end damping to soften the motion. The chamber helps keep the seal lubricated to extend the life of the gas spring, and it allows for alternative mounting configurations.

Sometimes, it's necessary to modify gas springs to get smooth, even motion throughout the stroke. Often, changing to a different-size piston rod will increase or decrease the force resistance. For instance, adding a larger piston rod to a cylinder with a smaller body increases the progression value (the force difference between two different rod positions). Conversely, using a slightly smaller rod than offered in the standard size may lower it.

To change the extension speed, manufacturers fine-tune the orifice and piston head.

If the required stroke length is in between those provided by an off-the-shelf spring,

the rod can be cut to the right length.

For gas springs that must operate in extreme temperatures, get the spring vendor to make springs from grades of steel that withstand harsh temperatures.



Gas springs prevent injuries during maintenance on harvesting machines such as this reaper. The blades of corn picking devices are arranged under plastic hoods. For maintenance, the 15-lb hoods must be lifted. To protect maintenance personnel from injury and keep hoods from falling, the hood is kept

in the open position by GS-22 industrial gas springs. As an added advantage, gas springs offer added stability under rough operating conditions due to a wear-resistant coating on the piston rod and housing.

Protecting Gas Springs

Some gas springs operate in demanding applications and environments, so consider the following accessories to make the springs last:

To keep them clean, use rod wipers attached to the rod to keep it clean, as well as protect it from debris and caustic fluids.

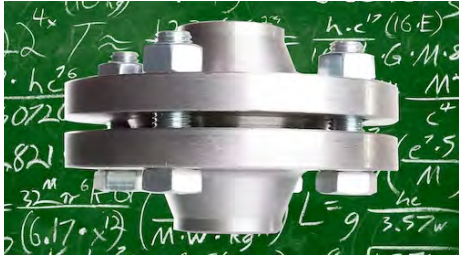
When safety is a concern, locking tubes will prevent your lids, gates, and covers from closing accidentally. These devices lock in the spring's extended position and eliminate the need for a support rod.

To make mounting easy and versatile, choose gas springs with interchangeable end fittings made of steel.

Selecting and installing off-the-shelf gas springs is often an inexact and time-consuming process. Although they may be a quick and inexpensive purchase, a lot can go wrong during sizing and, ultimately, implementation. That's why it often pays to buy gas springs from manufacturers with a multifaceted, engineered approach that include online selections and implementation resources, along with application engineers who will work through the data requirements and provide the tools, adjustments, and accessories to match it perfectly. An engineered approach means you'll only need to drill four holes, place the order, and install the springs. You'll also have the right calculations for future re-orders, so you'll always save time, effort, and money.

Dave Rowland is a product engineer at ACE Controls. If you have any questions about industrial gas springs, contact Ace at (248) 476-0213 or [online](#).

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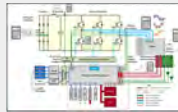
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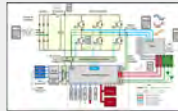
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MECHANICAL & MOTION SYSTEMS

Tactile Switches Simplify and Improve the User Interface Experience

May 3, 2023

New switch designs provide OEMs and designers with an optimum balance of size, capability and durability for many types of equipment and electronics operator interfaces.

[Chris Do Vale](#)

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Touchscreens and flat panel touch systems abound through consumer, commercial, industrial, medical and other markets. They are used in mobile devices, automotive interiors and many other types of appliances and equipment. Certainly, touchscreens are a useful way to present information and enable a variety of input.

However, there are cases where a more “physical” approach is desired or required. In many situations, electromechanical buttons are a preferred operator interface solution because they provide a clearly understood interface for essential functions. They also provide positive motion and tactile feedback, ensuring users experience a satisfactory interaction with equipment.

Among a wide array of options, tactile (tact) switches designed for printed circuit board (PCB) mounting provide an excellent balance among size, modularity and versatility. They are sealed and designed for long operating lifetimes under a variety of environmental conditions, making them the best choice for many commercial and industrial applications.

Choices for the Look and Feel

Tact switches, sometimes called board-mounted pushbuttons, are a leading category of operator interface for many types of digital systems. Depending on the application, a main or secondary circuit board is often mounted just below an operator control panel area. Instead of installing more standalone buttons and switches, and then

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wiring them to a remote board, it can be more efficient to design and support a circuit board in an orientation that can directly accept board-mounted pushbuttons. Tact switches can be equally or more robust than the surfaces onto which they are mounted.

The form factor of tact switches is very low profile (Fig. 1). In addition, while more traditional buttons are typically round or square, tact switches are available in those shapes—but also in many other styles—such as oval, arrow-shaped, rectangle and more. The shape of the button can actually convey some information regarding the function, making this an important feature.

[READ MORE: Understanding the Increased Demand for Industrial Switches in Food and Beverage Plants](#)



1. APEM MEC low profile tactile switches are available in many shapes, colors and arrangements, with a variety of marking, icon and illumination options. They can be basic buttons or more capable rockers and navigational arrangements.

Key caps for tact switches come in a wide range of colors and textures and they are available with legends and industry-standard icon markings, so designers can create easy-to-recognize layouts for users. Some are even available with glow-in-the-dark features.

Designers can choose from an extensive list of standard styles, or they can even work with a supplier to create custom types and different materials to provide a personal touch. For example, the buttons can be made to look like wood, leather, carbon fiber or other materials so that they blend or contrast with the mounting surface.

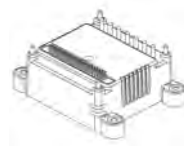
Caps should be thermoplastic or polycarbonate to best withstand high temperatures and extreme operating forces. In some cases, designers may choose to use an overall foil overlay, or a flexible over-molded surface skin, arranged over one or more tact switches without caps. This is a good solution providing even more protection, along

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with a smoother overall feel and appearance. And, even if the surface fails, the underlying switches can continue to operate.

One specialized arrangement useful for many applications is a “navigational” configuration, consisting of four up/down/left/right arrows and a central “OK” or “enter” button. This style can be contained in one overall device, or it can be created from five individual devices.

Tactile Switch Basics

A basic tact switch body is around 13/13/16 mm in height/width/depth, but some versions can be as small as 8/8/4 (Fig. 2). The switch has a plunger or pad on top to accept and interface with the cap, which activates an internal metallic dome mechanism arranged with electrical contacts. Plunger mechanical operation is usually momentary, but some are available as latch/unlatch type.

[READ MORE: The Right Lubricant Brings Out the Best in Electrical Switches](#)



2. Tactile switches are extremely compact and resistant to physical damage, dirt and liquids. They are soldered directly onto circuit boards and are designed for millions of operations.

Actuation will have a specified force value, and sometimes different forces are available for a given type of device. These devices are available as IP67 for protection against dust and temporary liquid immersion, making them ideal for marine applications and anywhere that liquids might be present.

Specifiers should look for robust switches designed for a lifetime numbered in the millions of actuations. Depending on the size and model, cycle lifetimes can be 1, 3, 10 or more million. In fact, some switches are built such that an adult can stand on them, with the switch still functioning normally afterwards.

One or two contacts (1-pole and 2-pole) are common for tact switches, in various combinations of normally-open (NO) and normally-closed (NC). These contacts should be designed to resist “bounce,” as this condition could otherwise introduce erroneous operation of digital control systems. For applications with safety concerns, users should look for switches that can offer combined simultaneous NC/NO operation, where the digital controller can monitor alternate contacts to ensure proper switch function.

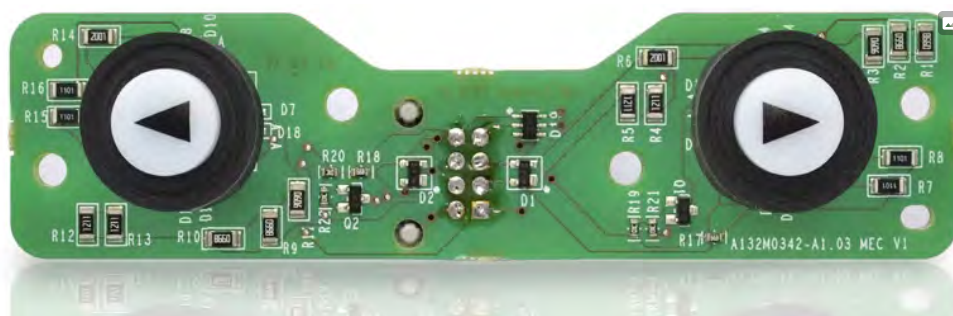
Electrical connections on the back/bottom of the switch can be through-hole (TH) pins, designed to be inserted through a PCB and soldered into place for a solid mechanical and electrical connection. For the most compact needs, some tact switches are available as surface-mount devices (SMD) so they can be soldered right onto the top of a PCB.

Non-illuminated tact switches are suitable for many applications and integrated chip-LED versions are available to backlight the cap and markings when this functionality is needed.

Quality and Elegance

OEMs and electronics manufacturers looking for best performance and reliability, with a dash of elegance, should consider choosing high-quality tact switches from proven suppliers for their designs (Fig. 3).

[READ MORE: Large Array of Fast Photonic Switches Will Serve as “Traffic Cop” for Fiber-Based Data Centers](#)



3. A proven tact switch supplier, like APEM's MEC switches, offers an extensive portfolio of high-quality standard components, backed by 100% testing, with the ability to provide custom devices and assemblies.

Some of the most suitable industries and applications include:

- Consumer goods. Push-to-talk radio buttons, control panels for consumer electronics and handheld remote controls are a good fit for tact switches. Illuminated versions confirm the operating status.
- Commercial/industrial devices. The barcode scanner gun at every store is just one example of electronics requiring user inputs, such as a trigger button to

be used—and abused—countless times each day. Boats, buses and many other vehicles need user input for auxiliary functions. Tact switches are low cost but feature high durability, making them a good fit for these types of applications.

- Off-highway equipment. Agricultural, construction site and many other types of equipment use control panels and joysticks, each of which often need numerous operator interface functions. Tact switches are easily arrayed on control panels, and can even fit on joystick surfaces to provide a tactile operator interface that can be arranged logically for users.
- Food, beverage, medical. Cookers, liquid dispensers and controls for medical devices are all subject to high temperatures, process liquids and cleaning fluids. Tact switches, especially when configured under a graphic overlay, provide the required user information and can resist conditions ranging from hot oil to cleaning solutions.

Designers should work with a tact switch supplier demonstrating longstanding experience in the field, with an expansive portfolio to meet most any need. When standard components just won't work, the supplier should have the ability to respond to custom requirements for tact switches and the ability to build complete configurations on PCBs to provide a full panel solution.

Suppliers should manufacture devices and components in-house for best quality control, with rigorous testing programs and 100% in-line testing during production. The right tact switch partner will help any OEM or manufacturer create the high-performance and cost-effective solutions they need for their applications.

Chris Do Vale is the senior component product manager for [APEM, Inc.](#)

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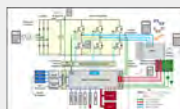
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EXHIBIT 8



Understanding Your Gas Lift Cylinder: How It Works (And How To Replace It)

By Ben Walsh / Knowledge Center / Updated August 2, 2022

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If you've assembled an office chair, you've no doubt seen one of these cylinders. The bottom goes into the wheelbase, the top inserts beneath the seat, and then you can magically raise or lower the seat to a comfortable height with just the flick of a lever, handle or paddle.

Most modern ergonomic office chairs come with these pneumatic cylinders. The “gas” is actually compressed air. And most of the time, they work flawlessly. Especially if you bought your chair from a reputable company.

But if you want to know more about how your height adjustable chair actually works, or **what to do if your gas cylinder fails and needs to be replaced**, you may find this guide helpful.

Office Chair Cylinder Replacement

Need an office chair gas cylinder replacement? Office Owl has you covered! Their cylinder comes with everything you need for a successful replacement of the old cylinder, including the tools you need to remove

and replace the old cylinder. Their easy-to-understand instructions will guide you through the process and you'll have the "new chair feeling" in no time.

[View on Amazon](#)

Our Rating: 5/5



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What is a gas cylinder?

A gas cylinder, also called a pneumatic cylinder or gas lift, is the unit that allows you to raise or lower your office chair with the use of a lever below the side of the seat.

Unlike older chair models that used a threaded spindle lift, where you had to turn the chair counter-clockwise to raise and

clockwise to lower the chair, a gas lift chair uses a chamber with compressed air to change the height of a chair.

Also called a spring, this chamber mechanism makes it quick and easy to adjust the chair relative to your desk height, so easily find a comfortable and ergonomic sitting position.

How does a pneumatic cylinder work?

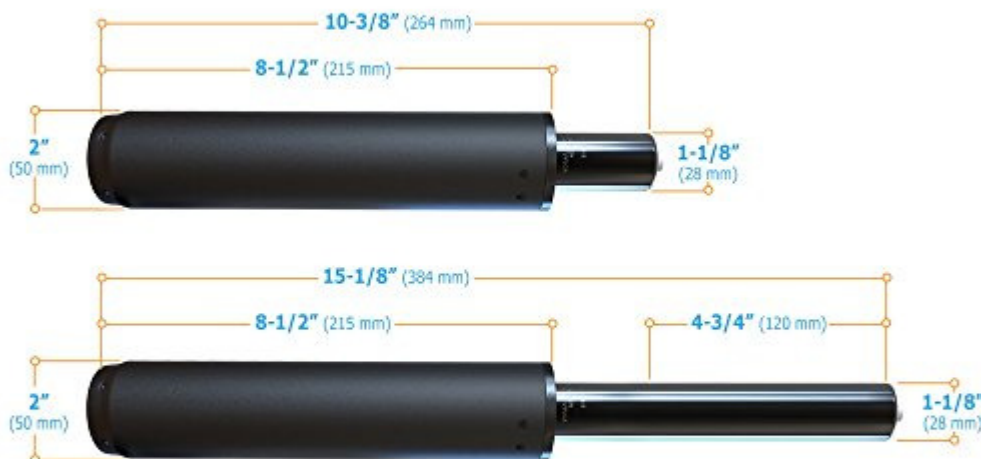
As mentioned, a gas cylinder relies on compressed air to raise and lower your seat.

When the lever on your chair is engaged, it activates the cylinder. If you engage the lever and while releasing your weight from the

seat, the air in the cylinder compresses and pushes the piston out of the air chamber, thereby raising your seat.

With the piston pushed out, the air in the chamber is expanded, allowing the seat to be lowered when you activate the lever and push down with your weight on the seat.

Parts of a Gas Cylinder



Standard pneumatic chair cylinders are composed of the following parts:

The Stand Pipe (aka outer column): This is a 2" diameter main

column that connects to the chairs' five-star base. The bottom of the column is tapered. This is the end you insert into the wheelbase when assembling an office chair. The length of the column and tapered section may vary from model to model, but the 2" diameter for the main column is standard with most cylinders.

Piston (aka inner column): The 1.1 inch diameter piston that connects to the seat base and raises or lowers to adjust the chair height. The end of this unit is also tapered to fit into the hole in the seat base unit (also known as the swivel unit). The top of the piston on a new cylinder has a plastic cover. You will remove that when installing to expose the button at the top (aka the actuator).

Actuator: The button at the top of the piston that gets pushed and activates the cylinder to raise or lower the chair.

Dust Cover: The telescoping plastic dust protector placed over the main column.

Retainer Clip: The little clip at the bottom of the piston column that keeps it from sliding out of the main column.

Retainer clip at bottom of the cylinder.

Replacing a gas cylinder

If you're reading an article about gas cylinders, there's a good chance you're here because you actually need to replace one.

Luckily, whether your chair came with a faulty cylinder, you need more "travel" and height, or your faithful pneumatic chair is no longer "pneumatic" after all these years, it's actually pretty simple to replace a gas cylinder.

The first step is to figure out what size you need.

Gas Cylinder Sizes

As mentioned above, most cylinders come with standard diameter measurements for the stand pipe and piston.

So, before you start looking at new cylinders, first confirm that

your current cylinder has the standard 2" diameter at the base of the main column. See the image above for an illustration of this measurement.

****Do not include the plastic cover in this measurement.**

Also check to see that you have a standard 1.1" diameter piston.

Once you've confirmed that you'll be able to use a standard diameter cylinder replacement, you'll then need to figure out how much "travel" you want.

What's your stroke (aka travel)?

If you've read many chair spec sheets (doesn't everyone spend their time reading chair spec sheets?) you might've seen the terms "stroke" and/or "travel" in reference to the chair cylinder.

This simply means that the cylinder will raise or lower the chair within a certain number of inches. For example, a 4 stroke chair cylinder is quite common, meaning the chair can be raised or lowered within a range of 4 inches.

The easiest way to determine the stroke of your current chair/cylinder is to do a quick measurement:

- Raise your chair up to it's highest point. Now measure the height from the floor to the seat.
- Lower your chair down to the lowest and take the same

measurement.

- The difference between the highest and lowest point is your travel or stroke.

As mentioned, you'll find that 4" is a pretty common travel for chairs, but this number can range from as low as 3" all the way up to 10".

What travel range is best for you will depend on your height, the height of the chair, and the height of your desk(s). For example, if you need more chair height for a taller desk setup, you can find a replacement cylinder with a longer piston and therefore more travel than your current cylinder offers.

Weight Capacity

Another important consideration when it comes to gas cylinders is the weight capacity.

Most chairs come with a stated maximum load capacity. For example, many [big and tall office chairs](#) can hold over 400 lbs, while standard ergonomic task chairs might be closer to 250 lbs.

If weight capacity of the chair frame is important, make sure your replacement cylinder is also up to the task.

For example, standard cylinders can adjust with a capacity up to 250 lbs. But "heavy duty" class 4 pneumatic devices can handle over 450 lbs (this would be necessary on a chair that qualifies for

ANSI/BIFMA large occupant standards).

Bottom line: Make sure you get the right class cylinder that's consistent with your chair's weight capacity limits.

Final note: Also be sure to check if the cylinder is **rotating** or **non-rotating** to match the needs of your chair.

Removing the Old Cylinder

Now comes the fun part. Just kidding, this can actually be kind of a pain. But if you want to revive your trusty old office chair with a fresh new cylinder, you'll need to take that old one out first.

You can try this method (explained in the video) or keep reading for simple basic steps that we've used in the past:

The New Way to Remove and Replace an Office Chair Cylinder (Without a Pipe Wrench)



Remove the tapered end from the wheelbase.

First, tip your chair over so you can access the wheelbase. Then, with a hammer or rubber mallet, start tapping around the edge of the tapered bottom of the cylinder.

Try not to hit dead center where the retainer clip is. Keep tapping around the edges to loosen the unit so you can pull the column from the base.

If you can't get it free, some people suggest using a flat head screwdriver to remove the retainer clip from the bottom.

This will release the piston from the cylinder. Now you'll just have a wheelbase with the empty cylinder column stuck in it.

In this case, you should be able to turn the wheelbase upside down and hammer the tapered end of the column through until it's free.

Remove the piston from the seat base.

Next, you'll have to remove the piston head from the seat base. To do this, tap around the edge of the top of the piston with a rubber mallet to loosen it. You can use WD 40 to make this easier.

Once it's a little loose, you should be able to wiggle it free from the seat base.

Find a Replacement

The final step is to go online, find a replacement cylinder, and

insert it back into your wheelbase and seat. Again, if you've confirmed that your cylinder is a standard diameter, this part should be pretty easy.

You can even find a bunch of standard [replacement gas chair cylinders on Amazon](#).

But if you have any questions or need a specific size cylinder or more obscure unit for your chair, we recommend dealing with a chair parts specialist.

Here are some good places to look online:

- [Chair Parts Online](#)
- [E-Chair Parts](#)
- [Office Replacement Parts Co.](#)

Hopefully, this primer on gas cylinders will help you appreciate this all-important component of your height-adjustable office or gaming chair.

And if you need a new one, you'll know just what to do.

About The Author

Ben Walsh

Ben loves discovering how new developments in office furniture design, technology and ergonomics can help us create better workspaces at home or in the office. He is one of the original editors of Office Chair Picks.

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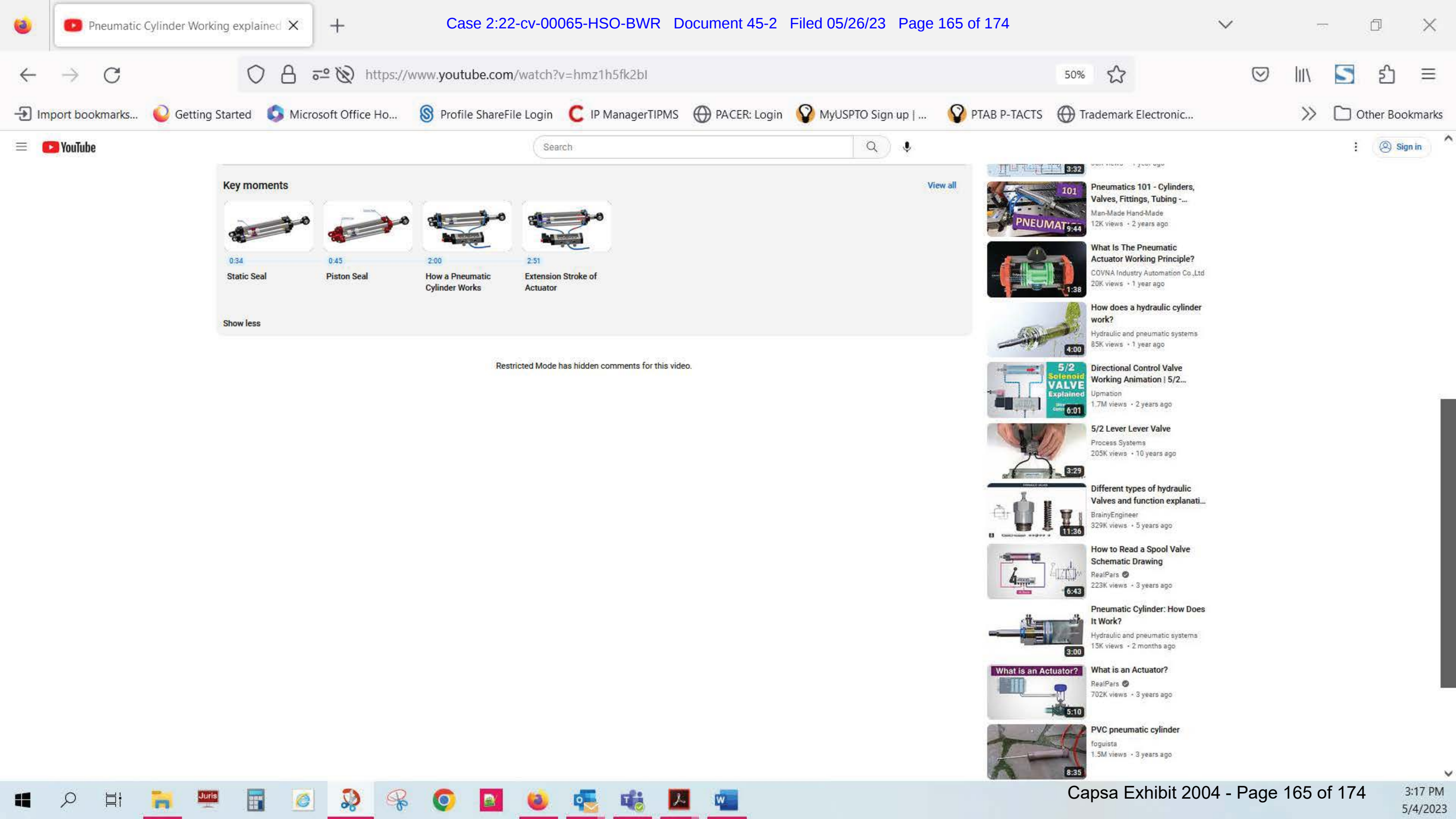


EXHIBIT 10

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Gas springs

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by [Chris Woodford](#). Last updated:
March 19, 2022.

Have you ever tried lifting the trunk lid (sometimes called tailgate, hatch, or boot) of your car with

just one finger? How come you can lift a heavy piece of metal and glass with so little force? The answer, if you didn't know already, lies in those clever piston-like hinges that support the lid either side. They're called **gas springs** (or gas dampers) and they make our lives a whole lot easier in all sorts of ways.

If you're sitting on an office chair right now, there's probably a gas spring underneath your body. Release the height lever and you'll feel (and probably hear) the gas in the spring being compressed as the seat gently falls down. Gas springs have loads of other uses too. Let's take a closer look at these handy gadgets and find out how they work!

Photo: A sturdy gas spring (the thin black cylinder and the silver rod that slides in and out) supports the tailgate of this car during loading and unloading. It looks a bit like a bicycle pump, but it works in a very different way.

Contents

1. [Why do we need gas springs?](#)
2. [How a gas spring works](#)
 - [How a gas spring generates a force](#)
 - [Gas springs as dampers](#)
 - [Gas springs as energy reservoirs](#)
 - [How a gas spring stores and releases energy](#)
3. [How does the gas stay inside?](#)
4. [Why use a gas spring?](#)
5. [Find out more](#)

Why do we need gas springs?

Suppose there were no springs on the hatchback of your car. It would be really heavy to lift, for one thing. Awkward too, given its length. There'd be nothing to hold it up in the air when you wanted to load in your shopping, which would be a real nuisance. You'd have to pin it open with a clumsy metal support, like you do with the hood (bonnet), which would probably be all dirty and oily. If you let the lid go, it would crash down onto your car's bodywork, probably doing a lot of damage in the process.

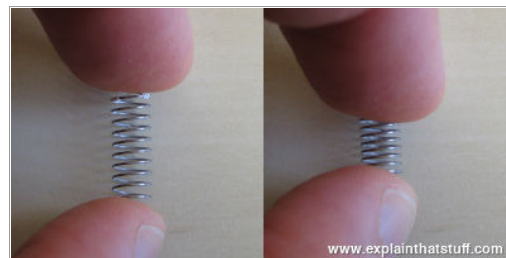


Photo: Ordinary springs tend to work better in one direction than another, so they're not the best option for holding a trunk lid in place or making it easier to move.

Saloon cars with small trunk lids often use normal metal [springs](#), but those are not a great solution for hatchbacks, liftbacks, and similar cars. A simple "tension" spring (one that you have to work to pull apart) would need to be very stiff and heavy, so it would take a huge amount of effort to lift the hatch high in the air. The higher you lifted it, the harder it would get to lift any further. With the lid opened up fully, the spring would be stretched out so much that it would pull straight back down again. You could use a "compression" spring instead (one you have to work to push together), but it's often better to use an entirely different kind of spring: one that doesn't rely on stretching or squeezing metal to absorb energy.

Photo: A vertically mounted gas spring supports the seat of this "gas-lift" office chair, making it easy to adjust the height. Gas springs generally work best in a vertical position like this. There's less chance of them buckling when fully extended and the oil inside lubricates



them more smoothly and evenly.

How a gas spring works

The basic idea

A gas spring is a bit like a super-sturdy version of a [bicycle pump](#), only it's filled with pressurized nitrogen [gas](#) (the major constituent of the air around us) and oil and completely sealed up so they can't escape. The gas allows the spring to store energy, while the oil damps (slows and smooths) the movement of the piston and also provides [lubrication](#). Just like in a bicycle pump, there's a tight-fitting piston mounted on a rod that can slide back and forth inside a cylinder (made from heavy gauge [steel](#), not light [plastic](#) as in a bicycle pump).



Push on a gas spring and you force the piston rod and piston into the cylinder and this compresses the gas. Stop pressing and let go and the pressure of the gas pushes the piston back out again. So far, that sounds just like a bicycle pump—but it's working in a different way. Unlike with a bicycle pump, gas inside the cylinder can actually flow through or around the piston from one side to the other as it moves back and forward. Exactly how this happens varies from one design of gas spring to another; usually the piston has one or more holes or valves in it. Now if the piston can move *through* the gas, you might think it isn't compressing the gas at all. But don't forget that the whole cylinder is completely sealed. When the piston rod is inside the cylinder, it's taking up room that the gas previously occupied. In other words, when a gas spring is fully pushed in, you've compressed the gas inside by an amount equal to the volume of the piston rod. If the piston rod occupies virtually the whole cylinder, you can see that the gas is getting compressed quite substantially. The gas pressure can be very high, typically up to about 170 times normal atmospheric pressure!

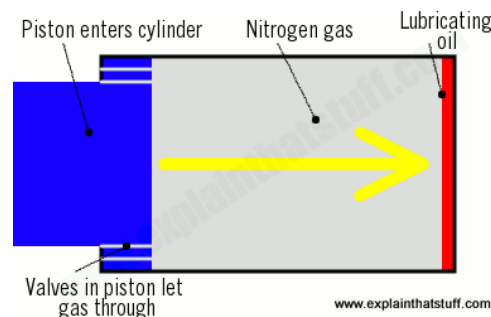


Photo: The gas inside a gas spring can flow through or around the piston from one side to the other, but it can't escape from the cylinder. The whole system is sealed so, as the piston enters, the gas is compressed by a volume equal to the space occupied by the piston rod.

How a gas spring generates a force

There's one particularly important difference between a bicycle pump and a gas spring—and that's the way in which force is generated when you push in the piston. Suppose you cover the end of a bicycle pump and push on the piston. You'll immediately find there's a force pressing outward against your hand, because the pressure of the gas on one side of the piston is higher than the pressure of the air on the other side. In other words, the force is produced by a *difference in pressure* on the two sides of the piston.

In a gas spring, things are different. Fluid can flow around or through the piston from one side to the other, so the pressure is the same on both sides. However, the pressure acts over a greater area on the inside surface of the piston than on the outside (because the piston rod takes up some room). That means there's more force on the inside face than on the outside—and that's how a gas spring produces a force when you push it in. In other words, the force is produced by a *difference in area*.

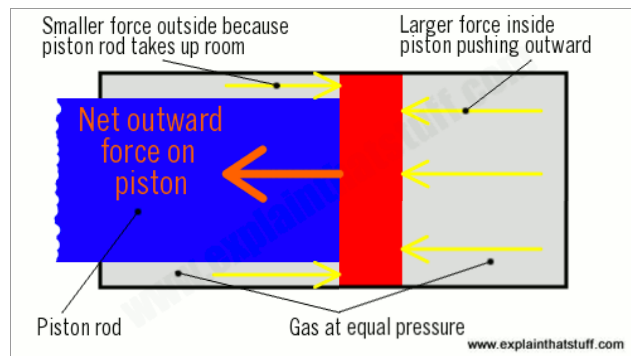


Photo: Where does the force come from? In a gas spring, fluid at equal pressure pushes against both sides of the piston. But the inside of the piston (on the right) has a bigger area than the outside (on the left, where the blue piston rod takes up room). This means there's more force pushing on the inside than on the outside—giving a net outward or "output" force.

The size of the force a gas spring produces (sometimes called its "output force") is equal to the area of the piston times the internal pressure. The output force is reduced by friction between the piston and the cylinder (which is one reason why lubrication is important) and increases with temperature (because, according to the basic [gas laws](#), higher temperatures increase the pressure of the gas inside the cylinder).

Much like metal springs, gas springs come in all different sizes. You can choose one with just the right size of cylinder and piston and the right amount of gas pressure to give precisely as much force in the spring as you need to do a particular job. To support the trunk lid of a car, you need the two gas springs either side to provide roughly as much force when they're compressed as the weight of the lid. For a gas-lift office chair, you need the spring to provide a little bit more force than the weight of the seat. In most chairs, the spring doesn't actually support the person's weight. Instead, it typically has a lever attached that grips and locks at a certain height, preventing the seat from moving up or down any further. The spring is simply designed to let the seat move up and down gently without your having to supply much force.

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Gas springs as dampers

One thing you'll notice about gas springs is that they work slowly and smoothly. The end of the piston is designed so the fluid inside the cylinder (gas and liquid) can flow through or around it very slowly. Different springs are designed in various different ways and some pistons are arranged so the fluid will flow more quickly past them when the spring moves in one direction than when it moves the opposite way. For example, when the piston is compressed into the cylinder, the end of the piston may be designed to close up a [valve](#) so fluid can flow through it only very slowly, reducing the speed at which the piston can move. When the piston moves the other way, the valve can be designed to open up so fluid will travel past it more quickly, allowing the piston to move much faster. Gas springs are usually designed with a particular size of load in mind so they expand very smoothly at a particular rate (so many centimeters or inches per second).



Photo: Gas springs aren't just used for holding car trunks open and supporting chair seats. This very large gas spring is part of a [dynamometer](#)—a device for testing the power of an engine. Photo by Warren Gretz courtesy of [US DOE/NREL \(Department of Energy/National Renewable Energy Laboratory\)](#). (image ID 6324202)

Gas springs as energy reservoirs

A gas spring's job is to make your life easy—and it does it by storing [energy](#) (when there's plenty available—usually when you're lowering something



heavy) and releasing that energy (when you need extra help—usually when you're lifting something up). Think of a gas spring as a kind of mechanical [battery](#) that stores and releases energy by squeezing and releasing a gas and you can see why it's so useful.

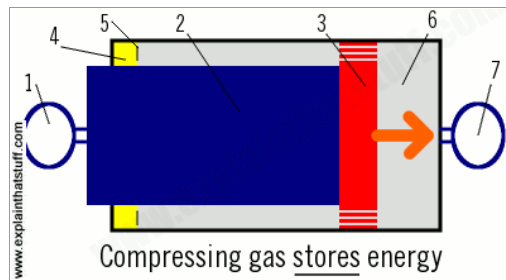
What's happening with energy when you lift a heavy trunk lid that has no springs of any kind? There's a lot of mass in the [steel](#) and [glass](#) lid so it takes a lot of energy to raise it up against the force of [gravity](#), which is constantly trying to pull it back down. Once the lid is high in the air, it has stored **potential energy**: you can release the lid and it'll crash straight back down again. If that happens, the potential energy is instantly converted into **kinetic energy**, as the lid accelerates, and then [heat](#) and [sound](#) energy when the lid smashes onto the car's body. What a waste!

With a couple of gas springs on either side of the lid, it works a different way. Now, when you gently lower the lid, the weight of the metal and glass forces the pistons into the gas springs, compressing the nitrogen gas inside. As you lower the lid, the potential energy it had when it was up in the air is slowly converted into potential energy inside the gas springs and stored there. Next time you want to raise the lid, that potential energy is waiting inside the springs ready to help you. Release the lid catch, lift the lid gently, and the potential energy stored in the gas springs is slowly released. The pistons push out from the gas springs and help you lift the lid back up again.

How a gas spring stores and releases energy

You *store* energy when you push a gas spring inward:

1. The spring is fixed to a mounting bracket that can move back and forth with the door, lid (or whatever else it's attached to).
2. When you apply a force, the bracket moves inward and pushes on the piston rod (blue), which moves into the cylinder (black).
3. The piston rod pushes the piston (red) through the gas (gray). The piston makes a tight seal as it slides along the cylinder, but gas (and oil) can flow through it from (in this case) the right side to the left (and back again).
4. The [lubricant oil](#) (yellow) greases the piston as it slides in and out.
5. Tight seals (usually [O-rings](#)) allow the piston rod to move freely but keep the lubricant oil and the gas safely inside the cylinder.
6. The nitrogen gas (gray) inside the cylinder is compressed as the piston moves in by an amount equal to the volume of the piston rod. **Note that the gas is compressed on *both* sides of the piston, to exactly the same pressure, as the piston moves in** (that's different to a bicycle pump where the gas is compressed only on one side).
7. The other mounting bracket stays in the same place throughout.

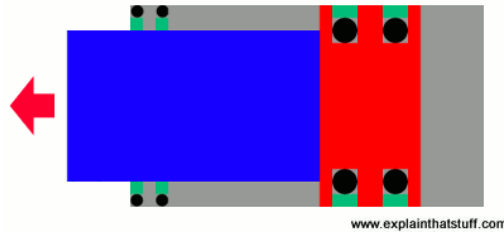


When you let the spring move outward, the pressurized nitrogen gas expands, the piston moves back the other way, and the stored energy is *released*.

How does the gas stay inside?

If you've ever blown up balloons to use as party decorations, you've probably been disappointed by how quickly they started to deflate. Trapping gas isn't easy. How, then, do gas springs manage to keep pressurized gas inside them—and carry on working for years or even decades? It's obviously all in the seal. Up above, I described the seals as simple O-rings, but a variety of different fluid seals can be used, sometimes individually, sometimes in

combination. Some gas springs use X-rings (similar to O-rings but with an X-shape cross-section, so giving a greater sealing surface area), some use Teflon™ (PTFE) glide rings, which sit snugly between the O-rings and the cylinder wall, some use T-seals (like O-rings with a protruding ridge), and there are various other sealing methods.



Artwork: One way of sealing gas springs. Here we're using traditional O-rings (black) with PTFE glide rings attached (green) to give an improved, long-lasting, low-friction seal.

Why use a gas spring?

A gas spring can do a similar job as an ordinary metal [spring](#), though it has a number of advantages. Because of the high pressure of the gas inside it, a gas spring can be much more compact than a metal spring that would provide the same amount of force. Gas springs expand and contract more smoothly than metal springs and can be designed to open and close at an exact and constant speed (unlike metal springs, which contract faster when they are extended further and can be very unpredictable). Mechanically, gas springs are simple and have few moving parts, so they are relatively cheap, extremely reliable, and often last many years without any maintenance at all. Metal springs are more likely to break through repeated stretching and releasing (loading and unloading) because of [fatigue](#).

Gas springs sound great, don't they? But that doesn't mean you'll find them everywhere. Some things that look very much like gas springs turn out to be a little bit different inside. Barber chairs, for example, are [hydraulic](#) (powered by a kind of fluid-filled piston). Why not a gas spring? The hydraulic mechanism is more precise and means the person cutting your hair can position the chair exactly where *they* want it without you having to do anything at all.



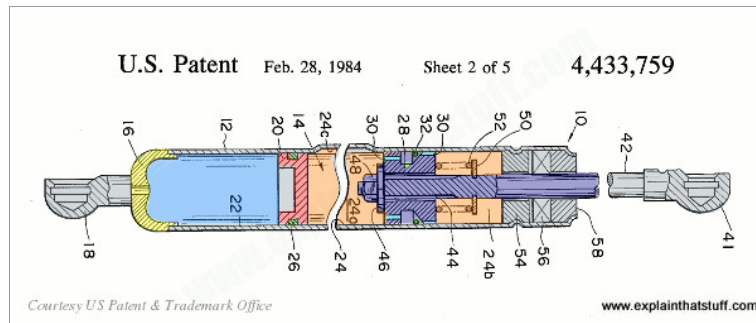
Photo: Barber chairs use hydraulic lift mechanisms (pumped up and down by a foot pedal). Photo by Justin Wolpert courtesy of US Navy and [Wikimedia Commons](#).

Doors often have elbow-like closing devices fitted onto their top edge that pull them shut automatically. At a glance, they look very much like gas springs but, inside, they use a combination of one or two hydraulic (oil-filled) pistons, a rack-and-pinion [gear](#), an ordinary coiled metal spring, and (sometimes) a [cam](#).



Photo: When is a gas spring not a gas spring? Automatic door closer arms like this look like gas springs but actually use a combination of liquid damping cylinders and traditional metal coil springs.

Some "gas springs" use a mixture of gas and liquid in their pistons; the one illustrated below is an example.



Artwork: Despite their name, some gas springs contain liquid as well as gas. This one has a chamber at one end, filled with compressed nitrogen gas (light blue, left), and a liquid chamber right next to it (orange, middle), through which a piston (blue) slides back and forth. The spring would normally be mounted with the left side down and the right side up, propping open the hatch on a car. Using a clever arrangement of O-rings and valves, it allows the piston to move easily to the right (upward) so the car's hatch lifts easily, but takes extra force to move to the left (downward); in other words, it props the hatch open until you push it down quite deliberately and forcefully. Using a liquid as well as a gas means the spring stays locked in its open position even in cold weather. The gas in a simple gas spring, without the added liquid (in other words, essentially just the light blue chamber on the left) would tend to compress significantly in cold weather and might be unable to keep the hatch open by itself. Artwork from [US Patent 4,433,759: Gas spring](#), by Hisao Ichinose, Nissan Motor Co. Ltd., 1984, courtesy of US Patent and Trademark Office.

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Books

- [Hydropneumatic Suspension Systems](#) by Wolfgang Bauer. Springer, 2014. A detailed engineering guide covering springs, shock absorbers, and gas springs.

Patents

- [US Patent 4,433,759: Gas spring](#) by Hisao Ichinose, Nissan Motor Co. Ltd., February 28, 1984. A typical telescopic gas spring used on an automobile's hatch door.
- [US Patent 4,309,026: Gas spring](#) by Hermann Reuschenbach and Willi Schafer, January 5, 1982. A typical suspension-type gas spring with an automatic built-in braking system.
- [US Patent 3,727,872: Column of an office chair](#) by Albert Spieth and Rudolf Spieth, April 17, 1973. An adjustable and lockable gas spring for office chairs.
- [US Patent 3,388,883: Hydropneumatic support column of adjustable length](#) by Felix Wossner and Ludwig Axthammer. Fichtel & Sachs Ag., June 18, 1968. A gas-liquid spring for supporting tables, chairs, and so on.

Technical

- [Standing Mobility Device With Passive Lower Limb Exoskeleton for Upright Locomotion](#) by Yosuke Eguchi et al, IEEE/ASME Transactions on Mechatronics (Volume: 23, Issue: 4, Aug. 2018). How gas springs and electric motors can be used together in a muscular exoskeleton for the disabled.
- [Application of gas spring for robot arm balancing](#) by Doo Hyeong Kim et al, IEEE 14th International Conference on Control, Automation and Systems (ICCAS 2014). Using gas springs to reduce the motor power needed by an industrial robot.

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