

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

Exotec Product France SAS,
Exotec North America Inc., and
Exotec Product USA Inc.,
Petitioners

v.

Opex Corporation,
Patent Owner

Case IPR2024-00850

U.S. Patent No. 11,472,632

DECLARATION OF WILLIAM E. SINGHOSE, PH.D.
ON BEHALF OF PATENT OWNER

TABLE OF CONTENTS

I. INTRODUCTION	4
A. Scope of Engagement	4
B. Compensation Professional Qualifications and Experience	4
C. Materials Considered	14
D. Compensation.....	15
II. RELEVANT LAW	16
A. Claim Construction	16
B. Obviousness	17
C. Ordinary Skill in the Art	19
III. SUMMARY OF OPINIONS	19
IV. OVERVIEW OF THE '632 PATENT.....	20
A. Summary	20
B. Prosecution History of the '632 Patent.....	25
V. OVERVIEW OF THE PRIOR ART	26
A. U.S. Patent Appl. Publ. No 2017/0158430 to Raizer (EX1005)	26
1. Raizer's Robots.....	28
2. Raizer's Navigation Control System	32
B. CN Patent Publication No. CN 109987366A to Hangzhou ("Hangzhou" [EX1006, HANGZHOU]).....	34
VI. Level of Ordinary Skill in the Art.....	42
VII. Claim Construction	42

VIII. Specific Grounds for Challenge.....	43
A. Petitioners Fail To Provide Sufficient Details For A POSITA To Implement The Proposed Combined System	43
B. Petitioners Declare A Motivation To Combine, Ignoring Explicit Teaching Away In The Specifications Of Hangzhou and Raizer.....	50
C. Petitioner’s Modified System Is Incompatible With Raizer As It Contradicts Raizer’s Goals and Principle Of Operation.....	52
1. Petitioner’s Proposed Modification Would Require Unacceptable Capital Equipment Investment, Reorganization, and Downtime And Thus Contradicts Raizer’s Goals	53
2. Petitioners Proposed Modified System Frustrates Raizer’s Principle Of Operation And Introduces Additional Issues, While Ignoring The Inventive Solutions Proposed By Raizer	57
D. A POSITA Would Not Have A Reasonable Likelihood Of Success Creating Petitioner’s Proposed Combination And Petitioner Fails To Address This Shortcoming.....	69
1. Petitioner Fails To Address A Reasonable Expectation Of Success In Their Petition.....	70
2. Petitioner Fails To Describe Their Proposed Combination With Sufficient Specificity As To Determine The Expectation Of Success	72
3. Petitioner’s Proposed Combination, Even If Described Sufficiently To Be Created, Would Not Have Operated Successfully	73
E. Dr. Spenko Misunderstands The Technology At Issue	80
IX. Conclusion	84
X. Availability for Cross-Examination.....	84
XI. Right to Supplement	84
XII. Jurat.....	84

I, William E. Singhose, declare as follows:

I. INTRODUCTION

A. Scope of Engagement

1. I have been retained as an expert witness on behalf of Patent Owner OPEX Corporation to provide expert opinions on the validity of U.S. Patent No. 11,472,632 (“the ’632 patent”).

2. The opinions, and the bases of those opinions, to which I will testify, if asked, are set forth in this Declaration. My opinions in this Declaration are based upon the information that I have received to date. They may be supplemented or modified if additional information is received. They may also be supplemented to rely on additional information or opinions provided by the parties (or witnesses retained by the parties) and issues that may arise.

B. Compensation Professional Qualifications and Experience

3. My qualifications as an expert are detailed in my *curriculum vitae*, attached hereto as Appendix A. A summary of my testimony in other cases over the past 5 years is attached hereto as Appendix B.

4. I am a Professor at The George W. Woodruff School of Mechanical Engineering at the Georgia Institute of Technology in Atlanta, Georgia (“Georgia Tech”). I attended the Massachusetts Institute of Technology (“MIT”) from 1987-1990, where I earned a B.S. in Mechanical Engineering. Then, I earned an M.S. in

Mechanical Engineering at Stanford University in 1992. I received a Ph.D. in Mechanical Engineering from MIT in 1997. From 1997-1998, I was a postdoctoral scholar at MIT.

5. As a professor at Georgia Tech, I develop curricula and teach courses in mechanical design, dynamics, and controls. For example, I teach students how to use sensors, design control systems, and rigorously test their developments using robotic systems. I also develop proposals and direct research programs. I supervise research of graduate students, undergraduate students, and postdoctoral researchers in the areas of robotics, dynamics, vibration suppression, spacecraft control, crane control, and active seating technology. I also serve on the Ph.D. qualifier exam committee for the Robotics program at Georgia Tech. During my tenure at Georgia Tech, I have also held visiting appointments at MIT, Stanford, the Tokyo Institute of Technology, and the Polytechnic University of Madrid.

6. At various times during my career, I have also worked as a full-time mechanical engineer for several companies, including Walt Disney World, Convolve, Apple, and Google.

7. For Walt Disney World, I designed and developed several structures and components for the parks' rides, including operational control procedures for the Body Wars ride and sensor placements for the Space Mountain control system. Space Mountain is a unique roller coaster that has numerous (approximately 16)

small vehicles moving through the building at any given time. The positions of the individual vehicles are monitored by numerous sensors, and they are kept separated by safe distances using a series of brakes and gating functions. The Body Wars ride was a large dynamic simulator room that moved up to 40 occupants through a series of complex motions in coordination with a video that played on the front wall of the room. The underlying structure was a large parallel-platform hydraulic manipulator.

8. For Convolve, I analyzed the dynamics of automated robots, satellites, and NASA high-altitude balloons. I also developed control systems for automation machinery and laser interferometer sensors.

9. For Apple, I designed and developed computer monitors with built-in speakers and microphones.

10. While working for Google, I designed several consumer electronic products and a shopping assistant that scanned clothing barcodes using a smartphone app to suggest the most appropriate size article for the shopper.

11. My work in material handling dates to at least 1995, during my doctoral work on crane dynamics and control. A portion of this research was directed at improving the safety and accuracy of material handling in nuclear environments by implementing semi-automatic control systems that aided human operators. I have continued to work in material handling on projects that have

involved a wide array of mechanical structures that use a variety of sensors and controllers to automatically analyze, sort, and move materials ranging from lightweight and flexible banknotes to multi-ton metal ingots.

12. For example, one of my technological developments combined an overhead image sensor and a laser range sensor with a command-shaping controller to greatly improve the speed and safety of crane operations.¹ This technology was installed on a 30-ton industrial bridge crane located at an aluminum sheet manufacturer, as well as many other locations. I have also developed crane controllers that utilized RFID sensing systems to help safely move crane payloads through cluttered work environments.² The RFID sensors were

¹K. Sorensen, W. Singhose, and S. Dickerson, “A Controller Enabling Precise Positioning and Sway Reduction in Bridge and Gantry Cranes,” *IFAC Control Engineering Practice*, vol. 15, No. 7, pp. 825-837, 2007; K. L. Sorensen, W. Singhose, and S. Dickerson, “Combined feedback and command shaping controller for multistate control with application to improving positioning and reducing cable sway in cranes,” June 28, 2011.

²K. C. C. Peng, W. Singhose, and D. Frakes, “Hand-Motion Crane Control Using Radio Frequency Real-Time Location Systems,” *IEEE/ASME Trans. on Mechatronics*, vol. 17, no. 3, pp. 364-471, 2012.

able to provide precise three-dimensional position information (typically 10-20 cm errors over a large crane workspace) when they were used in open space.

However, the position measurements were significantly degraded by the presence of obstacles because the sensing system suffered from path obstructions and multipath reflection effects that degraded the sensor's ability to measure position accurately. The figure below on the left shows the 3-D measurement error of the sensing system when used in an open space. The figure below on the right shows the 3-D measurement error of the sensing system when there was an obstacle placed in the workspace.³

³ S. Ragunathan, W. Singhose, K. C. C. Peng, L. Stokes, and D. Frakes, "Kalman Filtering for Improving Radio-Frequency Hand Motion Crane Control," in *ASME Dynamic Systems and Control Conference*, Ft. Lauderdale, FL, 2012.

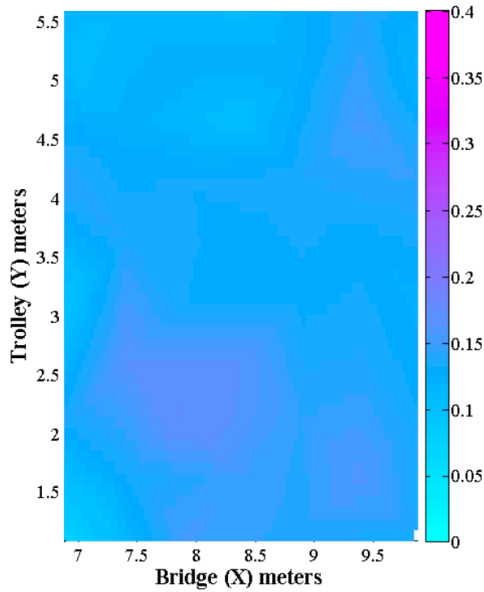


Figure 3. 3-D ERROR (METERS), TAG HEIGHT = 1 METER, NO OBSTACLE

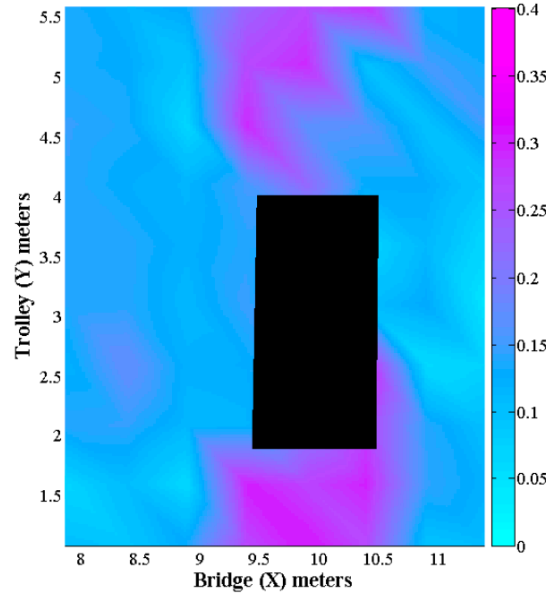


Figure 7. 3-D ERROR (METERS), TAG HEIGHT = 1 METER, WITH OBSTACLE

Measurement Degradation Resulting From an Obstacle (Obstacle Shown as Black Rectangle).

13. In addition to using the cameras, lasers, and RFID sensors described above to measure positions of automated machines, I have also conducted research on how best to use smart-phone-based radar sensors to measure position and motion.⁴ That work demonstrated that applying machine learning to radar data sensed on a portable scale could improve spatial localization.

⁴ W. Song, W. Singhose, D. Frakes, "Soli Radar Image-Based Target Localization," in *IEEE Int. Conf. on Image Processing*, Bordeaux, France, 2022

14. I also have experience designing autonomous vehicles with manipulator arms. The figure below shows a humanitarian demining robot that I worked on while I had a visiting appointment at the Tokyo Institute of Technology. The robot used stereo cameras to generate a map of its surroundings to help plan the motion of its long-reach scanning manipulator arm.⁵



Fig. 1 Photograph of Gryphon in a test humanitarian demining field.

⁵ M. Freese, S. P. N. Singh, W. Singhose, E. F. Fukushima, and S. Hirose, "Terrain Modeling and Following Using a Compliant Manipulator for Humanitarian Demining Applications," Springer Tracts in Advanced Robotics. Berlin, Heidelberg: Springer Berlin Heidelberg, 2010, pp. 3-12.

15. I have also designed, constructed, and evaluated a number of small autonomous robotic vehicles. For example, starting in 2003 I began serving as the faculty advisor for Georgia Tech's CanSat team. This group designs, constructs, and launches small robots up to 12,000 ft. over the Black Rock Desert in Nevada. Once the robots are ejected from the rocket at 12,000 ft., they attempt to travel autonomously to a target site on the ground. Over the years, I have supervised (and personally constructed) numerous such robots that have taken the form of gliders, quadrotors, hopping rotochutes, as well as wheeled rovers.

16. In addition to the gliders and rotocraft created by the CanSat team, I have also directed research on other types of autonomous flying robots, such as scale-model helicopters and quadrotors. For example, I conducted research directed at controlling rotorcraft sling load operations which was sponsored by the National Rotorcraft Technology Center. That project involved determining the effects of suspended loads on the control of rotorcraft and developing techniques to reduce the swinging of the load to improve the control response of such systems. The results of my research were presented in several papers. My paper "Dynamic Modeling and Simulation of a Remote-Controlled Helicopter with a Suspended Load" studied the dynamic effects of loads suspended below the helicopter by cables and created a dynamic model of the loaded system. The paper documented

the difficulty of maintaining a steady hover position after a horizontal movement of the helicopter, while carrying a suspended load.

17. I have also tested the physical designs, sensors, and navigation algorithms for robotic vacuum cleaners. Certain robotic vacuum cleaners attempt to map their workspaces, while simultaneously detecting obstacles and carpets. Then, the robots mop the workspace, while avoiding the carpeted regions. During the course of this work, I conducted numerous tests on the robots' sensing and navigation systems, as well as physically dissected several robots to evaluate their mechanical structures.

18. Furthermore, technology that I have developed has been installed on several elevators at automobile manufacturing plants. I have also served as a consultant for a major elevator manufacturer. Finally, I have published a paper on the control of elevators.⁶

19. I am a co-founder and the chief technology officer of InVekTek, Inc., where I develop and commercialize control systems for robotic and industrial material-handling systems. I was also a co-founder and board member of

⁶ J. Fortgang, W. Singhose, and V. Patrangenaru, "Scheduling of Input Shaping and Transient Vibration Absorbers for High-Rise Elevators," in American Control Conference, Minneapolis, MN, 2006.

CAMotion Cranes, Inc., where I developed and commercialized crane-control technology. The controllers I developed improved crane safety, throughput, and ease of operation by altering the manner in which the crane operator issues commands to the crane. Some of the crane control systems converted manually-operated cranes into robotic cranes that operated autonomously to both avoid obstacles and accurately position the machines. PaR Systems purchased CAMotion Cranes in November 2013.

20. In addition to commercializing material-handling technology developed at my laboratory at Georgia Tech, I have served as a consultant on several projects involving manual material handling (material carts, forklifts, aerial lifts, cranes), automated material handling (ATMs, stacking machines, machine tools), as well as automated manufacturing. For these projects, I have analyzed patent validity, conducted product evaluation testing, and performed infringement analyses.

21. In terms of my relevant previous work in intellectual property law, I worked as an expert on *ITC-1293: Certain Automated Put Walls and Automated Storage and Retrieval Systems, Associated Vehicles, Associated Control Software, and Component Parts Thereof* and also *ITC-1333: Certain Automated Put Walls and Automated Storage and Retrieval Systems, Associated Vehicles, Associated Control Software, and Component Parts Thereof (II)*. Like the matter here, both of

those cases involved automated storage and retrieval systems. In the course of my work for those ITC cases, I submitted a written report, was deposed, and testified at the hearing for ITC-1293.

22. Finally, I am a named inventor on the following issued patents in the areas of mechanical engineering, robotics, and controls: U.S. Patent No. 5,638,267; 6,920,378; 7,970,521; 8,235,229; 8,975,853; and 9,776,838.

C. Materials Considered

23. I have reviewed the documents and exhibits cited herein in preparing this declaration, including the following:

- Petition for Inter Partes Review of U.S. Patent No. 11,472,632;
- U.S. Patent No. 11,472,632 (EX1001, '632 PATENT);
- Expert Declaration of Dr. Stephen Derby (EX1003);
- File History of U.S. Patent No. 11,472,632 (EX1004);
- U.S. Patent Appl. Publ. No 2017/0158430 to Raizer ("Raizer" (EX1005));
- English Translation of CN Patent Publication No. CN 109987366A To Hangzhou ("Hangzhou" (EX 1006));
- Matthew Spenko, Ph.D. *Curriculum Vitae* (EX2003);

- Nagai et al, “Fault-Free Integrity of Urban Driverless Vehicle Navigation with Multi-Sensor Integration: A Case Study in Downtown Chicago” October 2023 (EX2004);
- U.S. Patent Publication No. 2017/0158430 (Raizer) (EX2005);
- Deposition Transcript of Matthew Spenko, Ph.D., dated January 23, 2025 (EX2006);
- Hong et al, “Semi-automated approach to indoor mapping for 3D as-built building information modeling” May 2015 (EX2008)
- Whyte, “Multipath Interference in Indirect Time-of-Flight Depth Sensors” March 2021 (EX2009)

24. I have considered certain issues from the perspective of a person of ordinary skill in the art, as described below, as of the effective filing date of the ’632 patent, which I have been asked to assume is August 14, 2019.

D. Compensation

25. I am working as an independent consultant in this matter and am being compensated at my normal consulting rate of \$850 per hour for my time. My compensation is not dependent on, and in no way affects, the substance of my statements in this Declaration.

26. I have no financial interest in the Patent Owner. I similarly have no financial interest in the ’632 patent.

II. RELEVANT LAW

27. I am not an attorney. For the purposes of this declaration, I have been informed about certain aspects of the law that are relevant to my opinions. My understanding of the law is as follows:

A. Claim Construction

28. I have been informed that claim construction is a matter of law and that the final claim construction will ultimately be determined by the Board. For the purposes of my analysis in this proceeding and with respect to the prior art, I have been informed that IPRs are currently reviewed under “the *Phillips* standard.”

29. I have been informed that under the *Phillips* standard, claim terms are given their plain and ordinary meaning as understood by a person of ordinary skill in the art at the time of the invention in light of the claim language and the patent specification.

30. I have been informed that embodiments described in the specification are encompassed by the claim terms.

31. I have been informed that the patentee can serve as their own lexicographer. As such, if a claim term is provided with a specific definition in the specification, I should interpret that claim term in light of the particular definition provided by the patentee.

B. Obviousness

32. I have been informed and understand that a patent claim can be considered to have been obvious to a person of ordinary skill in the art at the time the application was filed. This means that, even if all of the requirements of a claim are not found in a single prior art reference, the claim is not patentable if the differences between the subject matter in the prior art and the subject matter in the claim are such that the claimed invention as a whole would have been obvious to a person of ordinary skill in the art at the time the application was filed.

33. I have been informed and understand that a determination of whether a claim would have been obvious should be based upon several factors, including, among others:

- the level of ordinary skill in the art at the time the application was filed;
- the scope and content of the prior art; and
- what differences, if any, existed between the claimed invention and the prior art.

34. I have been informed and understand that a claim can be unpatentable in light of a single prior art reference if it would have been obvious to modify that reference to come up with the claimed subject matter.

35. I have been informed and understand that the teachings of two or more references may be combined in the same way as disclosed in the claims, if

such a combination would have been obvious to one having ordinary skill in the art.

36. In determining whether a combination based on either a single reference or multiple references would have been obvious, it is appropriate to consider, among other factors:

- whether the teachings of the prior art references disclose known concepts used in familiar ways, which, when combined, would yield predictable results;
- whether a person of ordinary skill in the art could implement a predictable variation, and would see the benefit of doing so;
- whether the claimed elements represent one of a limited number of known design choices, and would have a reasonable expectation of success by those skilled in the art;
- whether a person of ordinary skill would have recognized a reason to combine known elements in the manner described in the claim;
- whether there is some teaching or suggestion in the prior art to make the modification or combination of elements claimed in the patent; and
- whether the claim applies a known technique that had been used to improve a similar device or method in a similar way.

37. I understand that one of ordinary skill in the art has ordinary creativity and is not an automaton.

38. I understand that in considering obviousness, it is important not to determine obviousness using the benefit of hindsight derived from the patent being considered.

C. Ordinary Skill in the Art

39. I understand that, in the context of an invalidity analysis, a person having ordinary skill in the art (“POSITA”) is a hypothetical person who looks to prior art at the time of the invention.

40. I further understand that the factors that may be considered in determining the level of ordinary skill in the art include: (1) the problems encountered in the art; (2) the prior art solutions to the problems encountered in the art; (3) the rapidity of innovation; (4) the sophistication of the technology; and (5) the education level of active workers in the field. I understand that these factors need not all be taken into account for the analysis, one or more of these factors may control, and additional factors can be considered when appropriate.

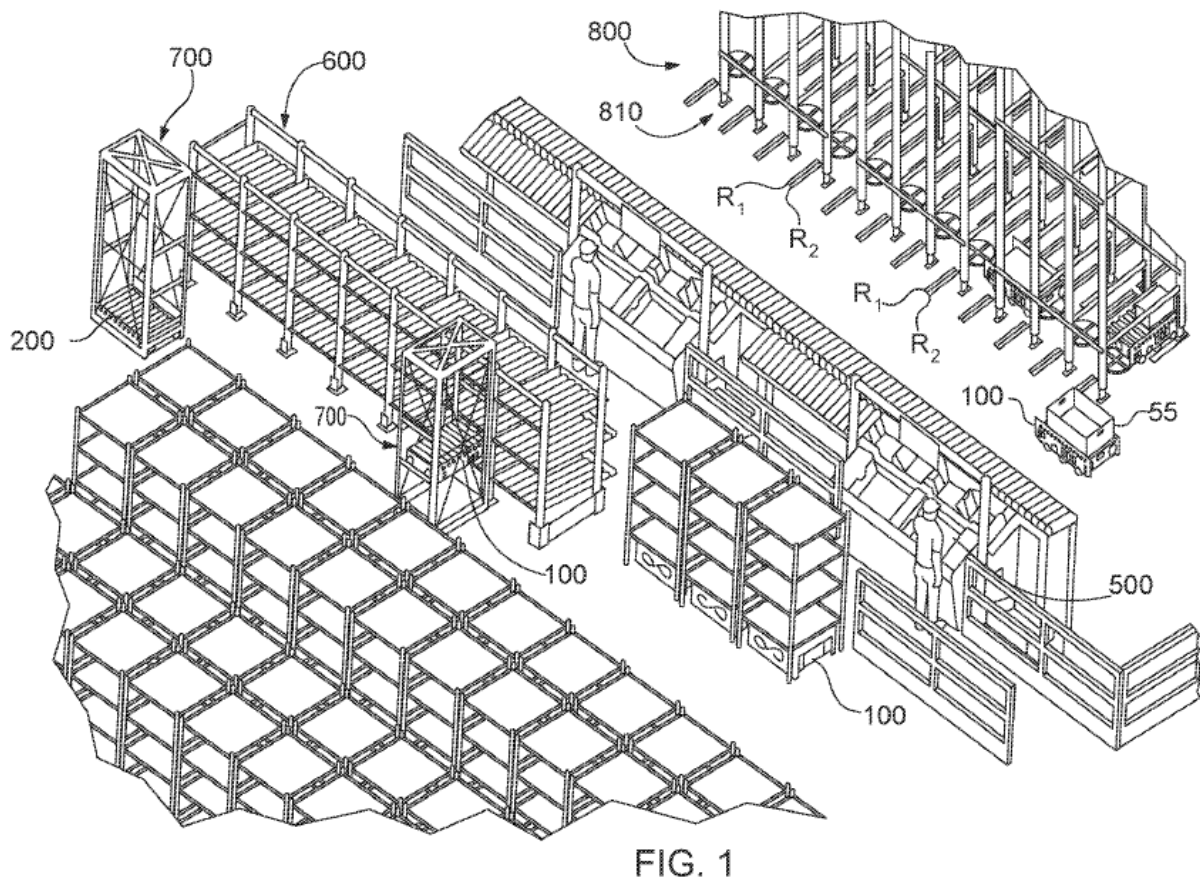
III. SUMMARY OF OPINIONS

41. It is my opinion that claims 1, 3-12, 14, and 23-27 (“the challenged claims”) of the ’632 Patent are not rendered obvious by the combination of prior art suggested by Petitioners (Raizer and Hangzhou).

IV. OVERVIEW OF THE '632 PATENT

A. Summary

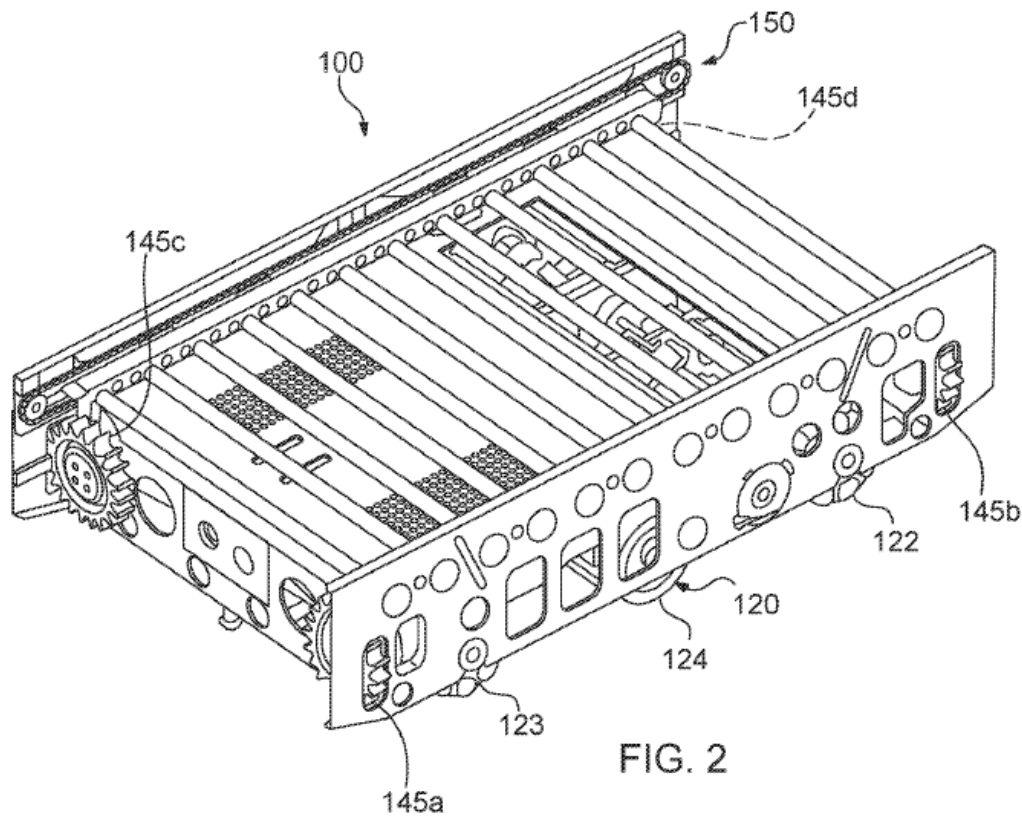
42. As the Specification of the '632 Patent explains, “embodiments of the [’632 Patent] invention relate to automated material and article handling systems which can be used in warehouse, storage and/or distribution environments.” [EX1001, ’632 PATENT, 1:12-15.] An exemplary material handling system according to embodiments of the ’632 Patent is illustrated in Figure 1 of the ’632 Patent, which I have reproduced below.



EX1001, '632 PATENT, Figure 1.

43. The material handling system shown in Figure 1 “includes one or more mechanisms for delivering items to and/or retrieving items from one of a plurality of locations, such as storage areas located in racks 800 or flow racks 600.” [EX1001, ’632 PATENT, 7:12-15.] For example, “[t]he delivery mechanism may include one or more vehicles 100 that transport items. For instance, ...the vehicles may retrieve items from storage locations 820 in the racks 800 and deliver the items to a workstation 500 where an operator can retrieve the item from the vehicle.” [EX1001, ’632 PATENT, 7:15-20.]

44. The ’632 Patent explains that “[t]he vehicles 100 may be autonomous systems that include an onboard power supply for driving the vehicle.” [EX1001, ’632 PATENT, 8:1-2.] Additionally, “[t]he vehicles may also include a communication system for wirelessly receiving and transmitting control signals between each vehicle and a control element...” [EX1001, ’632 PATENT, 8:3-5.] Details of an exemplary vehicle according to embodiments of the ’632 Patent are illustrated in Figure 2, which I have reproduced below for convenience. [See EX1001, ’632 PATENT, 7:62-63 (“FIG. 2 illustrates details of one of the vehicles 100 that are shown in FIG. 1.”)]



EX1001, '632 PATENT, Figure 2.

45. The vehicle 100 shown in Figure 2 includes two separate driving mechanisms: a horizontal one and a vertical one. The horizontal driving mechanism enables vehicle 100 to drive on a horizontal surface. [See EX1001, '632 PATENT, 8:9-14 (“The vehicle illustrated in FIG. 2 includes a horizontal drive assembly 120 for driving the vehicle 100 in a horizontal direction. The horizontal drive 120 may be configured to drive the vehicle along a track or along an open horizontal surface, such as a floor.”)] The vertical driving mechanism enables vehicle 100 to drive up and down (vertically) within a storage rack. [See EX1001, '632 PATENT, 9:12-14 (“In addition to the horizontal drive mechanism

120 the vehicle may also include a vertical drive mechanism 140 for driving the vehicle 100 vertically within the rack 20.”)]

46. The vehicles disclosed in the '632 Patent “may also include an optional transfer mechanism for transferring items between the vehicle and a destination, such as a storage location. For instance, the transfer mechanism 150 [shown in Figure 2] may be operative to transfer an item between a platform surface of the vehicle and one of the plurality of destination areas 820.” [EX1001, '632 PATENT, 10:1-6.]

47. The '632 Patent discloses that the vehicles of the '632 Patent can drive under the storage racks in different directions, e.g., parallel or perpendicular to an aisle. Furthermore, the vehicles can also turn while driving under the racks. [See EX1001, '632 PATENT, Abstract (“The vehicles are configured to drive horizontally along a path that may extend along a path under the racks that is parallel to the aisles. Additionally, the vehicles may be operated to turn while the vehicle is positioned under one of the racks. The vehicles may travel under the racks and cross one or more aisles to reach a particular column in one of the aisles.”)]

48. The different directions that a vehicle can travel in an exemplary embodiment of the material handling system of the '632 Patent is illustrated in Figure 7, which I have reproduced below in annotated form. Specifically, Figure 7

“illustrates a plurality of vehicles in different orientations relative to the racks 800 and the storage locations 820.” [EX1001, '632 PATENT, 17:7-9.]

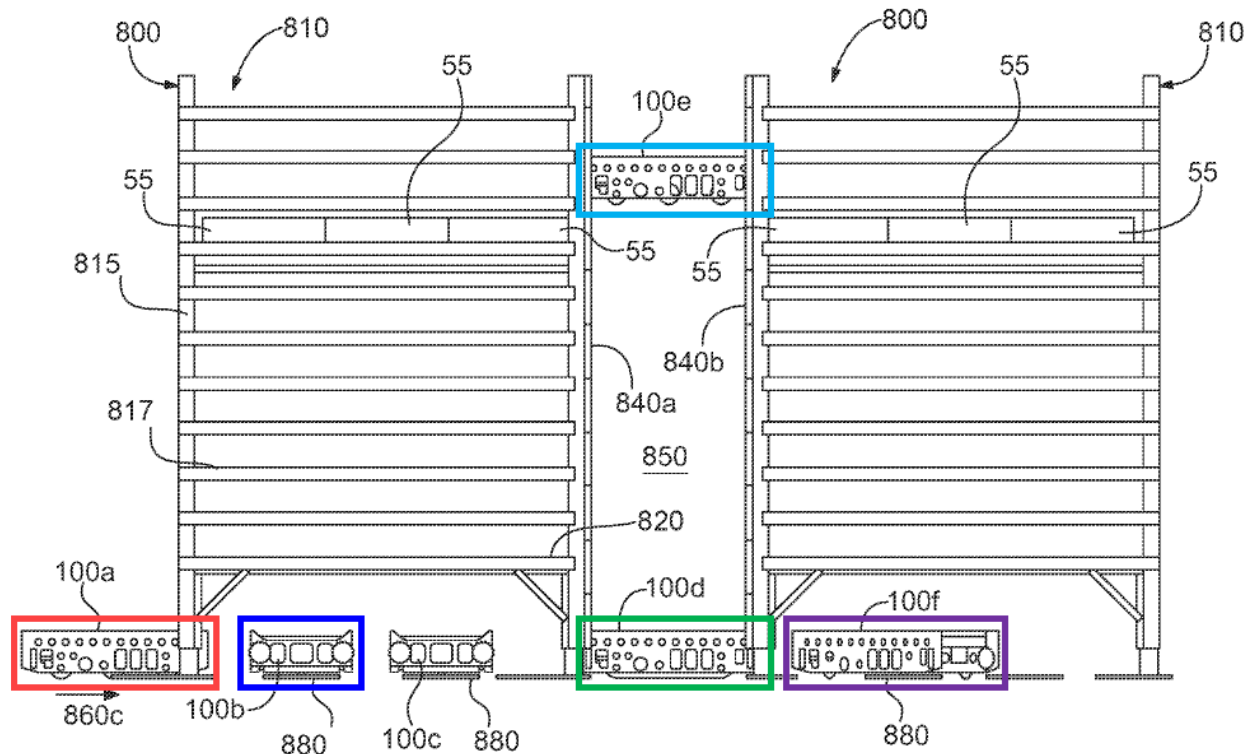


FIG. 7

EX1001, '632 PATENT, Figure 7.

49. At highlighted above, **first vehicle 100a** is driving in a direction that crosses aisle 850. **Second vehicle 100b** is driving in a direction parallel to aisle 850. **Third vehicle 100d** is within aisle 850 in a position that allows it to climb vertically. **Fourth vehicle 100e** is also within aisle 850; however, it is in an elevated position relative to **third vehicle 100d**. Finally, **fifth vehicle 100f** is turning from a direction that crosses aisle 850 to a direction that is parallel to aisle 850.

50. The '632 Patent describes the positions and actions of the vehicles in Figure 7 in the following passage:

[A] **first vehicle 100a** is oriented for horizontal movement along path 860c, transverse the length of aisle 850. A **second vehicle 100b** is oriented for horizontal movement under the rack along path 860b that is parallel to the length of the aisle 850. Additionally, a **third vehicle 100[d]** is positioned within the aisle 850 to climb vertical tracks along the racks 800 on either side of the aisle. A **fourth vehicle 100[e]** is also positioned within the aisle and has climbed up the track 840a,b to a storage location 820 in an upper portion of the column 810. Finally, a **fifth vehicle 100f** is positioned under the rack 800 and is oriented at an intermediate position between the orientation of **vehicle 100a** and the orientation of **vehicle 100b**. In particular, the racks may be configured to facilitate the vehicles turning horizontally underneath the racks. The **fifth vehicle 100f** illustrates the vehicle in the process of turning under the rack from a first path to a second path.

[EX1001, '632 PATENT, 17:7-25.]

B. Prosecution History of the '632 Patent

51. I have reviewed the file history of the '632 patent ([EX1002, '632 PATENT FILE HISTORY).] I summarize here the relevant information that I have reviewed.

52. The '632 Patent was filed on August 14, 2020, as US Patent Application No. 16/994,543. [EX1001, '632 PATENT, 1.] On October 20, 2020,

Applicant filed a Preliminary Amendment without making substantive changes to the claims. [EX1002, '632 PATENT FILE HISTORY, 137-143.] The Examiner did not reject the claims after that Preliminary Amendment and issued a Notice of Allowance on June 27, 2022. [EX1002, '632 PATENT FILE HISTORY, 76-77.] The '632 Patent was issued on October 18, 2022. [EX1001, '632 PATENT, 1.] A Certificate of Correction was issued on January 3, 2023, to make corrections to claim 11. [EX1001, '632 PATENT, 28.]

V. OVERVIEW OF THE PRIOR ART

A. U.S. Patent Appl. Publ. No 2017/0158430 to Raizer (EX1005)

53. Raizer is directed to “an automatic system for picking and placing boxes on shelves in a warehouse.” [EX1005, RAIZER ¶18.] Raizer’s system includes i) autonomous mobile robots, ii) vertical rails that are parallel to the vertical support posts of the shelves and horizontal rails that are parallel to the horizontal shelves in the warehouse, and iii) a central processing system that communications with the robots and other processors and servers in the warehouse. Specifically, Raizer discloses “[i]n a first aspect the invention is an automatic system for picking and placing boxes on shelves in a warehouse. The system comprises: a. a set of autonomous mobile robots; b. a network of vertical and horizontal rails that are parallel to the vertical support posts and horizontal shelves of the shelving system in the warehouse; and c. a Real Time Traffic Management

(RTTM) server, which is a central processing server configured to communicate with the robots and other processors and servers in the warehouse.” [EX1005, at 1].

54. Raizer is designed to satisfy an overarching goal described as: 1) providing “an automatic warehouse system that can be relatively inexpensive and easily added” which is 2) “suitable for small and existing warehouses.” [EX1005, RAIZER ¶¶ 15, 16].

55. Raizer’s improvements towards an “automatic warehouse solution” were meant to overcome a number of shortcomings in the prior art for implementing warehouse systems in existing warehouses. [EX1005, RAIZER ¶ 4.] The shortcomings in the prior art that Raizer sought to overcome were:

- 1) Large capital equipment investment;
- 2) Poor modularity – required significant reorganization and/or pre-planning;
- 3) Downtime – significant downtime for implementation;
- 4) Limited Flexibility – systems were designed in a specific manner for specific conditions and products/containers and could not adjust to different products or other demands;
- 5) No gradual implementation capability – required major structural changes in the facility and/or infrastructures that would demand overhaul to an existing warehouse; and

- 6) Redundancy capability – failure in one part of the system would stop operations in the entire system

[EX1005, RAIZER ¶¶ 4-13, *Id.*, ¶¶18-21.]

1. Raizer's Robots

56. Raizer's robots are illustrated in a series of schematic views that I have reproduced below. Specifically, Raizer discloses that “FIGS. 5A to 5D are schematic top perspective, bottom perspective, side, and top views respectively of the robot 10 of the system of the invention.” [EX1005, RAIZER ¶103.]

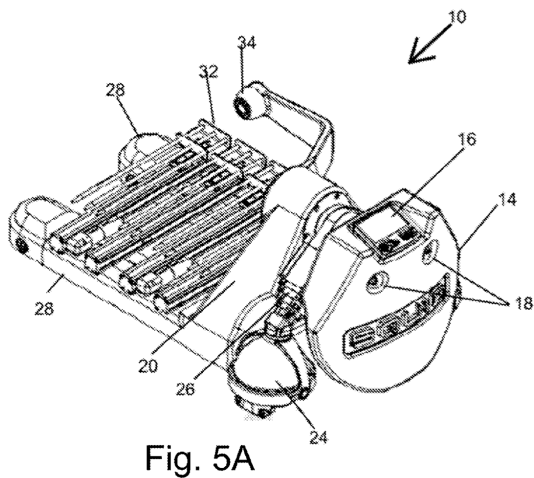


Fig. 5A

EX1005, RAIZER Figure 5A.

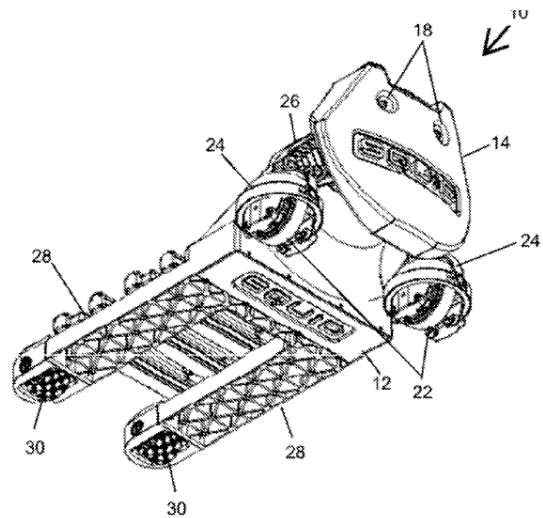


Fig. 5B

EX1005, RAIZER Figure 5B.

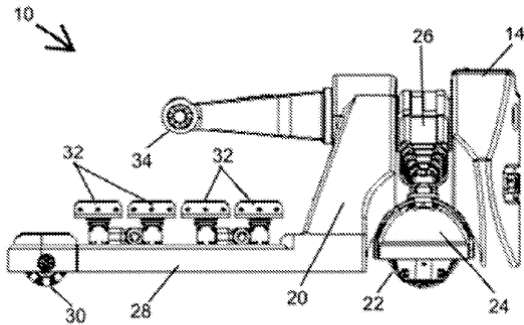


Fig. 5C

EX1005, RAIZER Figure 5C.

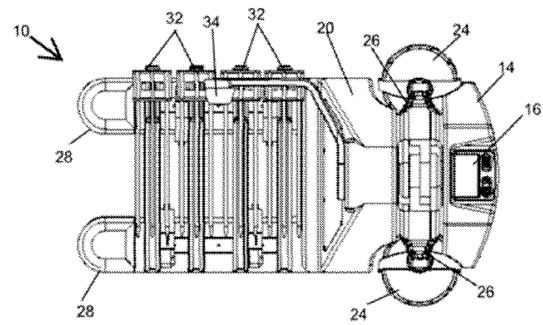


Fig. 5D

EX1005, RAIZER Figure 5D.

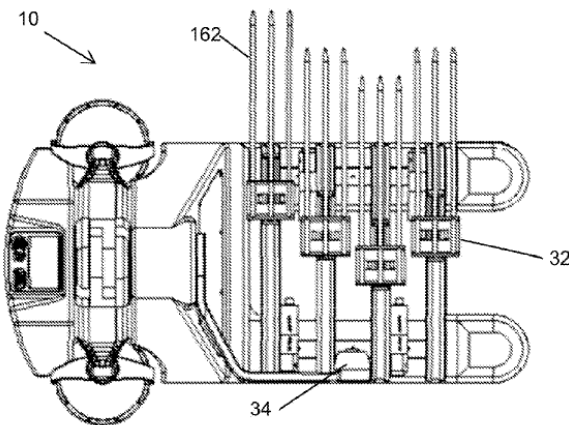


Fig. 5E

EX1005, RAIZER Figure 5E.

57. Raizer's robots are "autonomous [and] centrally controlled mobile robots that bring desired boxes to and from the picking station." [EX1005, RAIZER ¶84.] As Raizer explains, "[t]he robots have 3 dimensional travel capabilities enabling them to travel along the ground and up and along the shelves. The robots are pre-loaded with proprietary software which includes the warehouse layout, routes, intersections, and designated areas..." [EX1005, RAIZER ¶84.]

This warehouse information is initially recorded by the robot's automated mapping of the warehouse while in "Survey Mode". [EX1005, RAIZER ¶84.] Raizer also discloses that "[e]ach robot utilizes dedicated maneuvering algorithms and a proprietary "Fine Positioning" procedure to enable precise, quick and efficient loading." [EX1005, RAIZER ¶84.] "Utilizing at least one pair of motorized arms, the robots navigate both along the ground and up and along the shelves to the exact desired location." [EX1005, RAIZER ¶78.]

58. I reproduce below Figure 8B, which shows details of the terminal and rails of Raizer's storage rack structure, and Figure 12A, which shows the far end of Raizer's storage rack structure, along with one of the vertical supports that divide the shelving units. As shown in Figure 12A, this structure of rails allows multiple robots to travel simultaneously in the same horizontal direction because they are spaced apart in the vertical direction. In addition to the vertical and horizontal rails, the navigational structure in Raizer includes junctions, as shown below in Figure 11A. The rails and junctions allow Raizer's robots to travel through a

variety of paths in space above the floor. This helps reduce congestion when robots are busy filling orders. [EX1005, RAIZER ¶98]

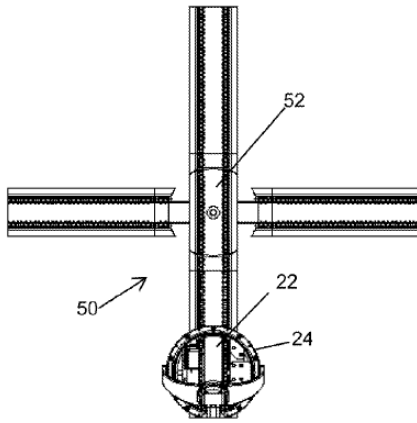


Fig. 11A

EX1005, RAIZER Figure 11A

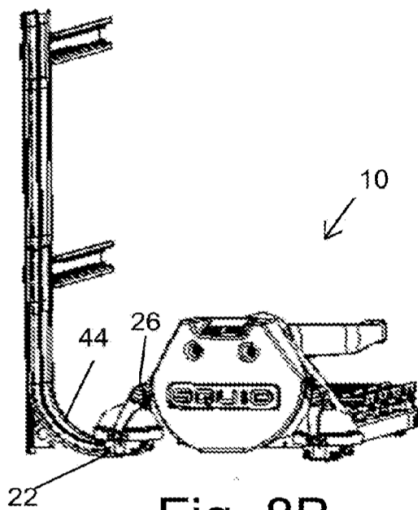


Fig. 8B

EX1005, RAIZER Figure 8B
Front Terminal and Rails of Storage
Racks

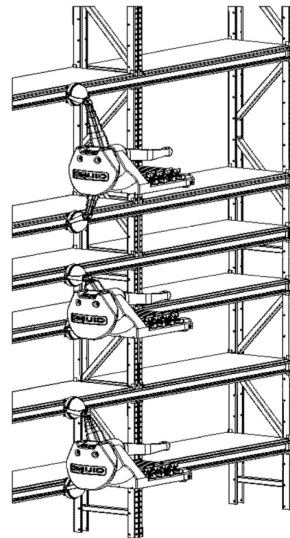


Fig. 12A

EX1005, RAIZER Figure 12A
Far End of Storage Racks

59. Figure 8B above shows that there is a curved ramp transitioning the front rail from the vertical direction to the horizontal direction on the floor. Raizer refers to these curved rail sections as “terminal 44.” These special pieces of rail allow a robot to attach and climb onto the vertical rail of the storage rack. [See EX1005, RAIZER ¶111 (“A curved piece of rail called a terminal 44 is attached to the bottoms of the vertical rails where they reach the ground.”)]

60. These terminals that are attached to the bottoms of the vertical rails are the only structures that allow Raizer’s robots to connect and disconnect from the vertical rails. Specifically, Raizer explains that terminal 44 “is the only place where robots 10 can connect or disconnect from the rails 42 in order to climb to or descend from the shelves.” [EX1005, RAIZER ¶111.] Raizer further explains that “[t]he robots engage the rails *only* at a designated ‘terminal’ located on the floor and use these rails to maneuver vertically and horizontally.” [EX1005, RAIZER ¶85.]

2. Raizer’s Navigation Control System

61. Raizer’s navigation control system and method include two discrete stages. During the first stage, Raizer’s robots drive along the ground, while during the second stage the robots climb up, down, and travel along the rails on the shelves. As Raizer explains, “[u]tilizing at least one pair of motorized arms, the

robots navigate both [1] along the ground and [2] up and along the shelves to the exact desired location.” [EX1005, RAIZER ¶78.]

62. During the first stage of Raizer’s navigation, when the robots drive horizontally on the ground, Raizer’s robots use “anchor point navigation.” Because Raizer’s robots use “anchor point navigation,” they “use *less accurate sensing and motions when travelling on the floor* in order to arrive at the designated destination as rapidly and efficiently as possible...” [EX1005, RAIZER ¶80.]

63. During the second stage of Raizer’s navigation, when the robots climb up vertically along the rails and travel horizontally along the shelves, the robots switch over to a more expensive, complex, and accurate navigation control system. Specifically, Raizer’s robots “employ dedicated algorithms and more precise sensing only when near anchor points, i.e. fixed specific locations in the warehouse such as terminals (locations at which the robot leaves the floor and climbs a vertical rail of the shelving system), picking stations, and battery charging stations.” [EX1005, RAIZER ¶80.]

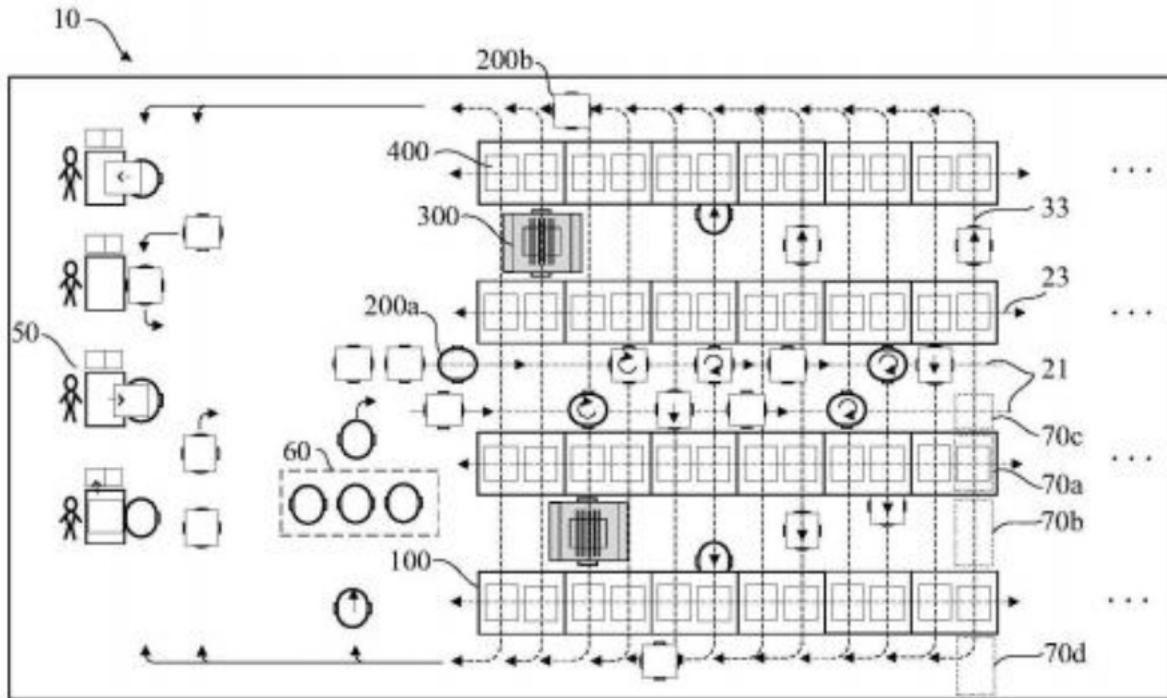
64. As Raizer explains, using the two-stage navigation control system and anchor point navigation is beneficial because “[t]his feature provides significant savings in energy and load on the sensor and navigation system since the robot has

to check exactly where it is only when approaching its destination.” [EX1005, RAIZER ¶80.]

65. Importantly, Raizer discloses that this two-stage navigation system that employs anchor point navigation during a first stage of navigation is what distinguishes Raizer’s system from other existing systems. [See EX1005, RAIZER ¶¶79-80, (“Some of the features of the invention that makes the system *unlike existing systems* are: The robots in the system of the invention use ‘*anchor point navigation*.’”)]

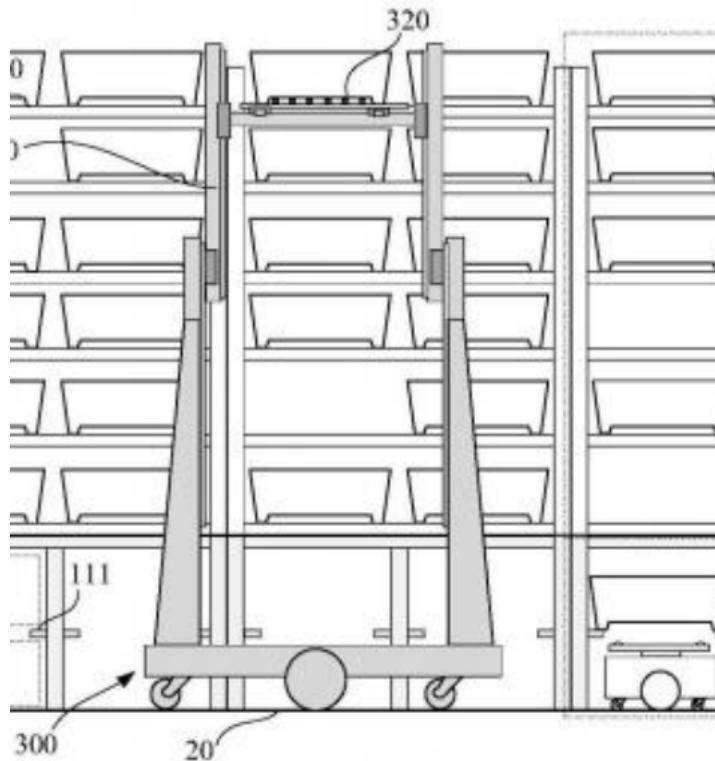
B. CN Patent Publication No. CN 109987366A to Hangzhou (“Hangzhou” [EX1006, HANGZHOU])

66. Hangzhou “relates to the technical field of warehousing, especially to an unmanned warehousing system and an inbound and outbound method therefor.” [EX1006, HANGZHOU, ¶1.] Hangzhou and Raizer disclose fundamentally different systems. *First*, in contrast to Raizer’s system in which the robots limit their movement on the ground to only certain regions of the floorplan, Hangzhou’s mobile robots (referred to as **trolleys**) are allowed to move all over the warehouse floor. [EX1006, HANGZHOU, Figure 10.] This freedom of movement can result in a complicated path for a trolley because there is such a large number of possible paths. For example, Hangzhou’s Figure 10, which I reproduce below, shows a complex array of possible robot paths, including under the storage shelves.



[EX1006, HANGZHOU, Figure 10.]

67. In addition to the floor-roaming mobile trolley, Hangzhou also requires the use of another type of very tall, automated robotic machine to store and retrieve items from the elevated shelves. This machine, which Hangzhou calls a **stacking vehicle 300**, is shown below in a cropped version of Hangzhou's Figure 2. The tall stacking vehicle rendezvous with a loaded trolley, receives the load from the floor-roaming trolley, lifts the load up to a desired storage level, and then deposits the load on the shelf. The stacking vehicle performs this process in reverse order to retrieve a stored item and loads it onto a trolley.



[EX1006, HANGZHOU, Figure 2.] Cropped to focus on Stacking Vehicle 300.

68. The increased degree of freedom in movement on the warehouse floor comes with a significant cost. Specifically, Hangzhou's **trolleys** must be equipped with an extensive sensor network and complex navigation control systems to allow the **trolleys** to traverse complex paths and rendezvous with a stacking vehicle at the correct time and place. Furthermore, this navigation and control task must be accomplished without colliding with other trolleys, workspace obstacles, and/or **stacking vehicles**. [See EX1006, HANGZHOU, ¶59 ("Potential collisions may occur since the stacking device and auto-guided trolleys carrying standardized containers need to use the cache space below shelf rows. *In addition to running in*

a time-shared manner at the dispatch level, auto-guided trolleys 200 also run an obstacle avoidance algorithm to ensure safety and reliability. Generally speaking, stacking vehicle path planning has a higher priority. Therefore, auto-guided trolley path planning will be adjusted based on the information on stacking vehicle path planning.”)]

69. When Hangzhou’s **trolleys** are operating under the racks, complex sensor networks are utilized to avoid obstacles, as well as sophisticated algorithms that analyze the information obtained wirelessly to determine whether a particular path is unobstructed or not. Specifically, as Hangzhou explains:

When an auto-guided **trolley** carrying standardized containers drives along the row channel below a shelf row and is about to enter the next channel support frame ahead, *the auto-guided trolley confirms the absence of obstacles*, such as other auto-guided trolleys or standardized containers, in the next channel support frame *according to the information obtained via wireless communication and through its sensor system.*”). [See EX1006, HANGZHOU, ¶59.]

70. *Second*, recall that, unlike Raizer that teaches using a single type of robot, Hangzhou utilizes two separate robot types that need to coordinate movements and work in tandem with each other: (1) **trolleys** and (2) a **stacking vehicle**, as shown in annotated Figures 2 and 3 of Hangzhou, which I have reproduced below in annotated form.

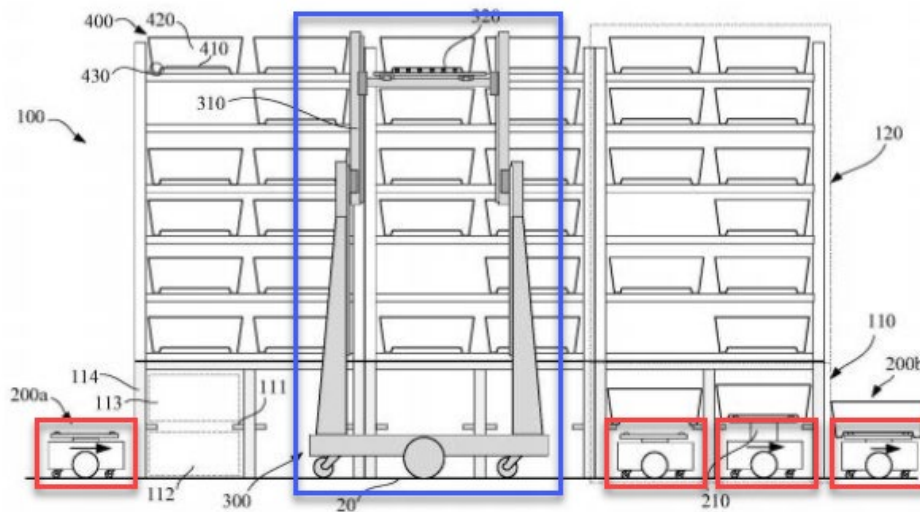


FIG. 2

[EX1006, HANGZHOU, Figure 2.] Annotated to highlight **trolley 200** and **stacking vehicle 300**.

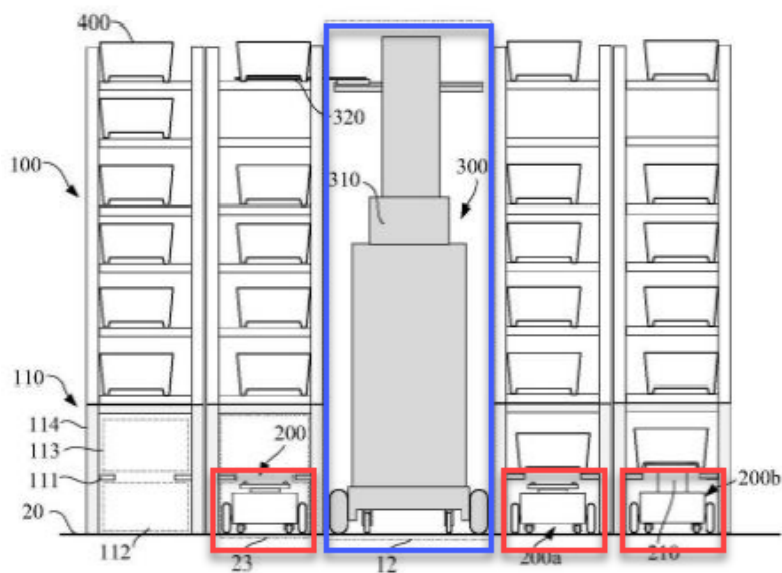


FIG. 3

[EX1006, HANGZHOU, Figure 3.] Annotated to highlight **trolley 200** and **stacking vehicle 300**.

71. Hangzhou utilizes two separate robot types because, unlike Raizer's robots that can climb up the shelves, Hangzhou's **trolleys** cannot leave the floor. Accordingly, in addition to the complex on-the-ground navigation algorithms associated with the **trolley**, Hangzhou's system must additionally coordinate the motions of the two different robots so that they can work together to store and retrieve items from the storage shelves.

72. For example, when the **trolleys** drive under the shelves, they must transfer an item to area 113 under the shelves, such that the **stacking vehicle** can then move it vertically up the storage racks. Similarly, the **trolleys** will receive items from area 113 under the shelves after the **stacking vehicle** has brought it down from the shelves.

73. More specifically, as shown in Figure 3 below, Hangzhou's **trolleys** dock the containers they carry onto cache space 113, so that the **stacking vehicle** can lift them and place them on the shelves. As Hangzhou explains, "[a] lifting platform 310 with a large lifting range is mounted above **a stacking vehicle 300**." [EX1006, HANGZHOU, ¶46.] This lifting platform "has a grabbing component 320 that can grab standardized containers 400 on different layers of a shelf 100." [EX1006, HANGZHOU, ¶46.]

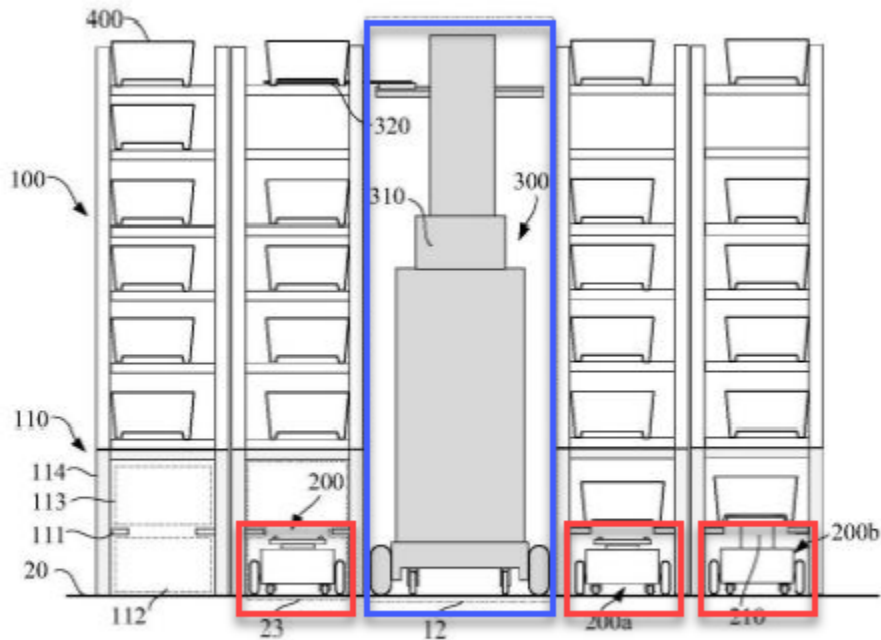


FIG. 3

[EX1006, HANGZHOU, Figure 3.] Annotated to highlight trolleys retrieving containers from cache space 113.

74. In a similar manner, **trolleys** can retrieve containers from cache space 113 after the **stacking vehicle** lowers the containers from the shelves and places them in cache space 113. [EX1006, HANGZHOU, ¶46 (“At the lowest position of the lifting platform 310, grabbing components can place standardized containers 400 into cache spaces 113 on both sides.”)]

75. Adjusting the **trolley** path planning to consider the **stacking vehicle** path planning, suggests that paths for the **stacking vehicles** are formed first, before the paths for the **trolleys**. Accordingly, during path planning, **trolleys** can end up

waiting for a clear path before they reach a location to retrieve an item. This problem with Hangzhou is described in the following passage.

Obtain the information on the **stacking vehicles** and space occupancy on the route ahead from the dispatch control system *when an auto-guided **trolley 200** has reached the edge of a stacking row laneway 12 the trolley is about to enter.* Then conduct an analysis, continuing the calculation if the auto-guided trolley passage space 112 and the cache space 113 opposite to the stacking row laneway 12 allow the **trolley** to enter to determine whether the time for passing through the stacking row laneway 12 is intersected with the time for **stacking vehicles 300** to running through this section of the row laneway. ***Move forward if there is no intersection. Otherwise, run the algorithm above again after waiting for some time.*** [EX1006, HANGZHOU, ¶63.]

76. Therefore, the movement of the **trolleys** on the ground are often slowed down to avoid collisions and to effectuate proper delivery of items to the cache space 113 under the shelves, such that **stacking vehicles** can retrieve the containers and store them on the shelves. Hangzhou further discloses that “[i]f there is not any standardized container 400 to be outbound at the right end, the trolley 200 waits or continues to move forward to other shelves that needs to be outbound.” [EX1006, HANGZHOU, ¶55.]

77. Given that Hangzhou’s trolleys never leave the floor surface to move vertically up the storage shelves, the trolleys clutter up the floor space and suffer

from congestion problems that do not arise in Raizer. Recall that Raizer's robots move up vertically into the storage racks, thereby clearing out the floor space.

VI. Level of Ordinary Skill in the Art

78. The Petitioner proposed that a person of ordinary skill in the art ("POSITA") "at the time of the alleged invention of the '632 Patent would have been a person with a working knowledge of mechanical design and automation. That person would have had a Bachelor of Science degree in an academic discipline emphasizing the design of mechanical, automation, and robotics technologies, in combination with training or at least one to two years of related work experience. Alternatively, that person could have also had a Master of Science degree in a relevant academic discipline with less than a year of related work experience in the same discipline. More education can supplement practical experience and vice versa." [Petition at 5 (internal citations omitted).]

79. For the purposes of this IPR, I adopt Petitioner's definition.

80. I exceeded these requirements for a POSITA at the time of the effective filing date of the '632 Patent (August 14, 2019).

VII. Claim Construction

81. I have reviewed the claims, specification, and file history of the '632 patent.

82. I have been informed and understand that in an IPR proceeding, only terms that are in controversy need to be construed and only to the extent necessary to resolve the controversy. In all cases, I have applied the ordinary and customary meaning of claim terms, as understood by a POSITA, in my analysis provided herein.

VIII. Specific Grounds for Challenge

83. The sections below demonstrate in detail how claims 1, 3-12, 14, and 23-27 of the '632 patent are patentable over the combination of Raizer and Hangzhou. Claims 1, 11, and 23 are independent. [EX1001, '632 PATENT, 24:1-36, 26:15-52, 28:20-46.] Claims 3-10, 12, 14, and 24-27 depend directly from one of independent claims. [EX1001, '632 PATENT, 25:47-26:14, 26:53-58, 27:3-6, 28:47-60.]

A. Petitioners Fail To Provide Sufficient Details For A POSITA To Implement The Proposed Combined System

84. Petitioners do not detail the system of their proposed combination or provide reasoning as to whether a POSITA would have an expectation of success in combining these references. Instead, Petitioners pick and choose elements from Raizer and Hangzhou element by element without explaining their integration. As such it would be unclear to a POSITA how to implement the system Petitioners attempt to describe.

85. I understand that to evaluate an obviousness combination the references in the combination “must be read together, not in isolation.” *Palo Alto Networks, Inc. v. Centripetal Networks, LLC*, 122 F.4th 1378, 1386 (Fed. Cir. 2024). Thus, it is not sufficient for these references individually to disclose all of the claim limitations. Instead, the proposed combination must meet the claim limitations. *Palo Alto Networks, Inc. v. Centripetal Networks, LLC*, 122 F.4th 1378, 1386 (Fed. Cir. 2024).

86. Exotec does not provide any details on how the proposed modified system would operate. Instead, Petitioners merely state “[a] POSITA would have been motivated to combine driving of trolleys under a rack of *Hangzhou* with the capabilities of *Raizer’s* robots.” Petition, 22. I disagree with their unsupported conclusion.

87. The missing details regarding the operation of the proposed combined system leads to key questions remaining unanswered. It would be unknown to a POSITA in the combined system, which uses the delivery robots of Raizer, how robots would navigate under the shelves, or how they would handle payloads while under the tracks. Petitioners fail to address these and other very basic questions going to the functionality of their proposed combination.

88. Petitioners mix and match from the references without a reasoned explanation as to why a POSITA would make such a combination. For instance,

although utilizing Raizer's robots, [EX2006, 89:10-13], in their combined system, the Petition and Dr. Spenko's declaration are simply devoid of any details as to how Raizer's system would have been modified to achieve the claimed "driving the first vehicle along a first path under a first one of the racks ... wherein the first path extends in a direction parallel to the first aisle and spaced apart from the first aisle," and "a first horizontal path that extends under the first rack in a direction parallel to the aisle," and "a second horizontal path that extends under the first rack in a direction parallel to the aisle." [See Petition, 20-23, 60-61.] Instead, without explanation, Petitioners pivot from Raizer's robots and instead rely on Hangzhou's disclosures to satisfy these limitations. [See e.g., Petition, 20] ("Should *Raizer* be determined to not disclose driving a vehicle along a path under one of the racks, a POSITA would have looked to *Hangzhou*.")

89. Exotec also does not provide any explanation on how to implement its proposed system. Exotec alleges it combines "the Raizer autonomous robots ... with Hangzhou's teaching of running robots in passage spaces beneath shelves," but does not provide any implementation details. [See e.g., Petition, 7.] A reader, and more importantly a POSITA, is left with many questions concerning how to implement the combination, such as; how the modified Raizer be implemented in warehouses with shelves along the ground, would there be the cache space and

channel support frames to guide the delivery robot under the shelves, and how would the system obtain the maps required for navigation?

90. A reader certainly must guess as to how the robots of the proposed system navigate—Raizer discloses a “survey mode” that must be conducted to develop a navigation map of the warehouse, while Hangzhou does not disclose any such mode or automated mapping technology. [EX1005, RAIZER ¶ 84.] As Hangzhou does not disclose a “survey mode,” a POSITA would be forced to use the Raizer “survey mode” to develop new types of navigational maps that can be used to implement the “driving and turning under the stacks” concept being imported from Hangzhou. However, Raizer does not teach its “survey mode” can map under racks and Petitioners provide no explanation of how this required task is accomplished in the combination.

91. Dr. Spenko also fails to describe with any particularity how his proposed system would operate. He could not even articulate whether the proposed system would use the stacking robots in Hangzhou, a key functionality of Hangzhou which allows for the efficient stocking and retrieval of packages. [EX2006 at 89:10-90:25.]

92. These ambiguities leave the Board, the Patent Owner, and a POSITA to guess as to how Exotec’s proposed combination would operate.

93. The Petition's ambiguities further underscore Petitioner's misunderstanding of Raizer and Hangzhou and their incompatibilities. For example, as discussed in more detail below, Raizer is directed to a cost-effective retrofitting of existing warehouse shelves with a single type of asymmetrical robot. On the other hand, Hangzhou uses two very different types of robots working in conjunction with a specialized shelf structure. [See *infra* VIII.C. and VIII.D.]

94. Because of these ambiguities and Petitioner's failure to address the incompatibility of the references, the Petitioners cannot possibly show a reasonable expectation of success in combining Raizer and Hangzhou. In fact, the Petitioners do not even try to provide a reasoned explanation for why there would be an expectation of success. In my opinion, a POSITA would have an expectation of failure with the proposed combination. In other words, from my understanding of Petitioners position/combination, the combination would not operate successfully.

95. There are several reasons to expect failure with the proposed combination. First, the combination would fail when one would attempt to implement it in a warehouse with bottom shelves that are on the ground, or very close to the ground. The Raizer robots simply could not drive under the storage racks. Note that one of the main goals of Raizer is to use its invention to retrofit existing warehouses, many of which would have shelves on the floor. [EX1005, RAIZER ¶112.] Therefore, a POSITA would certainly expect to fail in an attempt

to make this combination and use it for one of the primary applications intended by Raizer.

96. Second, even if there was enough vertical space under the storage racks, a POSITA would expect that the Raizer robot would experience collisions and snags with the rack support legs when trying to pass under and turn around in such confined spaces. Given its multi-purpose capabilities, Raizer's robot is complex, asymmetrical, and has extending appendages. [EX1005, RAIZER ¶104.] These attributes can clearly be seen in Figure 5A, which is reproduced below for convenience. Given the teachings of Hangzhou, a POSITA would know that a robot operating under storage racks should be low-profile and symmetrical in shape. [See e.g. "trolleys are generally designed in symmetrical so that they can turn in place", Hangzhou, 0048.]

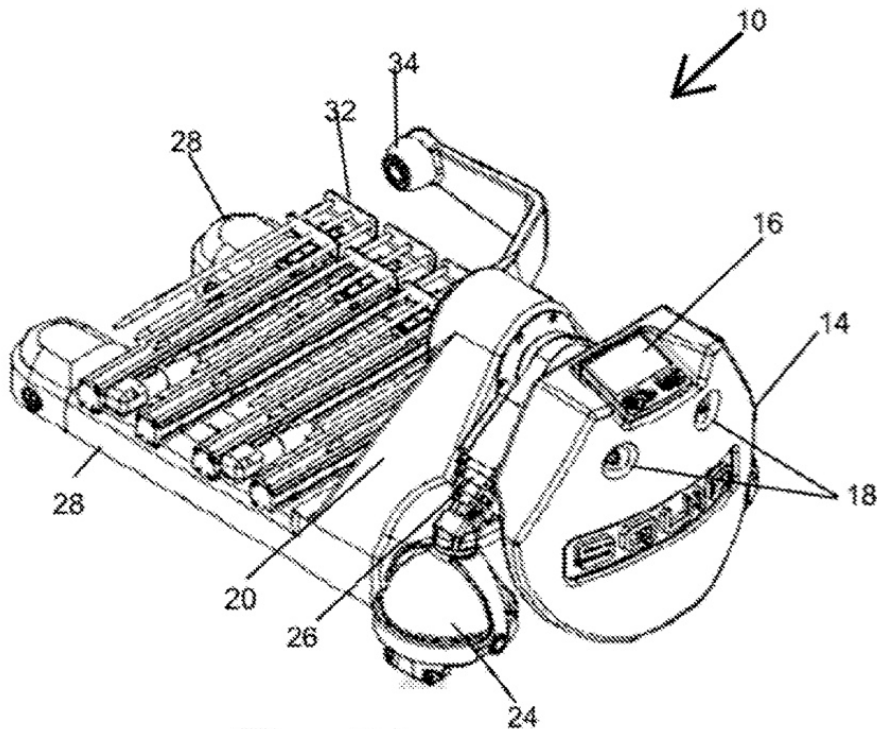


Fig. 5A

EX1005, RAIZER Figure 5A

97. The collision-and-snagging problem is exacerbated when we consider that the Raizer robot would often be carrying a load. A load would make it more difficult to turn in a confined space. Once again, given the teachings of Hangzhou, a POSITA would know about this problem and expect Raizer's system to fail because it cannot perform the turning operation in the manner taught by Hangzhou. For example, Hangzhou teaches that it is best to unload the robot payload before making a turn while under the storage racks. [EX1006, HANGZHOU ¶73.] Only after the turn is completed is the load transferred back onto the robot so that it can proceed on its way. [*Id.*] Raizer simply has no way of turning in this manner.

98. Finally, a POSITA would also expect failure from collisions occurring as the Raizer robots attempt to go under and come out from under the storage racks. Raizer's anchor point navigation is simply not designed to avoid collisions going under and coming out of the storage racks. To avoid this failure mode, a POSITA would know that a more complex and expensive navigation system would have to be developed. This required alteration would destroy one of the main functions and inventive aspects of Raizer.

B. Petitioners Declare A Motivation To Combine, Ignoring Explicit Teaching Away In The Specifications Of Hangzhou and Raizer

99. Petitioners do not provide evidentiary support regarding a motivation to combine the references. Petitioners merely repeatedly state that a "POSITA would have been motivated to combine specific teachings of Hangzhou with those of Raizer" Not only is this idea unsupported, it is incorrect. A POSITA would not have combined these two references.

100. Petitioner's arguments are simply ex-post reasoning, apparently using the '632 patent as a roadmap to guide their proposals. Furthermore, the Petitioners simply ignore the teachings and disclosures of the references that discourage the proposed combination.

101. For the "reasons" that the Petitioners do provide to modify the references, they point to generalized issues such as to "reduce congestion, avoid

traffic jams, [and] make more efficient use of space.” [Petition, 9.] These issues though, are vague, applicable to all automated systems, and do not actually articulate why a POSITA would look to specifically combine Raizer’s robots with Hangzhou’s ability to go under the storage racks—likely because a POSITA would not have combined Raizer’s robots with Hangzhou’s navigation methods.

102. A POSITA would not have combined the references because the references’ respective specifications pursue different goals and are incompatible. Raizer advocates for the benefits of an approach using rails added onto the outside of existing shelves to ascend and descend the shelves, flexibility of containers, and a one robot system comprising complex asymmetrical robots with lifting arms. [[EX1005, RAIZER ¶104.] Hangzhou, in contrast, advocates for the use of specific shelving patterns, standardized containers, and a two-robot system that each separately perform the task of container stacking and container transport—specifically teaching against a one robot system. [[EX 1006, HANGZHOU ¶1004]].

103. Of note, Petitioners seem to all but concede that the Raizer and Hangzhou systems are directed to implementations for different types of warehouse systems and, therefore, have different goals and approaches. Petitioners describe Raizer as “plug and play *in any warehouse*, integrating with an already in-use facility, shelving system and infrastructure resources of a conventional

warehouse.” [Petition, 20. *Emphasis added.*] In contrast, Exotec concedes that Hangzhou requires “a ‘lower layer’ of a ‘channel support frame’ [that] ‘is used to automatically guide a trolley to pass through.’” [*Id.*, 20-21.] Such a specific structure is certainly not found *in any warehouse*. In fact, a POSITA would know that such structure was exceedingly rare in warehouses. Petitioners fail to explain how the fundamentally different approaches can be reconciled.

C. Petitioner’s Modified System Is Incompatible With Raizer As It Contradicts Raizer’s Goals and Principle Of Operation

104. The specification of Raizer makes clear that Raizer’s invention is designed to satisfy an overarching goal described as: 1) providing “an automatic warehouse system that can be relatively inexpensive and easily added” which is 2) “suitable for small and existing warehouses.” [EX1005, RAIZER ¶¶ 15, 16.] Petitioners fail to address how their combination of Raizer and Hangzhou would satisfy these characteristics. Indeed, a combination of these references frustrates Raizer’s overarching purpose. Further, when analyzed in view of Raizer’s specification, Raizer teaches away from a combination with Hangzhou.

**1. Petitioner's Proposed Modification Would Require
Unacceptable Capital Equipment Investment,
Reorganization, and Downtime And Thus Contradicts
Raizer's Goals**

105. Raizer aims to solve specific shortcomings associated with the implementation of prior art systems. The shortcomings of the prior art that Raizer aims to address include “the requirement of a large capital equipment investment,” “poor modularity” including required reorganization, and required “downtime.” [EX1005, RAIZER ¶¶ 5-7.] Petitioner's proposed system of Raizer and Hangzhou exacerbates these shortcomings. A POSITA would thus not be motivated to look to Hangzhou to modify Raizer.

106. Petitioner's proposed modification to allow for travel underneath shelves, such as along a “path ... parallel to the aisle” would require modifications of Raizer that are unacceptable to a POSITA reading Raizer. Petitioner's only proposed modification to satisfying a “path ... parallel to the aisle” is to modify Raizer's storage racks by “installing shelving units with elevated lower shelves to allow robots loaded with containers to travel underneath.” [Petition, 7.] Installing new shelving units is incompatible with the teachings of Raizer and, therefore, a POSITA would not make this modification in view of Raizer.

107. First, a POSITA would know that installing new shelves would require unacceptable capital equipment investment because Raizer is directed to retrofitting existing warehouses. One of the key purposes of the inventive system of Raizer is to provide “an automatic warehouse system that can be relatively inexpensive and easily added.” [EX1005, RAIZER ¶ 16.] It is not possible to “install shelving units with elevated lower shelves” in an inexpensive manner for existing warehouses.

108. A POSITA reading Raizer would understand that installing new shelving units or installing a lift for a current shelving unit would be prohibitively expensive in view of Raizer. This is because it would require a time consuming and expensive process to install new shelves in warehouses that are currently operating—the type of warehouse a POSITA would understand Raizer is directed at improving. First, the warehouse operator would be required to take all items off of the shelves. This renders not only the shelf itself unusable for warehouse operations, but also requires the warehouse operator to find additional storage location(s) for the goods previously on the shelves being replaced. In many situations, this would require the warehouse to purchase/rent additional storage. Removing and storing these goods not only costs additional man-hours but also causes congestion in the warehouse by blocking travel lanes with machines to remove the goods. Further, if the warehouse decides against purchasing additional

storage space, these items would need to be stored somewhere else in the facility. This would cause additional issues for travel lanes and require the delivery robots to re-map their travel paths. All of these disruptions drastically lower a warehouse's efficiency.

109. Raizer's robots traveling under shelves based on Hangzhou without new shelves would also require unacceptable modifications based on the goals of Raizer, given that warehouses often store goods on the ground or have their first shelves at ground level. These ground-level goods include heavy or bulky items. These items could no longer be stored on the ground in order to allow Raizer's robots to travel underneath the shelves, requiring expensive relocation of goods and costing the warehouse valuable storage area. Raizer expressly teaches away from these sorts of expensive and complex reorganization requirements. [See EX1005, RAIZER ¶¶ 5, 6.] For at least this reason, a POSITA would not look to modify Raizer in the manner suggested by Petitioners.

110. Installing new shelves would also not allow for modularity for existing warehouses—a shortcoming expressly cautioned against by Raizer. [See EX1005, RAIZER ¶ 6.] As discussed above, a new shelf structure which allows for travel underneath would require reorganizing/relocating many items and either fully replacing the shelves or somehow lifting the shelves. A POSITA reading Raizer would understand that a combination requiring reorganizing the warehouse

and/or the goods inside would be the same as the prior art systems Raizer teaches against. [See EX1005, RAIZER ¶ 6] (cautioning against a system “if a business needs to reorganize the warehouse area/facility” as it has many constraints). For at least this reason, a POSITA would not look to modify Raizer in the manner suggested by Petitioners.

111. A POSITA would also understand that installing a new shelf structure would also require unacceptable downtime for existing warehouses, in view of Raizer. There is largely no meaningful difference between the downtime required for a warehouse to install a new shelf structure or to modify the existing shelf structure; therefore, a POSITA reading Raizer would understand either modification to be unacceptable. [See also EX1005, RAIZER ¶¶ 7-10.] Given the time and effort required for implementation, Raizer cautions that a new shelf structure would require “a temporary facility while implementing,” “relocation ... after implementation,” or “[s]hut[ting] down the business for the time of implementation.” [See EX1005, RAIZER ¶¶ 7-10.] A POSITA reading Raizer would understand that all three of those options would create unacceptable downtime costs. [See EX1005, RAIZER ¶¶ 7-10.]

112. A POSITA would understand Petitioner’s proposed modification takes a step back and causes the problems in the prior art identified by Raizer. Thus, Petitioners have failed to establish a motivation to combine.

**2. Petitioners Proposed Modified System Frustrates Raizer's
Principle Of Operation And Introduces Additional Issues,
While Ignoring The Inventive Solutions Proposed By Raizer**

113. Petitioners focus on “reducing congestion” and creating more travel paths while ignoring the solutions presented by Raizer, the massive switching costs that modification would create, and various other issues created by their proposed system—such as aisle traffic and collisions. [See *e.g.*, Petition, 9.] These ignored issues show the flaws of the proposed combination and illustrate why a POSITA would not be motivated to try Petitioner’s proposed combination.

114. First, Petitioners focus only on the proposition that increasing the number of travel paths on the floor level could hypothetically ease congestion. [Petition, 6.] They allege that because of this “[a] POSITA would have turned to Hangzhou and its teaching of running autonomous robots in passage spaces beneath the shelves to provide such added travel ways.” [Petition, 7.]

115. Dr. Spenko echoes this approach and only focuses on the hypothetical benefits regarding creating additional travel paths on the floor to compensate for the a “congestion” problem that does not actually exist in Raizer. To this point, he opines:

Considering congestion from a mathematical perspective, given a fixed number of autonomous robot vehicles, increasing the number of travel ways available implies reducing the probability that multiple

autonomous robot vehicles use the same travel way, thereby reducing the probability that two autonomous robot vehicles block one another. Thus, increasing the number of travel ways is a logical approach that the skilled person would readily consider. (EX1003 ¶ 106.)

116. In addition to focusing on a made-up “congestion” problem, Exotec and Dr. Spenko ignore the downsides of creating travel lanes under shelves. Modifying shelf structure would create switching costs for existing warehouses requiring massive capital equipment investment, something Raizer explicitly cautions against. [See EX1005, RAIZER ¶ 5.] Modifying the shelf structure of a warehouse to have Hangzhou’s undershelf travel lanes and guiding channel support frame would also create unacceptable periods of downtime and inflexibility in the system, a problem Raizer specifically seeks to solve. [EX1005, RAIZER ¶¶ 7-11]. Petitioners fail to address these downsides of modification, but nevertheless opine unsupported that “[a] POSITA would have turned to Hangzhou and its teaching of running autonomous robots in passage spaces beneath the shelves to provide such added travel ways.” [Petition, 7.] These are conclusory statements about non-existent problems that carry no weight.

117. Second, Petitioners focus only on hypothetically reducing congestion based on the number of pathways on the floor and ignore that by directing Raizer’s robots under shelves, as taught in Hangzhou, other traffic issues are created.

118. A key teaching of Hangzhou is the use of two vastly different robots in cooperation, instead of the single-type robot approach used by Raizer.

[EX1006, HANGZHOU ¶¶ 4-6.] In Hangzhou's multi-type robot approach Hangzhou utilizes two separate robot types that move in tandem with each other: (1) **trolleys** and (2) a **stacking vehicle**, as shown in annotated Figures 2 and 3 of Hangzhou below. See Paper 8 at 17-21.

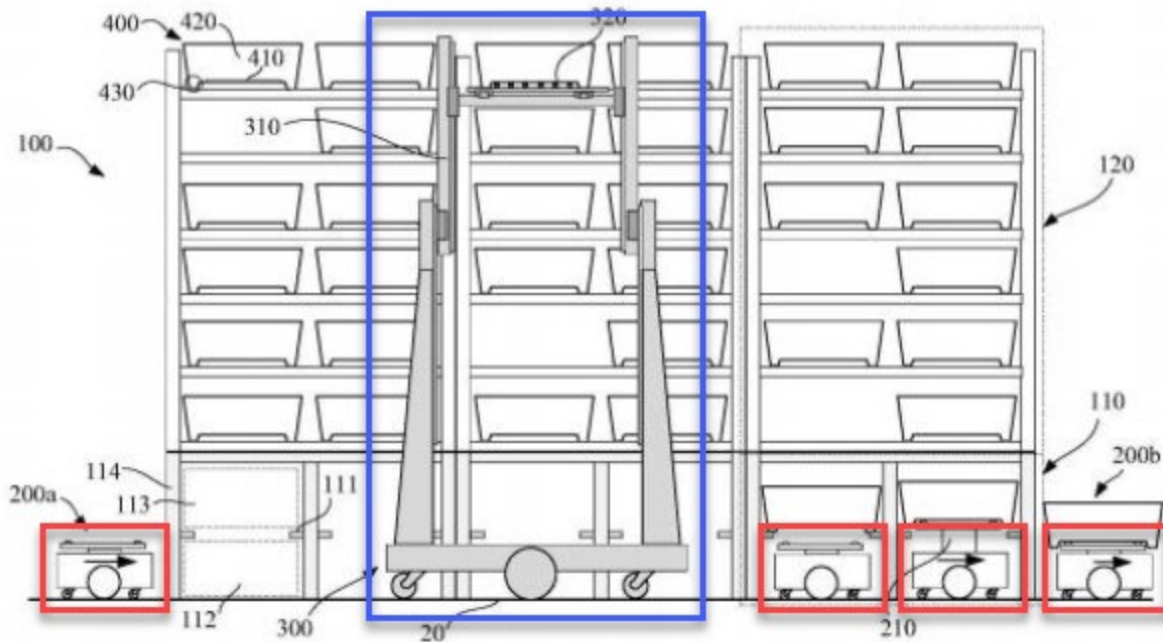


FIG. 2

[EX1006, HANGZHOU, Figure 2.]

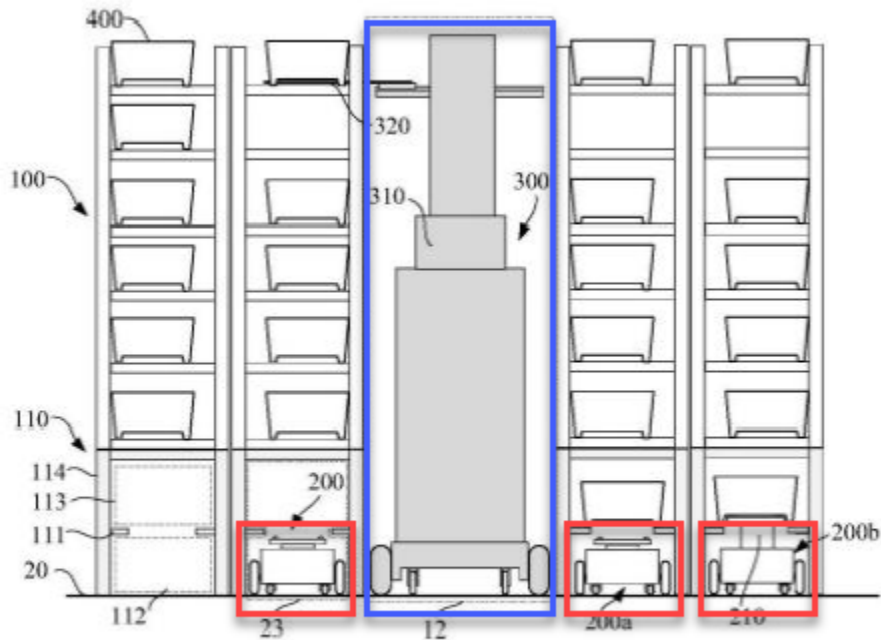


FIG. 3

[EX1006, HANGZHOU Figure 3.]

119. As I illustrate below in Figure 1 and explained by Hangzhou, the “**auto-guided trolley 200** preferentially travels in column laneways 32 and auto-guided trolley passage spaces 112, *never entering stacking row laneways 12* to avoid path conflicts with **stacking vehicles 300**.” [EX1006, HANGZHOU ¶ 48.] The trolleys of Hangzhou avoid congestion and collisions with the stacking vehicles by traveling in the column laneways (boxed in red) and in trolley passage space (located under the shelves and shown as red lines). [*Id.*] The trolleys preferably do not enter the stacking row laneway aisles reserved for the stacking vehicles (boxed in blue). *Id.* By preferably restricting the trolleys to traveling under the shelves instead of in the aisles, as well as giving stacking vehicles

priority over the trolleys, the system of Hangzhou is able to deliver goods and avoid collisions. [EX1006, HANGZHOU ¶¶ 48, 59.]

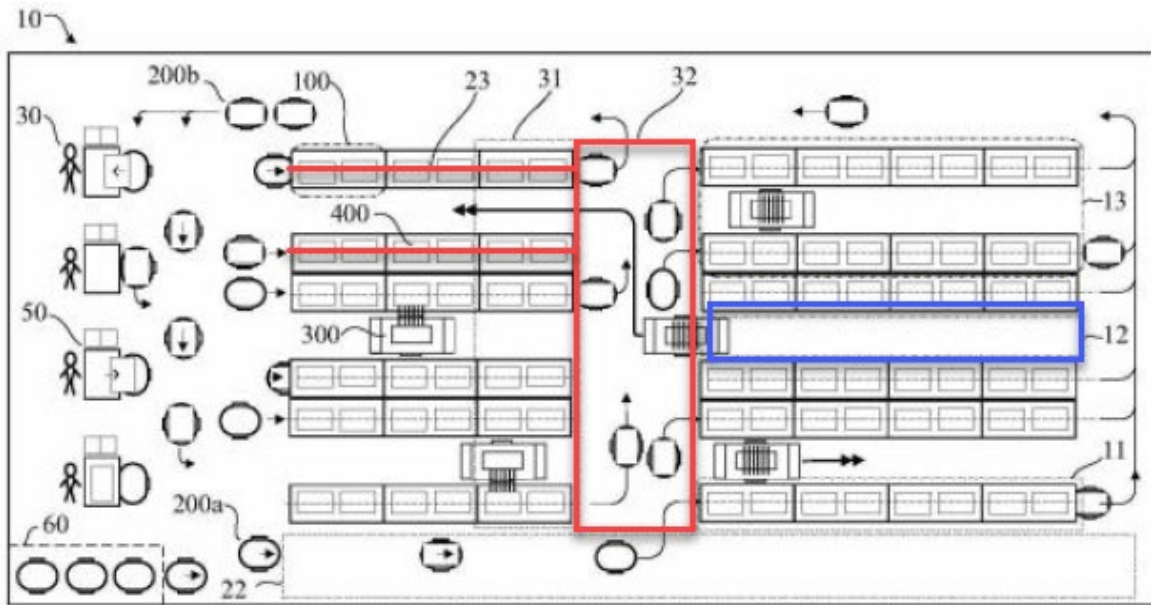


FIG. 1

[EX1006, HANGZHOU, Figure 3.]

120. Raizer, in contrast to Hangzhou's method of spacing out multi-type robots across the floor, avoids collisions by using only one type of robot and distributes them vertically on shelves to reduce floor congestion and avoid collisions. This strategy also reduces mapping issues by eliminating the need to go under shelves. As shown below in Figure 12A, Raizer's robots travel on the face of the shelves and can travel above and below each other to avoid colliding. This

operational strategy exploits the three-dimensional nature of automated warehouses and greatly reduces floor congestion.

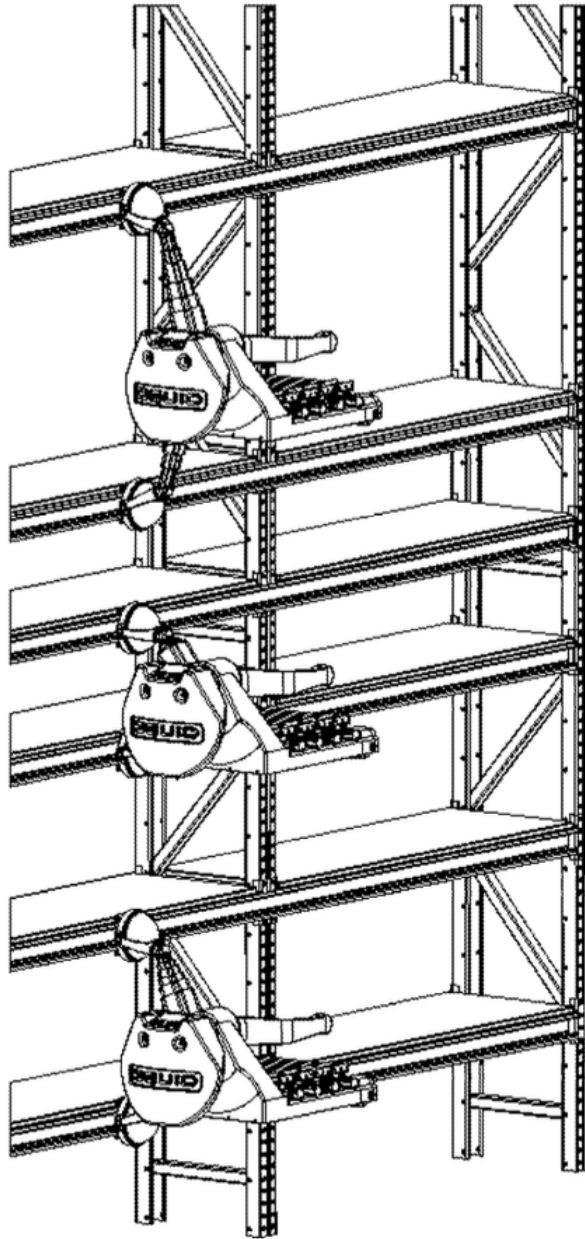


Fig. 12A

[EX1005, RAIZER, Figure 12A.]

121. During his deposition, Dr. Spenko analyzed four possible ways that the delivery robots in Petitioner's proposed system would operate in a warehouse. He stated how a robot in the modified system, which uses Raizer's robots, would retrieve a container from a specific location. Figure 1, below, shows the paths he proposed. I reviewed his example scenarios and they confirm that a POSITA would not combine Raizer and Hangzhou at least because of the issues created in Petitioner's proposed modification.

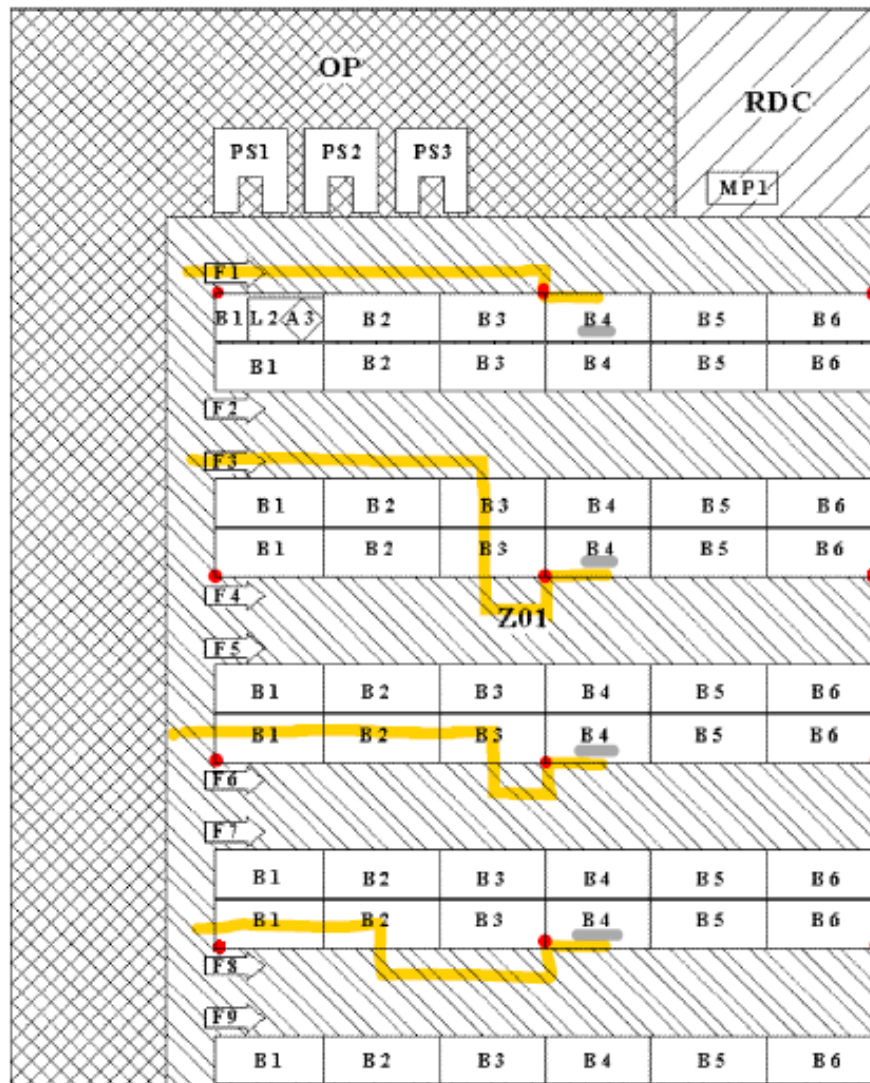


Fig. 1

EX2005 Figure 1 (showing possible container retrieval scenarios for the system of Raizer (top line) and Petitioner's modified system (2nd, 3rd, and 4th lines from the top)).

122. In his proposed modified system, the delivery robot would travel along a **path** (shown in yellow) until it reached a desired **terminal** (shown in red),

wherein it would climb the shelves vertically until it reached the desired bay (underlined in grey). Dr. Spenko described four different scenarios that he claimed were accurate representations of such a system's method for retrieving a container.

123. For his first scenario, Dr. Spenko described Raizer's unmodified system. [EX2006, 95:23-107:9.] He explained Raizer as a robot traveling down path F1 until it reached the middle terminal, vertically ascending the shelves until it reaches the height of the container, traveling horizontally to bay B4, retrieving the container, and then returning along the same path as it initially traveled. [EX2006, 95:23-107:9.]

124. In the second scenario, Dr. Spenko described Petitioner's modified system to go from starting point F3 to bay B4 in aisle F4. [EX2006 107:14-108:4.] As shown by the yellow line second from the top in Figure 1 below, Dr. Spenko described this scenario as a robot traveling along F3 until bay B3, traveling under the shelves at B3 into row F4, traveling out into the aisle of F4, turning around, vertically ascending the shelves until it reaches the height of the container, traveling horizontally to bay B4, retrieving the container, and then returning along the same path as it initially traveled. [EX2006, 107:14-112:18.]

125. In the third scenario, Dr. Spenko described Petitioner's modified system to go from starting point near F6 to bay B4 in F6. As shown by the yellow line third from the top in Figure 1 below, Dr. Spenko described this scenario as a

robot traveling horizontally under the shelf adjacent to F6 until bay B3, traveling out into the aisle of F6, turning around, vertically ascending the shelves until it reaches the height of the container, traveling horizontally to bay B4, retrieving the container, and then returning along the same path as it initially traveled. [EX2006, 112:19-114:21.]

126. Finally, in a fourth scenario, Dr. Spenko described another scenario of Petitioner's modified system to go from starting point near F8 to bay B4 in F8. As shown by the yellow line fourth from the top in Figure 1 below, Dr. Spenko agreed that in this scenario a robot could travel horizontally under the shelf adjacent to F8 until bay B2, at which point it would travel out into the aisle of F8 at bay B2, turn to travel along aisle F8, travel in aisle F8 until it reaches the terminal between B3 and B4, vertically ascend the shelves until it reaches the height of the container, travel horizontally to bay B4, retrieve the container, and then return along the same path as it initially traveled. [EX2006, 114:22-115:17.]

127. In every example that Dr. Spenko described Petitioner's proposed modified system, the robot was required to travel out into the aisle to engage the rails needed to vertically ascend the shelves. [EX2006 at 111:3-112:2, EX1005, RAIZER ¶ 111.] The terminals of Raizer are on the front of the shelving units and Raizer's robot engages the rails with arms in the front of the robot. [EX1005, RAIZER ¶ 103, 111, Figure 5A.] Therefore, robots are required to travel out into

the aisles to engage the terminals. [See EX1005, RAIZER ¶ 111.] These terminals are the “only place where robots 10 can connect or disconnect from the rails 42 in order to climb to or descend from the shelves.” [EX1005, RAIZER ¶ 111.] Dr. Spenko shows the required swing out of the robot in his illustrations of various scenarios of the modified system. [See EX2005, Figure 1.]

128. The solution described by Dr. Spenko is glaringly at odds with the system described in Raizer. As described above, the delivery trolley robots of Hangzhou preferentially did not enter the aisles, or only enter the aisles for a minimal amount of time. [EX1006, HANGZHOU, ¶¶ 48, 63 (describing the stacking vehicles of Hangzhou as preferably the only robot that is traveling in the aisle, or “stacking row laneway”)]. Hangzhou operates this way to limit congestion and avoid collisions between the trolley and the stacking vehicles. Crucially, this preference was created with two robots to avoid congestion and collisions.

129. Therefore, while the robots in Raizer could avoid collisions with each other by spacing vertically, when using Raizer’s robots to traverse beneath shelves as in Hangzhou, Raizer’s robots would inevitably be more prone to collision than when operating in the manner defined in Raizer. This is because in Raizer the terminals create a need to enter the aisle, in contrast to Hangzhou’s trolleys. This undercuts the supposed benefits of incorporating additional pathways. This is

unsurprising given the nature of Hangzhou's stacking robots, which by design, fill the aisles they are located in and are capable of servicing the shelves on either side of the aisle. [EX1006, HANGZHOU, ¶¶ 16, 46, Figure 3.] As explained in Hangzhou:

The width of a stacking vehicle 300 is slightly narrower than that of a stacking row laneway 12, and its grabbing components 320 can grab standardized containers 400 and items on shelves 100 on both sides of a stacking row laneway 12. [EX1006, HANGZHOU, ¶ 46.]

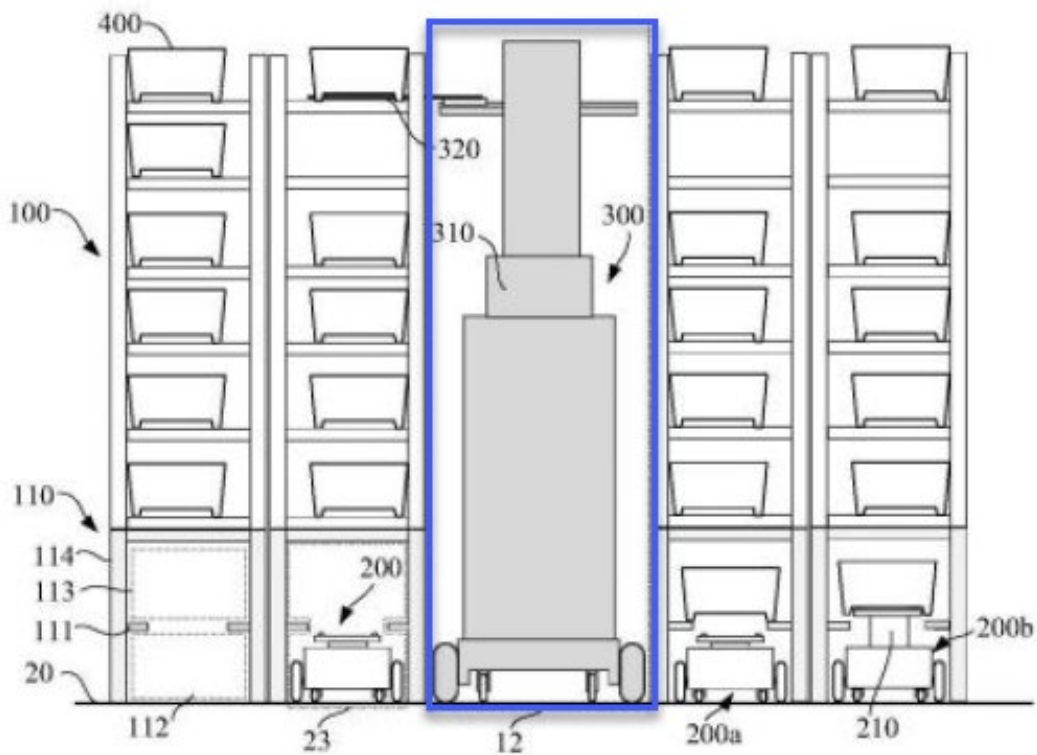


FIG. 3

[EX1006, HANGZHOU, Figure 3.]

130. Comparing the paths described by Dr. Spenko to Figure 3 of Hangzhou, it is clear to me—and would be to a POSITA as well—there is an issue with Petitioner’s proposed system. Raizer’s robots must be wide enough to support the containers they carry, in contrast to the trolleys in Hangzhou, where trolleys must drop off specialized containers onto support beams before turning so as to avoid colliding the container’s corners with the shelving.

131. Petitioner’s proposed modified system drastically increases the implementation costs and increases the likelihood of collisions between Raizer’s robots and the legs of the shelves. Therefore, a POSITA would not have been motivated to combine the systems of Raizer and Hangzhou.

D. A POSITA Would Not Have A Reasonable Likelihood Of Success Creating Petitioner’s Proposed Combination And Petitioner Fails To Address This Shortcoming

132. A POSITA would not have had a reasonable likelihood of success combining Raizer and Hangzhou, which is evident from Petitioner’s failure to address any likelihood of success. This lack of likelihood of success leads to three key shortcomings: 1) Petitioner fails to address a reasonable expectation of success in their petition 2) they fail to describe their proposed combination with sufficient specificity as to determine whether there would be a reasonable expectation of success and 3) even if Petitioner’s system is deemed sufficiently described, the system would not have operated successfully as described.

**1. Petitioner Fails To Address A Reasonable Expectation Of
Success In Their Petition**

133. When briefly mentioning expectation of success, Dr. Spenko only relies on conclusory statements and not the references' actual disclosures. For example, in the first paragraph of his Declaration Exotec relies on, Dr. Spenko merely opines:

A person of ordinary skill in the art would have had a reasonable expectation of success in the combination of Raizer and Hangzhou *based on the explicit teachings of the references and the knowledge of the person of ordinary skill in the art.* Moreover, in view of the disclosures of Raizer and Hangzhou indicating the robots and trolleys can travel throughout a warehouse, the choice of routing (e.g., turning, under racks, in, across, or parallel to aisles) is an obvious matter of design choice. [EX1003 ¶ 101.]

134. Dr. Spenko does not provide any examples of the “*explicit teachings*” which indicate a reasonable expectation of success, likely because there are not any in the references. [EX1003 ¶ 101.] As discussed above, Raizer and Hangzhou’s disclosures explicitly teach against any combination, let alone a successful one. [See *supra* ¶¶ 94-97.] A POSITA would understand these teachings and not try to force these incompatible designs into a combination despite their teaching away from each other.

135. Dr. Spenko also does not provide any support for his statement that expectation of success would come from “*knowledge of the person of ordinary skill in the art.*” Similar to “*explicit teachings,*” he offers no examples of such knowledge. I am unaware of any POSITA knowledge that would lead to an expectation of success. In fact, the POSITA knowledge that I am aware of would lead to an expectation of failure, as I have described above.

136. Dr. Spenko also does not provide any support for his statement that the robot routing for Petitioner’s combined system is “an obvious matter of design choice.” [EX1003 ¶ 1001.] In fact, it is not an obvious matter of design choice. As discussed above, Petitioner failed to provide what those “design choice[s]” would be. [See *supra* ¶¶ 83-93.] I do not believe there are obvious design choices for a combination of these references as Raizer and Hangzhou take drastically different approaches to robot routing in automated warehousing. Raizer uses a single type of robot that travels only through aisles to climb rails to retrieve items. On the other hand, Hangzhou uses a multi-type robot system where the trolley robots cannot climb vertically, but they can travel under the shelves through the use of a specially designed channel support frame to automatically guide a trolley. Furthermore, they must utilize a specific unload-turn-reload-payload process for turning while under the racks. [See *supra* ¶97.] Dr. Spenko’s conclusory statement that the choice of routing is “an obvious matter of design choice” is incorrect.

Raizer's system cannot choose a route that would cause the robot to collide with a preexisting shelf, for example, on the floor level. Nor could Raizer's system choose a route that does not appear on the map that is created from its automated survey mode.

137. In their petition, Exotec repeatedly relies on Dr. Spenko's Declaration, but again, it offers no evidence to support his position regarding a reasonable expectation of success. [Petition, 6- 9, EX1003 ¶ 116.] Dr. Spenko merely states "it is my opinion that a person of ordinary skill in the art would have been motivated to combine the teachings of Raizer and Hangzhou." [EX1003 ¶ 116.]

138. A POSITA would not have combined Raizer and Hangzhou, nor would a POSITA have a reasonable expectation of success in doing so. Neither Exotec nor Dr. Spenko provide any meaningful arguments or evidence to the contrary.

2. Petitioner Fails To Describe Their Proposed Combination With Sufficient Specificity As To Determine The Expectation Of Success

139. As I discuss above, Exotec and Dr. Spenko failed to provide adequate disclosure of their proposed modified system. [See *supra* ¶¶83-97.] Petitioner identified only singular elements from each of the references, instead of describing an actual combined system. A POSITA would not understand what Petitioner's

actual proposed system would be and how it would function. Therefore, there is simply no way that a POSITA would be able to determine the expectation of success of this hypothetical system.

3. Petitioner's Proposed Combination, Even If Described Sufficiently To Be Created, Would Not Have Operated Successfully

140. Assuming Petitioner had actually described the proposed combination sufficiently, Petitioner's modified system likely would not have operated successfully.

141. First, as I have explained above, Petitioner's proposed system is incompatible with the goals and teachings of Raizer. [*See supra* ¶¶103-122.] For at least those reasons, there is no evidence that a POSITA would have a motivation to combine Raizer and Hangzhou, nor reasonable expectation of success in attempting to do so in the manner suggested by Petitioner.

142. Second, Petitioner's proposed combination leverages proprietary components, such as those of Raizer, and therefore, a POSITA cannot have a reasonable expectation of success creating this combination.

143. Raizer describes its automated storage-and-retrieval invention as using proprietary components to perform critical features:

- The robots are pre-loaded with **proprietary software** which includes the warehouse layout, routes, intersections, and designated areas (this mapping Survey is recorded by a “Survey Mode” of the robot's software). [EX1005, RAIZER ¶84.]
- Each robot utilizes dedicated maneuvering algorithms and a **proprietary “Fine Positioning” procedure** to enable precise, quick and efficient loading. [EX1005, RAIZER ¶84.]

144. Proprietary components are by their nature, not available to the public, and cannot be combined with technology from a secondary source by a POSITA, because a POSITA would not have access to the proprietary components.

145. For example, a POSITA would not know how to modify the proprietary component to achieve the proposed combination because the operating principles of the proprietary components would not be known to a POSITA. Thus, because proprietary components are not known to a POSITA, they cannot be modified.

146. The proprietary components used in Raizer perform critical features *vis-à-vis* the claim language. Example uses of the proprietary components in the claimed features include:

- “*driving a first one of the vehicles to drive the first vehicle to the storage racks.*” ’632 Patent Claim [1.c].⁷ This limitation cannot be practiced without the proprietary software that includes the warehouse layout, routes, intersections, and designated areas. There is no way to drive vehicles to the storage racks without the layout, routes, and intersections provided by the proprietary software.
- “*driving the first vehicle along a first path under a first one of the racks.*” ’632 Patent Claim [1.d1]. This limitation cannot be practiced without the proprietary software that includes the warehouse layout, routes, intersections, and designated areas. There is no way to drive vehicles under the storage racks without the layout, routes, and intersections provided by the proprietary software.
- “*a transfer mechanism operable to transfer an item between the vehicle and one of the storage locations.*” ’632 Patent Claim [11.c5]. This limitation cannot be practiced without the **proprietary “FinePositioning” procedure** to enable precise, quick and efficient loading.
- “*transferring an item between the first vehicle and the first storage location.*” ’632 Patent Claim [23.e]. This limitation is

⁷ Patent Owner adopts the claim numbering convention from Petitioner’s petition for ease of reference.

practiced using the **proprietary “FinePositioning” procedure** to enable precise, quick and efficient loading.

147. Petitioner defined a POSITA for this proceeding as “a person with a working knowledge of mechanical design and automation. That person would have had a Bachelor of Science degree in an academic discipline emphasizing the design of mechanical, automation, and robotics technologies, in combination with training or at least one to two years of related work experience. Alternatively, that person could have also had a Master of Science degree in a relevant academic discipline with less than a year of related work experience in the same discipline. More education can supplement practical experience and vice versa.” [Paper 8 at 5 (internal citations omitted), Paper 11 at 9-10.]

148. A POSITA is not a person that developed Raizer’s proprietary components. A POSITA is also not a person working at a company that makes systems using Raizer’s proprietary components. Therefore, a POSITA would not know how to modify Raizer’s proprietary components or have any expectation of success in performing any such modification.

149. Petitioner’s proposed modifications include changing Raizer’s operating principle by using a routing system taught by Hangzhou. Raizer’s system does not drive or turn its robots under the shelves. However, the proposed

combination uses the concept of driving robots under the shelves and turning the robots under the shelves. [See Petition, 6-9.]

150. Raizer uses its proprietary software, including a “Survey Mode,” [EX1005, RAIZER ¶84] to establish the routes and intersections that its robots use to navigate. Raizer’s invention does not travel or turn its robots under the shelves, instead the robots travel through the aisles and ascend via rails on the front of the shelving units. Thus, Raizer’s proprietary software does not establish routes and intersections under the shelves. Therefore, Raizer’s proprietary software would have to be changed so that it can establish the required new routes and intersections. As I explained above, given the qualities of “proprietary” components and the definition of a POSITA in this proceeding, such modifications would not be obvious, or even possible via undue experimentation, to a POSITA.

151. Even assuming that a POSITA could or would get access to Raizer’s proprietary software, the POSITA would need to alter the proprietary process such that the robots could drive and turn under the shelves during the “Survey Mode” portion of the proprietary software execution. However, this does not account for mapping under shelves being very challenging and beyond the skill of a POSITA. Further, *Raizer’s* sensors that perform *Raizer’s* “Survey Mode” mapping would operate very differently when driving under a shelf than when driving in the open area of the warehouse. Sensors used in such mapping activities generally use

signal emitting-and-detecting measurements. For example, LiDAR sensors emit laser pulses and measure reflected signals. While this can, and often does, work well in open spaces, such a system being used under shelves would be subject to an array of noisy reflected signals that bounce off of the overhead shelves, the support legs, and more distant objects beyond the shelves. These conditions lead to the well-known multipath reflection problems that significantly degrade emitting-and-detecting sensors in such closed spaces. The reprogramming of such sensors to achieve reliable operation in under-the-shelf conditions is too complex of a modification for a POSITA to achieve, especially in conjunction with proprietary software.

152. These reflected signals cause issues with both proprietary and non-proprietary software and highlight the issues with Petitioner's proposed combination.

153. Petitioner has offered no evidence that Raizer's robots would operate successfully underneath shelves in light of the multipath effects that would degrade its automated mapping during its survey mode. As described above, Raizer uses sensors to navigate the aisles of a warehouse, while Hangzhou uses a channel support frame to help guide its trolleys. Attempting to use Raizer's robot and its sensors to navigate under shelves would create serious navigation issues due to these multipath effects. A POSITA at the time of invention of the '632 patent

would not have a reasonable expectation of success for solving these navigation issues, especially in a manner that would be acceptable in the warehouse settings described in Raizer or Hangzhou. Thus, it cannot be said there is a reasonable expectation of success for Petitioner's proposed combination.

154. In fact, such sensor challenges are even beyond the abilities of large robotics companies staffed with numerous research Ph.Ds. For example, I personally conducted numerous tests on the automapping features offered in autonomous mobile robots around the time of the priority date of the '632 Patent (2021). Although large robotics companies, such as iRobot and SharkNinja, offered features that could "automatically" map a home and detect carpets and furniture in 2021, the mapping systems worked poorly and often needed to be manually overridden with adjusted maps. In particular, the robots could not reliably map the environment near or under low-hanging obstacles such as beds or coffee tables. As explained above, low-hanging overhead structures or numerous closely-spaced obstacles, such as furniture legs, create reflection patterns that are too complicated for the sensor algorithms to figure out and provide accurate position measurements.

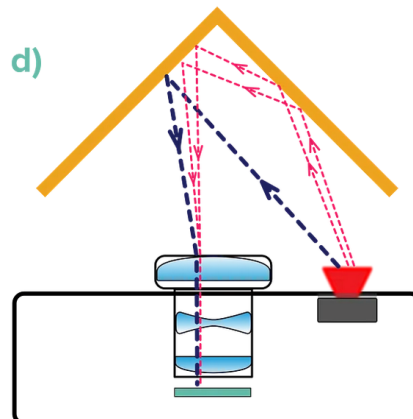
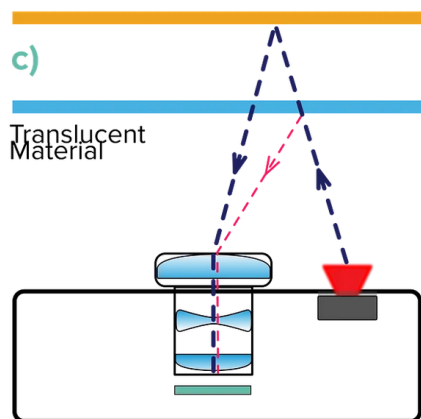
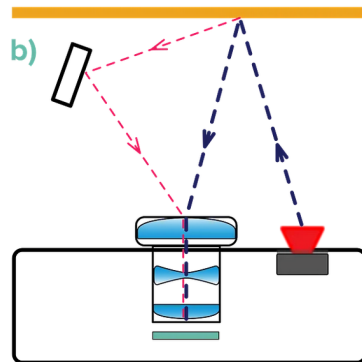
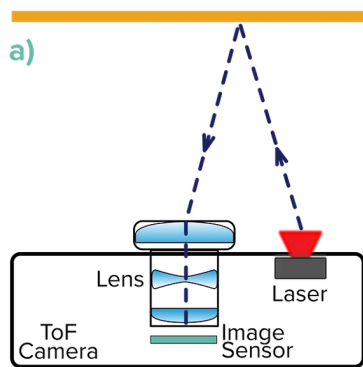
155. Therefore, even if a POSITA somehow knew how to modify proprietary components, then the proposed modification is still nonobvious and beyond the abilities of a POSITA.

E. Dr. Spenko Misunderstands The Technology At Issue

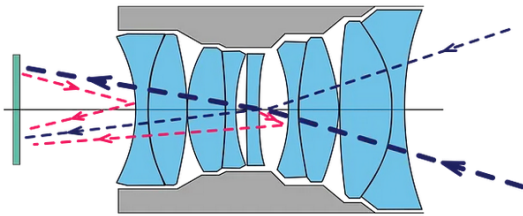
156. Dr. Spenko's oversimplistic view of the issues involved with automation systems, in particular warehouse automation, shows his opinions cannot be given much weight.

157. For example, Dr. Spenko testified that for "everything that we've ever done with Lidar on cars we've never had to deal with multipath errors." [EX2006 at 41:2-3.] This shows Dr. Spenko either does not understand the sensor systems at issue or Lidar behaves differently for him than for most other researchers. It is well known that Lidar suffers from multipath effects. Lidar sends out laser signals and measures the reflections to determine the distance to objects and/or targets. If the signals are reflected back via multiple paths, then the detector has great difficulty in determining which reflected signal corresponds to the distance to the object of concern. Robots navigating cluttered environments suffer much more from multipath effects than robots navigating in an open space.

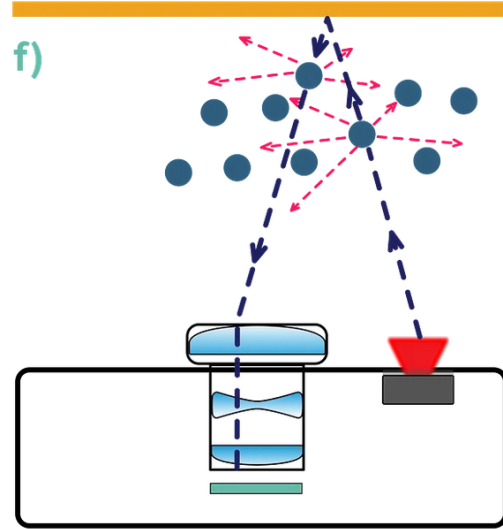
158. Example diagrams showing multipath problems can be readily found in technical publications, or even with simple Google-based searches. For example, a search using "lidar multipath effects" produced a first result that contained the multipath diagrams below.



e)



f)



The causes of multi-path interference. The dark blue line is the desired return to measure, and the pink lines are the interference source. a) the ideal case of no MPI. b) MPI is caused by inter-reflections in the scene. c) MPI is caused by translucent objects. d) Diffuse interreflections, such as in corners. e) MPI caused by lens flare, interreflections inside the lens cavity. f) MPI caused by bulk diffuse scatters, such as by fog (water vapor) or by smoke particles.

Multipath Reflection Diagrams (EX2009)

159. A POSITA would be aware of such problems and understand that such multipath scenarios greatly degrade emitter-detector sensors normally used in automated mapping. In fact, I provide such sensors to my sophomore-level mechanical design class and the students learn that the sensors need a clear and direct path to any obstacle they are attempting to accurately measure.

160. Dr. Spenko also testified that “a person of ordinary skill in the art wouldn’t really care that much like if [mapping is] disclosed or not” because “getting around the warehouse is not a hard -- is not hard.” [EX2006, 86:20-24.] Dr. Spenko goes on to testify that mapping is not that important because “a person of ordinary skill in the art see [Hangzhou] and is like all right, well, create a map.

Like, done. Not an issue.” [EX2006, 87:12-15.] Dr. Spenko’s opinion on mapping is certainly incorrect and shows he does not understand the technology at issue. Accordingly, his opinion on obviousness cannot be assigned much weight.

161. Mapping is critical for autonomous robots and is one of the largest hurdles to overcome. For example, an abstract from a paper from 2015 states: “the proposed method is limited to building interiors consisting of planar structures; the modeling of detailed objects, such as windows and doors, unfortunately, still requires manual operation. Thus, further research on detail modeling and refinement is necessary in order to increase the method’s automation and enhancement of its overall suitability for mapping complex indoor environments.” [Hong et al., “Semi-automated approach to indoor mapping for 3D as-built building information modeling” May 2015.] This admission is a clear indication that even an advanced method being published in 2015 could not perform the required mapping without manual intervention. As indicated by the statement above, mapping becomes progressively more difficult when the robots are traveling in a cluttered environment, or operating with low-overhanging obstacles.

162. Dr. Senko does not fully grasp what he is describing to the Board and clearly has not considered all that is involved with a combination of Raizer and Hangzhou. Thus, it cannot be said there is a motivation to combine nor a reasonable expectation of success.

IX. Conclusion

163. In my opinion, for the reasons discussed above, the challenged claims of the '632 Patent are patentable.

X. Availability for Cross-Examination

164. In signing this declaration, I recognize that the declaration will be filed as evidence in a case before the Patent Trial and Appeal Board of the United States Patent and Trademark Office. I also recognize that I may be subject to cross examination in the case and that cross examination will take place within the United States. If cross examination is required of me, I will appear for cross examination within the United States during the time allotted for cross examination.

XI. Right to Supplement

165. I reserve the right to supplement my opinions in the future to respond to any arguments that the Petitioners may raise and to take into account new information as it becomes available to me.

XII. Jurat

166. I declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false

statements and the like so made are punishable by fine or imprisonment, or both,
under Section 1101 of Title 18 of the United States Code.

February 7, 2025


Dr. William E. Singhose

APPENDIX A

Professor William Singhose, PhD

I. Earned Degrees	2
II. Employment History	2
III. Honors and Awards.....	4
IV. Research, Scholarship, and Creative Activities.....	5
A. Published Books, Book Chapters, and Edited Volumes	5
B. Refereed Publications and Submitted Articles.....	5
D. Presentations.....	37
E. Grants and Contracts.....	41
F. Other Scholarly and Creative Accomplishments	49
G. Other Professional	49
V. Education	50
B. Individual Student Guidance	50
C. Educational Innovations and Other Contributions.....	55
a) New Course Development	55
VI. Service	56
A. Professional Contributions	56
B. Public and Community Service	57
C. Institute Contributions.....	57

WILLIAM SINGHOSE
Professor
The George W. Woodruff School of Mechanical Engineering
Georgia Institute of Technology
813 Ferst Drive, N.W., Atlanta, GA 30332
Office: 404-385-0668 fax: 404-894-9342
Singhose@gatech.edu

I. Earned Degrees

1997, Ph.D. Mechanical Engineering, Massachusetts Institute of Technology
1992, M.S. Mechanical Engineering, Stanford University
1990, B.S. Mechanical Engineering, Massachusetts Institute of Technology

II. Employment History

Georgia Institute of Technology (8/98 – present) Atlanta, GA
Professor of Mechanical Engineering (2014-Present). Associate Professor (2004-2014).
Assistant Professor (1998-2004). Director of Crane Safety Research Center (2023-
Present). Head of Automation and Mechatronics Group (2006-2010). Develop curriculum
and teach courses in mechanical design, dynamics, controls, and rehabilitation
engineering. Develop research programs and proposals. Direct research of graduate
students, undergraduate students, and postdoctoral researchers in the areas of dynamics,
vibration suppression, robotics, spacecraft, crane control, flight control, active seating
technology, and product design. Advise SME, ASME, and CanSat student groups. Held
visiting appointments at MIT, Stanford, the Tokyo Institute of Technology, and
Polytechnic University of Madrid.

InVekTek, Inc. (12/15 – present) Atlanta, GA
Co-Founder and CTO. Develop and commercialize control systems for robotic and
industrial material-handling systems. The control systems are embedded in motor drives
to reduce unwanted machine motion.

Google, Inc. (9/17 – 12/19) Mountain View, CA
Pennington Advisor mechanical engineer to Google's augmented reality (Daydream) and
Advanced Technology and Projects (ATAP) facilities. Performed mechanical design and
analysis of hand-held consumer electronic products and wearable devices. Performed
failure and hazard analyses. Directed and performed research activities on human-motion
measurement, human-machine interactions, actuation system design, and activity
monitoring.

Stanford University (3/18 – 7/19) Stanford, CA
Visiting Professor in the Department of Mechanical Engineering. Delivered lectures on
product design, safety analysis, and sensors. Advised student design teams.

CAMotion Cranes, Inc. (9/08 – 11/2013) Atlanta, GA
Co-Founder and Board Member. Developed and commercialized crane-control
technology. Controllers improve crane safety, throughput, and ease of operation. Sold
company to PaR Systems in Nov. 2013.

Massachusetts Institute of Technology (9/10 – 6/11) Cambridge, MA
Taught graduate-level controls course. Supervised research projects. Developed textbook on command-shaping control methods.

Polytechnic University of Madrid (5/10 – 8/10) Madrid, Spain
Taught course in manufacturing controls. Supervised construction of experimental equipment. Developed international collaborative research projects.

Tokyo Institute of Technology (10/05 – 4/06) Tokyo, Japan
Visiting Associate Professor in Center of Excellence in Robotics. Taught advanced control course. Conducted experiments with robotic crane. Developed research proposals with Japanese collaborators.

Massachusetts Institute of Technology (6/97 – 7/98) Cambridge, MA
Postdoctoral Fellow in the NSF Center for Innovation in Product Development. Directed the development of an internet-controlled machine. Conducted research in design process optimization. Taught senior-level design course.

Convolve, Inc. (4/92 - 8/94) Armonk, NY
Managed NSF sponsored project investigating techniques for inspecting manufactured parts using measurement robots. Developed computer simulations of manufacturing robots, coordinate measuring machines, car seats, and NASA weather balloons. Designed control systems for automated machines. Designed data acquisition system using a laser interferometer.

Apple Computers, Inc. (6/91 - 3/92) Santa Clara, CA
Designed and performance evaluation tests for the Audio-Visual 14" Monitor. Designed and constructed test equipment. Organized, interpreted and reported test results produced by product evaluation team. Made design recommendations based on test results and dynamic simulations.

Walt Disney World (5/90-8/90) Orlando, FL
Designed components for the Space Mountain rehabilitation project. Performed failure analysis and developed design changes for Star Tours and Body Wars simulators. Performed stress analysis of the Star Jets base plate and specified welds. Designed IR sensor mount and cable management for the Norway Pavilion water ride. Formulated repair procedures for Pirates of the Caribbean roller bearings.

Artificial Intelligence Laboratory (12/87 - 6/90) Cambridge, MA
Developed computer simulations of flexible robots. Performed research on command-shaping methods to eliminate vibration in computer controlled machines. Performed robotic experiments to verify controller's robustness to modeling errors and changing configurations. Verified new control theory by performing simulations of the space shuttle's robotic arm. The control methods were tested on-orbit in Space Shuttle Endeavour.

Cable News Network (Summer '89) Atlanta, GA
AAAS Mass Media Science and Engineering Fellow. Wrote several stories for CNN Science and Technology. Field producer on stories covering the Starship 1 aircraft and

an international climate study. Produced a story reporting on a car seat that lowers impact forces during head-on collisions.

Riverside Cement Company (Summer '88) Riverside, CA
Cement lab technician. Designed and performed experiments to test mechanical properties of cement. Operated a wide range of equipment including forklifts, cement pumps, sand sifters, trucks, climatic test chambers, and compression testing machines.

Bill's Asphalt Repair (8/85-8/87) Springfield, OR
Developed bids and executed construction projects involving asphalt and concrete structures. Operated heavy machinery including: dump trucks, paving machines, steam rollers, and compactors.

III. Honors and Awards

Academic

- 2015 Asian Control Conference, Best Application Paper Finalist
- 2013 Zeigler Woodruff School Outstanding Educator Award
- 2009 Georgia Tech SAIC Student Paper Contest Winner, Graduate Division
- 2006 Georgia Tech SAIC Student Paper Contest Winner, Undergraduate Division
- 2004 CETL Educational Partnership Award
- 2003 SME Jiri Tlustý Outstanding Young Manufacturing Engineer Award
- 2002 Georgia Tech SAIC Student Paper Contest Winner, Undergraduate Division
- 2002 CETL/BP Junior Faculty Teaching Excellence Award
- 2002 Japan Society for the Promotion of Science Invitation Fellowship
- 2001 Georgia Tech SAIC Student Paper Contest Winner, Undergraduate Division
- 1996 Massachusetts Space Grant Fellowship
- 1990 Office of Naval Research Fellowship
- 1990 Phi Beta Kappa
- 1989 AAAS Mass Media Science and Engineering Fellowship
- 1989 Tau Beta Pi
- 1989 Pi Tau Sigma

Academic and Athletic

- 1990 The GTE Academic All-American, Collegiate Division (only one award nationally each year)
- 1990 NCAA Postgraduate Scholarship
- 1990 NACDA/Walt Disney Scholar-Athlete Award

Athletic

- 1989 NCAA Division III National Decathlon Champion
- 1990 New England Division III Athlete of the Year
- 1990 All New England Field Athlete of the Year
- 1988-1990 NCAA Division III All-American (8-Times)

IV. Research, Scholarship, and Creative Activities

A. Published Books, Book Chapters, and Edited Volumes

- [1] J. Vaughan and W. Singhose, "Advances in Delays and Dynamics at Springer," in *The Influence of Time Delay on Crane Operator Performance*. 2014
- [2] W. Singhose, "Trajectory Planning for Flexible Robots," in *CRC Robotics and Automation Handbook*, T. Kurfess, Ed.: CRC Press, 2004.
- [3] W. Singhose and W. Seering, "Control of Flexible Manipulators with Input Shaping Techniques," in *Flexible Robot Manipulators: Modelling, Simulation and Control*, M. O. Tokhi and A. K. M. Azad, Eds. Stevenage, UK: The Institution of Engineering and Technology, 2008, pp. 235-257.
- [4] W. Singhose and J. Donnell, *Introductory Mechanical Design Tools*: www.lulu.com/content/3365814, 978-0-9842210-4-2, 2009.
- [5] W. Singhose, J. Donnell, and D. Frakes, *Introductory Biomechanical Design Tools*: www.lulu.com/content/8235890, 978-0-9842210-5-9, 2010.
- [6] W. Singhose and W. Seering, *Command Generation for Dynamic Systems*: www.lulu.com/content/621219, 978-0-9842210-0-4, 2010.
- [7] M. A. Lau and W. E. Singhose, "Optimal Control of Dynamical Systems," in *Applications of Spreadsheets in Education The Amazing Power of a Simple Tool*, M. L. a. S. Sugden, Ed.: Bentham Science Publishers Ltd., 2011, pp. 41–63.
- [8] W. Singhose, J. Donnell, and Y. Hu, *Introductory Mechanical Design Tools (in Chinese)*. Wuhan, China: Huazhong University of Science and Technology Press, 978-7-5609-7926-7, 2012.

B. Refereed Publications and Submitted Articles

Journal Articles

- [1] W. Singhose, W. Seering, and N. Singer, "Residual Vibration Reduction Using Vector Diagrams to Generate Shaped Inputs," *ASME J. of Mechanical Design*, vol. 116, no. June, pp. 654-659, 1994.
- [2] W. Singhose, K. Bohlke, and W. Seering, "Fuel-Efficient Pulse Command Profiles for Flexible Spacecraft," *AIAA J. of Guidance, Control, and Dynamics*, vol. 19, no. 4, pp. 954-960, 1996.
- [3] W. Singhose, S. Derezinski, and N. Singer, "Extra-Insensitive Input Shapers for Controlling Flexible Spacecraft," *AIAA J. of Guidance, Control, and Dynamics*, vol. 19, no. 2, pp. 385-91, 1996.
- [4] W. Singhose and N. Singer, "Effects of Input Shaping on Two-Dimensional Trajectory Following," *IEEE Trans. on Robotics and Automation*, vol. 12, no. 6, pp. 881-887, 1996.
- [5] W. Singhose, N. Singer, and W. Seering, "Improving Repeatability of Coordinate Measuring Machines with Shaped Command Signals," *Precision Engineering*, vol. 18, no. April, pp. 138-146, 1996.

- [6] L. Y. Pao and W. E. Singhose, "Verifying Robust Time-Optimal Commands for Multi-Mode Flexible Spacecraft," *AIAA J. of Guidance, Control, and Dynamics*, vol. 20, no. 4, pp. 831-833, 1997.
- [7] W. Singhose, A. Banerjee, and W. Seering, "Slewing Flexible Spacecraft with Deflection-Limiting Input Shaping," *AIAA J. of Guidance, Control, and Dynamics*, vol. 20, no. 2, pp. 291-298, 1997.
- [8] W. Singhose and L. Pao, "A Comparison of Input Shaping and Time-Optimal Flexible-Body Control," *IFAC Control Engineering Practice*, vol. 5, no. 4, pp. 459-467, 1997.
- [9] W. Singhose, L. J. Porter, T. D. Tuttle, and N. C. Singer, "Vibration Reduction Using Multi-Hump Input Shapers," *ASME J. Dynamic Systems, Measurement, and Control*, vol. 119, no. June, pp. 320-326, 1997.
- [10] W. Singhose, N. Singer, and W. Seering, "Time-Optimal Negative Input Shapers," *ASME J. Dynamic Systems, Measurement, and Control*, vol. 119, no. June, pp. 198-205, 1997.
- [11] W. E. Singhose, E. A. Crain, and W. P. Seering, "Convolved and Simultaneous Two-Mode Input Shapers," *IEE Control Theory and Applications*, vol. 144, no. Nov., pp. 515-520, 1997. [Online].
- [12] W. E. Singhose, L. Y. Pao, and W. P. Seering, "Slewing Multi-Mode Flexible Spacecraft Using Zero Derivative Robustness Constraints," *AIAA J. of Guidance, Control, and Dynamics*, vol. 20, no. 1, pp. 204-206, 1997.
- [13] A. K. Banerjee and W. E. Singhose, "Command Shaping in Tracking Control of a Two-Link Flexible Robot," *AIAA J. of Guidance, Control, and Dynamics*, vol. 21, no. 6, pp. 1012-1015, 1998.
- [14] L. Y. Pao and W. E. Singhose, "Robust Minimum Time Control of Flexible Structures," *Automatica*, vol. 34, no. 2, pp. 229-236, 1998.
- [15] N. C. Singer, W. E. Singhose, and W. P. Seering, "Comparison of Filtering Methods for Reducing Residual Vibration," *European Journal of Control*, vol. 5, no. 2, pp. 208-219, 1999.
- [16] W. Singhose, B. Mills, and W. Seering, "Closed-Form Methods for Generating On-Off Commands for Undamped Flexible Structures," *AIAA J. of Guidance, Control, and Dynamics*, vol. 22, no. 2, pp. 378-82, 1999.
- [17] W. Singhose, T. Singh, and W. Seering, "On-Off Control with Specified Fuel Usage," *ASME J. Dynamic Systems, Measurement, and Control*, vol. 121, no. 2, pp. 206-212, 1999.
- [18] K. Grosser and W. Singhose, "Command Generation for Reducing Perceived Lag in Flexible Telerobotic Arms," *JSME International Journal*, vol. 43, no. 3, pp. 755-761, 2000.
- [19] R. A. Masterson, W. E. Singhose, and W. P. Seering, "Setpoint Generation for Constant-Velocity Motion of Space-Based Scanners," *AIAA J. of Guidance, Control, and Dynamics*, vol. 23, no. 5, pp. 892-895, 2000.

- [20] W. Singhose, L. Porter, M. Kenison, and E. Kriikku, "Effects of Hoisting on the Input Shaping Control of Gantry Cranes," *IFAC Control Engineering Practice*, vol. 8, no. 10, pp. 1159-1165, 2000.
- [21] A. Banerjee, N. Pedreiro, and W. Singhose, "Vibration Reduction for Flexible Spacecraft Following Momentum Dumping with/without Slewing," *AIAA J. of Guidance, Control, and Dynamics*, vol. 24, no. 3, pp. 417-428, 2001.
- [22] M. Kenison and W. Singhose, "Concurrent Design of Input Shaping and Proportional Plus Derivative Feedback Control," *ASME J. of Dynamic Systems, Measurement, and Control*, vol. 124, no. 3, pp. 398-405, 2002.
- [23] U. Andresen and W. Singhose, "A Simple Procedure for Modifying High-Speed Cam Profiles for Vibration Reduction," *ASME J. of Mechanical Design*, vol. 126, no. Nov., pp. 1105-1108, 2004.
- [24] K. Kozak, I. Ebert-Uphoff, and W. Singhose, "Locally Linearized Dynamic Analysis of Parallel Manipulators and Application of Input Shaping to Reduce Vibrations," *ASME J. of Mechanical Design*, vol. 126, no. Jan., pp. 156-168, 2004.
- [25] W. Singhose, E. Biediger, Y.-H. Chen, and B. Mills, "Reference Command Shaping Using Specified-Negative-Amplitude Input Shapers for Vibration Reduction," *ASME J. of Dynamic Systems, Measurement, and Controls*, vol. 126, no. March, pp. 210-214, 2004.
- [26] J. Fortgang and W. Singhose, "Concurrent Design of Vibration Absorbers and Input Shapers," *ASME J. Dynamic Systems, Measurement, and Control*, vol. 127, no. September, pp. 329-335, 2005.
- [27] J. Fortgang and W. Singhose, "Design Of Vibration Absorbers For Step Motions and Step Disturbances," *ASME J. of Mechanical Design*, vol. 127, no. March, pp. 160-163, 2005.
- [28] J. Lawrence, W. Singhose, and K. Hekman, "Friction-Compensating Input Shaping for Vibration Reduction," *ASME J. of Vibration and Acoustics*, vol. 127, no. August, pp. 307-14, 2005.
- [29] T. Watanabe, H. A. Fujii, H. Kojima, and W. Singhose, "Design of Electric Current Profile for Electrodynamic Tether System by Input Shaping Method (In Japanese)," *J. of the Japan Society for Aeronautical and Space Sciences*, vol. 53, no. 623, pp. 569-576, 2005.
- [30] S.-W. Hong, V. Patrangenaru, W. Singhose, and S. Sprigle, "A Method for Identifying Human-Generated Forces During an Extensor Thrust," *Int. J. of Precision Engineering and Manufacturing*, vol. 7, no. 3, pp. 66-71, 2006.
- [31] S.-W. Hong, V. Patrangenaru, W. Singhose, and S. Sprigle, "Identification of Human-Generated Forces on Wheelchairs During Total-Body Extensor Thrusts," *Clinical Biomechanics*, vol. 21, no. 8, pp. 790-798, 2006.
- [32] A. Khalid, J. Huey, W. Singhose, J. Lawrence, and D. Frakes, "Human Operator Performance Testing Using an Input-Shaped Bridge Crane," *ASME J. of Dynamic Systems, Measurement, and Control*, vol. 128, no. 4, pp. 835-841, 2006.

- [33] K. Kozak, W. Singhose, and I. Ebert-Uphoff, "Performance Measures For Input Shaping and Command Generation," *ASME J. Dynamic Systems, Measurement, and Control*, vol. 128, no. 3, pp. 731-6, 2006.
- [34] J. d. J. Márquez, J. Fortgang, W. Singhose, and J. M. Perez, "Optimización del Proceso de Microfresado Mediante La Reducción de Vibraciones Empleando Técnicas de Generación de Ordenes de Movimiento," *Revista Internacional de Información Tecnológica*, vol. 17, no. 6, pp. 3-6, 2006.
- [35] M. Robertson, K. Kozak, and W. Singhose, "Computational Framework for Digital Input Shapers Using Linear Optimization," *IEE Control Theory and Applications*, vol. 153, no. 3, pp. 314-322, 2006.
- [36] W. Singhose, E. Biediger, H. Okada, and S. Matunaga, "Experimental Verification of Real-Time Control for Flexible Systems with On-Off Actuators," *ASME J. of Dynamic Systems, Measurement, and Controls*, vol. 128, no. 2, pp. 287-96, 2006.
- [37] W. Singhose, E. Biediger, H. Okada, and S. Matunaga, "Closed-Form Specified-Fuel Commands for On-Off Thrusters," *AIAA J. of Guidance, Control, and Dynamics*, vol. 29, no. 3, pp. 606-11, 2006.
- [38] W. Singhose, J. Lawrence, K. Sorensen, and D. Kim, "Applications and Educational Uses of Crane Oscillation Control," *FME Transactions*, vol. 34, no. 4, pp. 175-183, 2006.
- [39] K. A. Hekman and W. E. Singhose, "A Feedback Control System for Suppressing Crane Oscillation with On-Off Motors," *Int. Journal of Control, Automation, and Systems*, vol. 5, no. 3, pp. 223-233, 2007.
- [40] H. Kojima and W. Singhose, "Adaptive Deflection Limiting Control for Slewing Flexible Space Structures," *AIAA J. of Guidance, Control, and Dynamics*, vol. 30, no. 1, pp. 61-67, 2007.
- [41] S.-W. Park, S.-W. Hong, H.-S. Choi, and W. Singhose, "Discretization Effects of Real-Time Input Shaping in Residual Vibration Reduction for Precise XY Stage (in Korean)," *Trans. of the Korean Society of Machine Tool Engineers*, vol. 16, no. 4, pp. 71-78, 2007.
- [42] M. J. Robertson and W. E. Singhose, "Specified-Deflection Command Shapers for Second-Order Position Input Systems," *ASME J. Dynamic Systems, Measurement, and Control*, vol. 129, no. 6, pp. 856-859, 2007.
- [43] K. Sorensen, W. Singhose, and S. Dickerson, "A Controller Enabling Precise Positioning and Sway Reduction in Bridge and Gantry Cranes," *IFAC Control Engineering Practice*, vol. 15, no. 7, pp. 825-837, 2007.
- [44] Y.-G. Sung and W. Singhose, "Closed-Form Specified-Fuel Commands for Two Flexible Modes," *AIAA J. of Guidance, Control, and Dynamics*, vol. 30, no. 6, pp. 1590-6, 2007.
- [45] T. Bradley, J. Danielson, J. Lawrence, and W. Singhose, "Command Shaping for Non-Symmetrical Acceleration and Braking Dynamics," *ASME J. of Vibration and Acoustics*, vol. 130, no. Oct., pp. 054503-1-5, 2008.

- [46] J. Danielson, J. Lawrence, and W. Singhose, "Command Shaping for Flexible Systems Subject to Constant Acceleration Limits," *ASME J. Dynamic Systems, Measurement, and Control*, vol. 130, no. 5, pp. 0510111-0510118, 2008.
- [47] S.-W. Hong, S.-W. Park, and W. Singhose, "Input Shaping for Vibration Control in Precise Positioning System (in Korean)," *Korean Society for Precision Engineering*, vol. 25, no. 4, pp. 26-31, 2008.
- [48] J. R. Huey, K. L. Sorensen, and W. E. Singhose, "Useful Applications of Closed-Loop Signal Shaping Controllers," *IFAC Control Engineering Practice*, vol. 16, no. 7, pp. 836-846, 2008.
- [49] W. Singhose, D. Kim, and M. Kenison, "Input Shaping Control of Double-Pendulum Bridge Crane Oscillations," *ASME J. Dynamic Systems, Measurement, and Control*, vol. 130, no. May, p. 034504, 2008.
- [50] K. Sorensen, A. Daftari, W. Singhose, and K. Hekman, "Negative Input Shaping: Eliminating Overcurrenting and Maximizing the Command Space," *ASME J. of Dynamic Systems, Measurement, and Control*, vol. 130, no. 6, pp. 0610121-0610127, 2008.
- [51] K. Sorensen and W. Singhose, "Command-Induced Vibration Analysis Using Input Shaping Principles," *Automatica*, vol. 44, no. 9, pp. 2392-2397, 2008.
- [52] Y.-G. Sung and W. Singhose, "Deflection-Limiting Commands for Systems with Velocity Limits," *AIAA J. of Guidance, Control, and Dynamics*, vol. 31, no. 3, pp. 472-8, 2008.
- [53] J. Vaughan, J. Fortgang, W. Singhose, J. Donnell, and T. Kurfess, "Using Mechatronics to Teach Mechanical Design and Technical Communication," *Mechatronics*, vol. 18, no. 4, pp. 179-186, 2008.
- [54] J. Vaughan, A. Yano, and W. Singhose, "Comparison of Robust Input Shapers," *J. of Sound and Vibration*, vol. 315, no. 4-5, pp. 797-815, 2008.
- [55] M. Robertson and W. Singhose, "Robust Discrete-Time Deflection-Limiting Commands for Flexible Systems," *IET Control Theory and Applications*, vol. 3, no. 4, pp. 473-480, 2009.
- [56] W. Singhose, "Command Shaping for Flexible Systems: A Review of the First 50 Years," *Int. J. of Precision Engineering and Manufacturing*, vol. 10, no. 4, pp. 153-168, 2009.
- [57] Y.-G. Sung and W. Singhose, "Robustness Analysis of Input Shaping Commands for Two-mode Flexible Systems," *IET Control Theory and Applications*, vol. 3, no. 6, pp. 722-30, 2009.
- [58] Y.-G. Sung and W. E. Singhose, "Limited-State Commands for Systems with Two Flexible Modes," *Mechatronics*, vol. 19, no. August, pp. 780-87, 2009.
- [59] J. Vaughan, A. Yano, and W. Singhose, "Robust Negative Input Shapers for Vibration Suppression," *ASME J. Dynamic Systems, Measurement, and Control*, vol. 131, no. 3, pp. 031014-1-9, 2009.

- [60] D. Blackburn, J. Lawrence, J. Danielson, W. Singhose, T. Kamoi, and A. Taura, "Radial-Motion Assisted Command Shapers for Nonlinear Tower Crane Rotational Slewing," *Control Engineering Practice*, vol. 18, no. May, pp. 523-531, 2010.
- [61] D. Blackburn *et al.*, "Command Shaping for Nonlinear Crane Dynamics," *J. of Vibration and Control*, vol. 16, no. 4, pp. 477-501, 2010.
- [62] J. Hong-Xia, L. Wan-Li, and W. Singhose, "Dynamic Modeling and Vibration Analysis of Cherry Pickers with Flexible Arms (in Chinese)," *Zhendong yu Chongji/Journal of Vibration and Shock*, vol. 29, no. 12, pp. 136-140, 2010.
- [63] J. R. Huey and W. Singhose, "Trends in the Stability Properties of CLSS Controllers: A Root-Locus Analysis," *IEEE Trans. on Control Systems Technology*, vol. 18, no. 5, pp. 1044-56, 2010.
- [64] D. Kim and W. Singhose, "Performance Studies of Human Operators Driving Double-Pendulum Bridge Cranes," *IFAC Control Engineering Practice*, vol. 18, no. June, pp. 567-576, 2010.
- [65] J. Lawrence and W. Singhose, "Command Shaping Slewing Motions for Tower Cranes," *ASME J. of Vibration and Acoustics*, vol. 132, no. Feb., pp. 011002-1-11, 2010.
- [66] R. Manning, J. Clement, D. Kim, and W. Singhose, "Dynamics and Control of Bridge Cranes Transporting Distributed-Mass Payloads," *ASME J. Dynamic Systems, Measurement, and Control*, vol. 132, no. Jan., pp. 014505-3, 2010.
- [67] W. Singhose, R. Eloundou, and J. Lawrence, "Command Generation for Flexible Systems by Input Shaping and Command Smoothing," *AIAA J. of Guidance, Control, and Dynamics*, vol. 33, no. 6, pp. 1697-1707, 2010.
- [68] K. Sorensen, K. Hekman, and W. Singhose, "Finite-State Input Shaping," *IEEE Trans. on Control Systems Technology*, vol. 18, no. 3, pp. 664-72, 2010.
- [69] J. Vaughan, D. Kim, and W. Singhose, "Control of Tower Cranes with Double-Pendulum Dynamics," *IEEE Trans. on Control Systems Technology*, vol. 18, no. 6, pp. 1345 –1358, 2010.
- [70] A. E. Vela, S. Solak, J.-P. Clarke, W. Singhose, E. Barnes, and E. Johnson, "Near Real-Time Fuel-Optimal En Route Conflict Resolution," *IEEE Trans. on Intelligent Transportation Systems*, vol. 11, no. 4, pp. 826-837, 2010.
- [71] J. Fortgang, W. Singhose, J. d. J. Márquez, and J. Perez, "Command Shaping Control for Micro-milling Operations," *Int. Journal of Control, Automation, and Systems*, vol. 9, no. 6, 2011.
- [72] E. Maleki and W. Singhose, "Dynamics and Control of a Small-Scale Boom Crane," *ASME J. of Computational and Nonlinear Dynamics*, vol. 6, no. 3, pp. 031015-1-8, 2011.
- [73] W. Singhose and J. Vaughan, "Reducing Vibration by Digital Filtering and Input Shaping," *IEEE Trans. on Control Systems Technology*, vol. 19, no. 6, pp. 1410-1420, 2011, doi: 10.1109/TCST.2010.2093135.

- [74] W. Singhose *et al.*, "Use of Cranes in Education and International Collaborations," *J. of Robotics and Mechatronics*, vol. 23, no. 5, pp. 881-891, 2011.
- [75] K. L. Sorensen, P. W. Cross, W. E. Singhose, and S. Prakash, "Vibration Analysis and Mitigation of Dead-Zone on Systems Using Two-Impulse Zero-Vibration Input Shaping," *ASME J. of Computational and Nonlinear Dynamics*, vol. 6, no. 1, p. 011011, 2011, doi: 10.1115/1.4001818.
- [76] J. Vaughan, P. Jurek, and W. Singhose, "Reducing Overshoot in Human-Operated Flexible Systems," *ASME J. Dynamic Systems, Measurement, and Control*, vol. 133, pp. 011010-1-10, 2011, doi: 10.1115/1.4002074.
- [77] J. Vaughan, A. Smith, S. J. Kang, and W. Singhose, "Predictive Graphical User Interface Elements to Improve Crane Operator Performance," *IEEE Trans. on Systems, Man, and Cybernetics--Part A: Systems and Humans*, vol. 41, no. 2, pp. 323-330, 2011.
- [78] J. R. Huey and W. Singhose, "Design of Proportional Derivative Feedback and Input Shaping for Control of Inertia Plants," *IET Control Theory and Applications*, vol. 6, no. 3, pp. 357-364, 2012.
- [79] E. Maleki, B. Pridgen, W. Singhose, U. Glauser, and W. Seering, "Educational Use of a Small-Scale Cherrypicker," *International Journal of Mechanical Engineering Education*, vol. 40, no. 2, pp. 104-120, 2012.
- [80] E. Maleki and W. Singhose, "Swing Dynamics and Input-Shaping Control of Double-Pendulum Boom Cranes," *ASME J. Computational and Nonlinear Dynamics*, vol. 7, no. July, pp. 031006-1-10, 2012.
- [81] K. C. C. Peng, W. Singhose, and P. Bhaumik, "Using Machine Vision and Hand-Motion Control to Improve Crane Operator Performance," *IEEE Trans. on Systems, Man, and Cybernetics - Part A: Systems and Humans*, vol. 42, no. 6, pp. 1496-1503, 2012.
- [82] K. C. C. Peng, W. Singhose, and D. Frakes, "Hand-Motion Crane Control Using Radio Frequency Real-Time Location Systems," *IEEE/ASME Trans. on Mechatronics*, vol. 17, no. 3, pp. 464-471, 2012.
- [83] B. Pridgen and W. Singhose, "Comparison of Polynomial Cam Profiles and Input Shaping for Driving Flexible Systems," *ASME J. of Mechanical Design*, vol. 134, no. 12, p. 124505 (7 pp.), 2012.
- [84] A. Vela, K. Feigh, S. Solak, W. Singhose, and J.-P. Clarke, "Formulation of Reduced-Taskload Optimization Models for Conflict Resolution," *IEEE Trans. on Systems, Man, and Cybernetics*, vol. 42, no. 6, pp. 1552-61, 2012.
- [85] D. Frakes, C. Zwart, and W. Singhose, "Extracting Motion Data from Video Using Optical Flow with Physically-Based Constraints," *Int. J. of Control, Automation, and Systems*, vol. 11, no. 1, p. 48:57, 2013.
- [86] S. S. Gürleyük, K. C. C. Peng, and W. Singhose, "Hand Motion Input Shaping Control of a Crane System: El Hareketini Takip Eden Vinç Sisteminin Giriş

- Şekillendirici Denetimi (in Turkish)," *Karaelmas Science and Engineering Journal*, vol. 3, no. 2, pp. 43-47, 2013.
- [87] S.-W. Hong, Y.-K. Seo, and W. Singhose, "A New Command Shaper Design for Residual Vibration Reduction in Flexible Systems Using Artificial Mode Constraints," *IACSIT Int. Journal of Engineering and Technology*, vol. 5, no. 2, pp. 210-213, 2013.
 - [88] J. Huang, E. Maleki, and W. Singhose, "Dynamics and swing control of mobile boom cranes subject to wind disturbances," *IET Control Theory and Applications*, vol. 7, no. 9, pp. 1187-1195, 2013.
 - [89] J. J. Potter and W. E. Singhose, "Improving Manual Tracking of Systems with Oscillatory Dynamics," *IEEE Trans. on Human-Machine Systems*, vol. 43, no. 1, pp. 46-52, 2013.
 - [90] B. Pridgen, K. Bai, and W. Singhose, "Shaping Container Motion for Multi-Mode and Robust Slosh Suppression," *AIAA J. of Spacecraft and Rockets*, vol. 50, no. 2, pp. 440-448, 2013, doi: 10.2514/1.A32137.
 - [91] A. Rauch, W. Singhose, D. Fujioka, and T. Jones, "Tip-Over Stability Analysis of Mobile Boom Cranes with Swinging Payloads," *ASME J. of Dynamic Systems, Meas., and Control*, vol. 135, no. 3, pp. 031008-1-6, May 2013.
 - [92] H. Seong-Wook, S. Yong-Kyu, and W. Singhose, "A New Command Shaper Design for Residual Vibration Reduction in Flexible Systems Using Artificial Mode Constraints," *International Journal of Engineering and Technology*, vol. 5, no. 2, pp. 210-13, 04/ 2013, doi: 10.7763/IJET.2013.V5.544.
 - [93] B. Xiao, Q. Hu, W. Singhose, and X. Huo, "Reaction Wheel Fault Compensation and Disturbance Rejection for Spacecraft Attitude Tracking," *AIAA J. of Guidance, Control, and Dynamics*, vol. 36, no. 6, pp. 1565-1575, 2013, doi: 10.2514/1.59839.
 - [94] E. Maleki, W. Singhose, and S. S. Gürleyük, "Increasing Crane Payload Swing by Shaping Human-Operator Commands," *IEEE Transactions on Human-Machine Systems*, vol. 44, no. 1, pp. 106-114, 2014.
 - [95] J. J. Potter and W. Singhose, "Effects of Input Shaping on Manual Control of Flexible and Time-Delayed Systems," *Human Factors*, vol. 56, no. 7, pp. 1284-1295, 2014.
 - [96] J. Yoon, S. Nation, W. Singhose, and J. Vaughan, "Control of Crane Payloads that Bounce During Hoisting," *IEEE Trans. on Control Systems Technology*, vol. 22, no. 3, pp. 1233-1238, 2014.
 - [97] C. Adams, J. Potter, and W. Singhose, "Input-Shaping and Model-Following Control of a Helicopter Carrying a Suspended Load," *AIAA J. of Guidance, Control, and Dynamics*, vol. 38, no. 1, pp. 94-105, 2015, doi: 10.2514/1.G000326.
 - [98] J. J. Potter and W. Singhose, "A Planar Experimental Remote-Controlled Helicopter with a Suspended Load," *IEEE/ASME Transactions on Mechatronics*, vol. 20, no. 5, pp. 2496-2503, 2015, doi: 10.1109/TMECH.2014.2386801.

- [99] A. Dhanda, J. Vaughan, and W. Singhose, "Vibration Reduction Using Near Time-Optimal Commands for Systems With Nonzero Initial Conditions," *Journal of Dynamic Systems, Measurement, and Control*, vol. 138, no. 4, pp. 041006-041006, 2016, doi: 10.1115/1.4032064.
- [100] S.-W. Hong, S.-W. Kwon, and W. Singhose, "Vibration suppression of axially-extending cantilever beams under gravity using command shaping," *Research J. of Applied Sciences, Engineering and Technology*, vol. 12, no. 12, pp. 1196-1203, 2016.
- [101] J. J. Potter and W. Singhose, "Design and Human-in-the-Loop Testing of Reduced-Modification Input Shapers," *IEEE Trans. on Control System Technology*, vol. 24, no. 4, pp. 1513-1520, 2016.
- [102] W. Singhose, C. Adams, and D. Kim, "A Dynamics-Based Hazard Analysis of Inverted-Pendulum Human Transporters Using Data-Mined Information," *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part B: Mechanical Engineering*, vol. 2, no. Sept., pp. 031007-1-12, 2016, doi: 10.1115/1.4032459.
- [103] W. Singhose, K. Peng, A. Garcia, and A. Ferri, "Modeling and Control of Crane Payload Lift-off and Lay-down Operations," *FME Transactions*, vol. 44, pp. 237-248, 2016.
- [104] A. Garcia, W. Singhose, and A. Ferri, "Three-Dimensional Dynamic Modeling and Control of Off-Centered Bridge Crane Lifts," *ASME J. Dynamic Systems, Meas., and Control*, vol. 139, no. 4, p. 041005, 2017, doi: doi:10.1115/1.4035030.
- [105] A. Kivila, W. Book, and W. Singhose, "Exact Modeling of n-link Spatial Serial Structures using Transfer Matrices," *ASME J. of Dynamic Systems, Measurement, and Control*, vol. 139, no. 11, pp. 114502-114506, 2017, doi: doi.org/10.1115/1.4036555.
- [106] R. Mar, A. Goyal, V. Nguyen, T. Yang, and W. Singhose, "Combined Input Shaping and Feedback Control for Double-Pendulum Systems," *Mechanical Systems and Signal Processing*, vol. 85, pp. 267-277, 2017.
- [107] F. Schlagenhauf, P. P. Sahoo, and W. Singhose, "A Comparison of Dual-Kinect and Vicon Tracking of Human Motion for Use in Robotic Motion Programming," *J. of Robotics and Automation Engineering*, vol. 1, no. 2, p. 555558, 2017.
- [108] C. Adams and W. Singhose, "Robust Constant-Amplitude Input Shapers with Selectable Duration," *AIAA Journal of Guidance, Control, and Dynamics*, vol. 41, no. 12, pp. 2543-2553, 2018.
- [109] D. Fujioka and W. Singhose, "Optimized Input-Shaped Model Reference Control on Double-Pendulum System," *Journal of Dynamic Systems, Measurement, and Control*, vol. 140, no. 10, 2018, doi: 10.1115/1.4039786.
- [110] S. Wang, A. Ferri, and W. Singhose, "Slipping Dynamics of Slender-Beam Payloads During Lay-Down Operations," *Journal of Dynamic Systems, Measurement, and Control*, vol. 140, no. 8, 2018, doi: 10.1115/1.4039154.

- [111] J. Peng, J. Huang, and W. Singhose, "Payload twisting dynamics and oscillation suppression of tower cranes during slewing motions," *Nonlinear Dynamics*, vol. 98, no. 2, pp. 1041–1048, 2019, doi: doi.org/10.1007/s11071-019-05247-4.
- [112] J. Vaughan, W. Singhose, and D. Kim, "Analysis of Unrestrained Crawler-Crane Counterweights During Tip-Over Accidents," *Mechanics Based Design of Structures and Machines*, no. May, 2020, doi: 10.1080/15397734.2020.1768113.
- [113] A. Kivila, W. Book, and W. Singhose, "Modeling spatial multi-link flexible manipulator arms based on system modes," *International Journal of Intelligent Robotics and Applications*, vol. 5, no. 3, pp. 300-312, 2021/09/01 2021, doi: 10.1007/s41315-021-00201-3.
- [114] A. E. Vela, W. Singhose, K. Feigh, J.-P. Clarke, and E. Feron, "Evaluation of conflict-resolution policies on controller taskload," *Chinese Journal of Aeronautics*, vol. 34, no. 5, pp. 315-330, 2021.
- [115] T. Gao, J. Huang, and W. Singhose, "Eccentric-Load Dynamics and Oscillation Control of Industrial Cranes Transporting Heterogeneous Loads," *Mechanism and Machine Theory*, no. 172, p. 104800, 2022, doi: doi.org/10.1016/j.mechmachtheory.2022.104800.
- [116] K. Sorensen *et al.*, "Electromagnetic Model of Linear Resonant Actuators," *ASME J. Dynamic Systems, Measurement, and Control*, vol. 145, no. 5, pp. 051003-1-051003-9, 2023, doi: Electromagnetic Model of Linear Resonant Actuators.
- [117] G. Li, J. Huang, W. Singhose, and C. Adams, "Cooperative-Transportation Dynamics of Two Helicopters Transporting a Rocket Booster Undergoing Planar Motions," *Aerospace Science and Technology*, vol. 145, p. 108873, 2024, doi: doi.org/10.1016/j.ast.2024.108873.
- [118] W. Singhose, "Diminishing Safety Margins of Telescoping-Boom Aerial Lifts," *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems Part B: Mechanical Engineering*, vol. 10, no. September, pp. 024502-1-7, 2024.
- [119] W. Tian, J. Huang, and W. Singhose, "Control of Cooperative-Transportation Dynamics in Twin-Lift Cranes Suspending a Liquid Container," *IEEE Trans. on Industrial Electronics*, vol. 71, no. 4, pp. 4016-4025, 2024, doi: 10.1109/TIE.2023.3274868.
- [120] C. Yang, J. Huang, and W. Singhose, "Dynamic Modeling and Oscillation Control of Industrial Cranes Transporting Upright Slender Flexible Payloads," *Mechanical Systems and Signal Processing*, vol. 220, no. Nov., p. 111676, 2024.
- [121] K. Sorensen, J. Spiers, T. Hall, S. Dickerson, and W. Singhose, "Design and Performance Evaluation of a Visual Operator Interface for Cranes," *Submitted to Automation*.

Refereed Conference Papers

- [122] W. Singhose, C. Adams, A. Rana, D. Kim, and W. Li, "Use of Data-Mined Customer Reviews to Inform Design Evaluation and Testing of Bassinets," in *ASME International Design Engineering Technical Conferences*, Boston, MA, 2023.
- [123] R. Schmidt, M. H. Guzman, F. Schlagenhauf, and W. Singhose, "Back-EMF Sensing of Linear Resonant Actuators for Detection of Tap-Induced Vibration," in *ASME International Design Engineering Technical Conferences*, Boston, MA, 2023.
- [124] T. Rome, C. Adams, and W. Singhose, "Experimental Comparison of Manual and Automated Crane Control Through Obstacle Fields," in *IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM)*, Seattle, WA, 2023.
- [125] M. W. Lui, D. Kotten, E. Dushaj, and W. Singhose, "Improving Human Positioning Control of Oscillatory Systems," in *IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM)*, Seattle, WA, 2023.
- [126] A. Jenkins, D. V. Delden, W. Singhose, F. Schlagenhauf, and K. Dobson, "Controlling Human Perception of Haptic Profiles Using Contextual Cues," in *IEEE World Haptics Conference*, Delft, Netherlands, 2023.
- [127] C. Adams and W. Singhose, "Stability Margins of Heavy-Lifting Machines with a Telescoping Boom and Jib," in *IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM)*, Seattle, WA, 2023.
- [128] T. Rome, W. S. K. D. K. Sorensen, F. Schlagenhauf, and J.-W. Kang, "Impact of Input Shaper Discretization on Linear Resonant Actuators for Haptic Feedback," in *IEEE International Symposium on Industrial Electronics*, Anchorage, AK, 2022.
- [129] W. S. W. S. D. Frakes, "Soli Radar Image-Based Target Localization," in *IEEE Int. Conf. on Image Processing*, Bordeaux, France, 2022.
- [130] F. Schlagenhauf, W. Singhose, K. Sorensen, and K. Dobson, "Command-shaping control of linear resonant actuators for haptic force generation," in *21st IFAC World Congress 2020, July 12, 2020 - July 17, 2020*, Berlin, Germany, 2020, vol. 53: Elsevier B.V., in IFAC-PapersOnLine, 2 ed., pp. 8675-8682, doi: 10.1016/j.ifacol.2020.12.303. [Online]. Available: <http://dx.doi.org/10.1016/j.ifacol.2020.12.303>
- [131] S. Wang, A. Ferri, W. Singhose, and Y. Yang, "Control of Slender-Beam Payloads During Lift-Up Operations," in *ASME 2018 Dynamic Systems and Control Conference*, 2018, vol. Volume 3: Modeling and Validation; Multi-Agent and Networked Systems; Path Planning and Motion Control; Tracking Control Systems; Unmanned Aerial Vehicles (UAVs) and Application; Unmanned Ground and Aerial Vehicles; Vibration in Mechanical Systems; Vibrations and Control of Systems; Vibrations: Modeling, Analysis, and Control, V003T40A003, doi: 10.1115/dscc2018-8967. [Online]. Available: <https://doi.org/10.1115/DSCC2018-8967>

- [132] K. Sorensen and W. Singhose, "Wheeled Inverted Pendulum Control and Slip Dynamics," in *IEEE Int. Conf. on Control and Automation*, Anchorage, Alaska, 2018.
- [133] F. Schlagenhauf, S. Sreeram, and W. Singhose, "Comparison of Kinect and Vicon Motion Capture of Upper-Body Joint Angle Tracking," in *IEEE Int. Conf. on Control and Automation*, Anchorage, Alaska, 2018.
- [134] F. Schlagenhauf and W. Singhose, "Comparison of Sway Reduction Controllers for Construction Cranes," in *IEEE Int. Conf. on Control and Automation*, Anchorage, Alaska, 2018.
- [135] P. P. Sahoo and W. Singhose, "Effects of Input Shaping on Impact Loads During Collisions Involving Flexible Robots," in *IEEE Int. Conf. on Control and Automation*, Anchorage, Alaska, 2018.
- [136] N. Johnson and W. Singhose, "Dynamics and Modeling of a Quadrotor with a Suspended Payload " in *AIAA Aviation Forum Applied Aerodynamics Conference*, Atlanta, GA, 2018.
- [137] S. Ichikawa, A. Castro, N. Johnson, H. Kojima, and W. Singhose, "Dynamics and command shaping control of quadcopters carrying suspended loads," in *14th IFAC Workshop on Time Delay Systems TDS (IFAC-PapersOnLine)*, Budapest, Hungary, 2018, vol. 51, no. 14, pp. 84 - 88.
- [138] F. Schlagenhauf, P. P. Sahoo, and W. Singhose, "Comparison of Single-Kinect and Dual-Kinect Motion Capture of Upper-Body Joint Tracking," in *Asian Control Conference*, Gold Coast, Australia, 2017.
- [139] S. Rishmawi and W. Singhose, "Control of Robotic Crawler Cranes in Tandem Lifting Operations," in *Future Technologies Conference*, Vancouver, Canada, 2017.
- [140] A. Kivila, J. Burgin, W. Book, and W. Singhose, "Development and Verification of a 2-Link Flexible Serial Arm Testbed for 3D Spatial Movements," in *IEEE 11th Asian Control Conference*, Gold Coast, Australia, 2017: IEEE.
- [141] S. Grazioso, G. D. Gironimo, W. Singhose, and B. Siciliano, "Input Predictive Shaping for Vibration Control in Flexible Systems," in *IEEE Conference on Control Technology and Applications*, Kohala Coast, Hawai'i, USA, 2017.
- [142] A. Castro, W. Singhose, X. Liu, K. Sorensen, and E. C. Kwak, "Modeling and Experimental Testing of Hoverboard Dynamic Behavior," in *ASME Dynamic Systems and Control Conference*, Tysons Corner, Virginia, 2017.
- [143] A. S. Miller, W. Singhose, and U. Glauser, "Integrating PLC Theory and Programming into Advanced Controls Courses," in *American Control Conference*, Boston, MA, 2016.
- [144] R. Khodambashi, G. Weinberg, W. Singhose, S. Rishmawi, V. Murali, and E. Kim, "User oriented assessment of vibration suppression by command shaping in a supernumerary wearable robotic arm," in *IEEE-RAS International Conference on Humanoid Robots*, Cancun, Mexico, Nov 15-17 2016.

- [145] Y. Hu, D. Han, L. Ling, T. Kurfess, W. Singhose, and J. Vaughan, "Case Study: Comparison of Project-based, Creative Engineering Courses at Georgia Tech and Huazhong University of Science and Technology," in *Int. Conf. on Engineering Education and Research*, Sydney, Australia, Nov. 21-24 2016.
- [146] W. Singhose, K. Peng, A. Garcia, and A. Ferri, "Dynamics and Control of Crane Payload Lift-off and Lay-down Operations," in *International Conference on Material Handling, Constructions and Logistics*, Vienna, Austria, 2015.
- [147] S. Rishmawi and W. Singhose, "Static Tip-Over Stability of Crawler Cranes with Moveable Counterweights," in *International Conference on Material Handling, Constructions and Logistics*, Vienna, Austria, 2015.
- [148] C. Rhee, A. Miller, and W. Singhose, "Operator Testing on Dual-Hoist Cranes Moving Triangular Payloads," in *ASME Dynamic Systems and Control Conference*, Columbus, OH, 2015.
- [149] K. Peng and W. Singhose, "Prediction and Measurement of Payload Swing from Off-Centered Crane Lifts," in *ASME IDETC, 11th International Conference on Multibody Systems, Nonlinear Dynamics, and Control*, Boston, MA, 2015.
- [150] R. Mar, A. Goyal, V. Nguyen, T. Yang, and W. Singhose, "Combined Input Shaping and Feedback Control of a Double-Pendulum System Subject to External Disturbances," in *Dynamic Systems and Control Conference*, Columbus, OH, 2015.
- [151] A. Kivila, J. Potter, and W. Singhose, "Manual Tracking Using Touchscreen Interfaces," in *Asian Control Conference*, Kota Kinabalu, Malaysia, 2015.
- [152] Y. Hu, T. Kurfess, W. Singhose, D. Frakes, and B. Wu, "Design of a Hands-on Mechatronic Project Integrated into an Introductory Course," in *19th Int. Conf. on Engineering Education*, Zagreb, Croatia, 2015.
- [153] J. Harber, C. Adams, A. Castro, and W. Singhose, "Dynamic Effects of Obstacles on Two-Wheeled Inverted-Pendulum Transporters," in *ASME International Design Engineering Technical Conferences*, Boston, MA, 2015.
- [154] A. Garcia, W. Singhose, and A. Ferri, "Dynamics and Control of Off-Centered Crane Lifts," in *Asian Control Conference*, Kota Kinabalu, Malaysia, 2015.
- [155] A. Garcia, W. Singhose, and A. Ferri, "Three-Dimensional Modeling and Experimental Verification of Off-Centered Crane Lifts," in *Dynamic Systems and Control Conference*, Columbus, OH, 2015.
- [156] D. Fujioka and W. Singhose, "Input-Shaped Model Reference Control of a Nonlinear Time-Varying Double-Pendulum Crane," in *Asian Control Conference*, Kota Kinabalu, Malaysia, 2015.
- [157] D. Fujioka and W. Singhose, "Performance Comparison of Input-Shaped Model Reference Control on an Uncertain Flexible System," in *IFAC Workshop on Time Delay Systems*, Ann Arbor, MI, 2015.
- [158] D. Fujioka, M. Shah, and W. Singhose, "Robustness Analysis of Input-Shaped Model Reference Control on a Double-Pendulum Crane," in *American Control Conference*, Chicago, IL, 2015.

- [159] W. Singhose, A. Kivila, and W. Seering, "Development of an Interactive Textbook for Command-Shaping Control Methods," in *Hawaii Education and STEM Conference*, Honolulu, HI, 2014.
- [160] W. Singhose, D. Kim, and J. Vaughan, "Post-Ejection Failure Mode of Post Driving Machines," in *International Scientific Conference Heavy Machinery*, Zlatibor, Serbia, 2014.
- [161] W. Singhose, J. Donnell, and A. Kivila, "An Interactive Textbook for Introductory Engineering Design," in *Int. Conference on Computer Supported Education*, Barcelona, Spain, 2014.
- [162] J. J. Potter and W. Singhose, "Reduced-Modification Input Shapers for Manually Controlled Systems with Flexibility," in *American Control Conference*, Portland, OR, 2014.
- [163] J. Potter, W. Singhose, A. AlSaibie, and A. Kivila, "Fostering Global Collaboration between Engineering Students through a Robotic Design Competition," in *Hawaii Education and STEM Conference*, Honolulu, HI, 2014.
- [164] A. Miller, P. Sarvepalli, and W. Singhose, "Dynamics and Control of Dual-Hoist Cranes Moving Triangular Payloads," in *ASME Dynamic Systems and Control Conference*, San Antonio, TX, 2014.
- [165] H. Liu and W. Singhose, "Tip-over stability of crawler cranes with moveable counterweights," in *International Scientific Conference Heavy Machinery*, Zlatibor, Serbia, 2014.
- [166] Y. Hu, W. Singhose, T. Kurfess, B. Wu, J. R. Mayor, and J. A. Donnell, "Introductory Mechatronics Creative Decision and Design Tools—the Design and Realization of a Mechatronics Course," in *ICEE/ICIT Conference on Engineering Education and International Conference on Information Technology*, Riga, Latvia, 2014.
- [167] Y. Hu, L. Ling, T. Kurfess, W. Singhose, and B. Wu, "International Collaboration Teaching Method for Mechatronic Innovation Decision-making and Design Tools," in *International Conference on Engineering Education and Research*, Hamilton, Canada, 2014.
- [168] D. Fujioka and W. Singhose, "Control Effort Reduction Analysis of Zero-Vibration Model Reference Control for Controlling a Time-Varying Plant," in *American Control Conference*, Portland, OR, 2014.
- [169] J. Vaughan, J. Yoo, N. Knight, and W. Singhose, "Multi-Input Shaping Control for Multi-Hoist Cranes," in *American Control Conference*, Washington, DC, 2013.
- [170] W. Singhose, J. Donnell, and A. Kivila, "Development of an Interactive Textbook for Introductory Mechanical Design," in *Int. Symp. on Mechatronics and its Applications*, Amman, Jordan, 2013.
- [171] J. J. Potter, R. Simpson, and W. Singhose, "Dynamic Modeling and Simulation of a Remote-Controlled Helicopter with a Suspended Load," in *ASME Dynamic Systems and Control Conference*, Stanford, CA, 2013.

- [172] J. J. Potter, C. J. Adams, and W. Singhose, "An Experimental Remote-Controlled Helicopter with Suspended Load," in *2013 Int. Symp. on Mechatronics and its Applications*, Amman, Jordan, 2013.
- [173] K. C.-C. Peng and W. Singhose, "Low-Oscillation Command Switch-Times for Relay-Driven Cranes with Asymmetrical Acceleration and Deceleration," in *Asian Control Conference*, Istanbul, Turkey, 2013.
- [174] E. Maleki, W. Singhose, J. Hawke, and J. Vaughan, "Dynamic Response of a Dual-Hoist Bridge Crane," in *ASME Dynamic Systems and Control Conference*, Stanford, CA, 2013.
- [175] E. Maleki and W. Singhose, "Maximizing the Swing of a Human-Operated Wrecking Ball," in *IEEE Int. Conference on Industrial Technology*, Cape Town, South Africa, 2013.
- [176] A. Kivila and W. Singhose, "Touchscreen Crane Control Interfaces with Oscillation Suppression," in *IEEE Conf. on Decision and Control*, Florence, Italy, 2013.
- [177] A. Kivila, C. Porter, and W. Singhose, "Human Operator Studies of Portable Touchscreen Crane Control Interfaces," in *IEEE Int. Conference on Industrial Technology* Cape Town, South Africa, 2013.
- [178] Y. Hu, B. Wu, J. Vaughan, and W. Singhose, "Oscillation Suppression for an Energy Efficient Bridge Crane Using Input Shaping " in *Asian Control Conference*, Istanbul, Turkey, 2013.
- [179] Y. Hu, W. Singhose, B. Wu, L. Zhou, and L. He, "Practice Competence Training in Mechatronics Engineering Education under the Cooperation Project Between HUST and GATECH," in *Int. Conference on Engineering Education and Research*, Marrakesh, Morocco, 2013.
- [180] D. Frakes, C. Zwart, and W. Singhose, "Analyzing Accident Videos with Optical Flow and Physically-Based Constraints," in *ASME Summer Bioengineering Conference*, Sunriver, OR, 2013.
- [181] A. Castro, C. Adams, and W. Singhose, "Dynamic Response Characteristics of a Two-Wheeled Inverted-Pendulum Transporter," in *IEEE Conf. on Decision and Control*, Florence, Italy, 2013.
- [182] A. AlSaibie and W. Singhose, "Experimental Testing of Liquid Slosh Suppression in a Suspended Container with Compound Pendulum Dynamics," in *Asian Control Conference*, Istanbul, Turkey, 2013.
- [183] C. Adams, W. Singhose, and D. Kim, "A System-Dynamics-Based Hazard Analysis of Inverted-Pendulum Human Transporters," in *ASME Dynamic Systems and Control Conference*, Stanford, CA, 2013.
- [184] B. Xiao, Q. Hu, and W. Singhose, "Adaptive Compensation Control for Spacecraft Attitude Stabilization with Actuator Misalignment and Faults," in *AIAA Guidance, Navigation, and Control Conference*, Minneapolis, MN, 2012.

- [185] J. Vaughan, J. Yoo, and W. Singhose, "Using Approximate Multi-crane Frequencies for Input Shaper Design," in *Int. Conference on Control, Automation and Systems*, Jeju, Korea, 2012.
- [186] J. Vaughan, J. Yoo, N. Knight, and W. Singhose, "Dynamics and Control of Multiple Cranes with a Connected Payload," in *Int. Congress on Sound and Vibration*, Vilnius, Lithuania, 2012.
- [187] J. Vaughan, K. C. C. Peng, W. Singhose, and W. Seering, "Influence of Remote-Operation Time Delay on Crane Operator Performance," in *IFAC Workshop on Time Delay Systems*, Boston, MA, 2012.
- [188] S. Ragunathan, W. Singhose, K. C. C. Peng, L. Stokes, and D. Frakes, "Kalman Filtering for Improving Radio-Frequency Hand Motion Crane Control," in *ASME Dynamic Systems and Control Conference*, Ft. Lauderdale, FL, 2012.
- [189] J. J. Potter and W. Singhose, "Effects of Input Shaping on Manual Tracking with Oscillatory Controlled-Element Dynamics," in *American Control Conference*, Montréal, Canada, 2012.
- [190] J. J. Potter and W. Singhose, "Using Manual Tracking Performance to Tune a Specified-Negative-Amplitude Input Shaper," in *IEEE Conference on Systems, Man, and Cybernetics*, Seoul, Korea, 2012.
- [191] J. Potter and W. Singhose, "Effects of Input Shaping on Manual Tracking with Flexible and Time-Delayed System Dynamics," in *IFAC Workshop on Time Delay Systems*, Boston, MA, 2012.
- [192] K. C. C. Peng, W. Singhose, and S. S. Gürleyük, "Initial Investigations of Hand-Motion Crane Control with Double-Pendulum Payloads," in *American Control Conference*, Montréal, Canada, 2012.
- [193] K. C.-C. Peng and W. Singhose, "Stability Analysis of a Hand-Motion Crane Controller Using Describing Functions: An Initial Investigation," in *Int. Congress on Sound and Vibration*, Vilnius, Lithuania, 2012.
- [194] A. S. Murthy, A. Kivila, and W. Singhose, "Slosh Suppression of a Liquid in a Suspended Container Using Robust Input Shaping," in *Int. Congress on Sound and Vibration*, Vilnius, Lithuania, 2012.
- [195] G. Mann, P. Danilochkin, and W. Singhose, "Attenuation of Initial Oscillation in Bridge Cranes via Input-Shaping-Based Feedback Control Methods," in *ASME Dynamic Systems and Control Conference*, Ft. Lauderdale, FL, 2012.
- [196] E. Maleki, F. Bazerghi, W. Singhose, and S. Gürleyük, "Shaping Commands to Maximize Pendulum Swing," in *Int. Congress on Sound and Vibration*, Vilnius, Lithuania, 2012.
- [197] S.-W. Hong and W. Singhose, "Command Shaper Design for Transverse Vibration Suppression of Axially-Extending Cantilever Beams Under Gravity," in *Int. Congress on Sound and Vibration*, Vilnius, Lithuania, 2012.
- [198] S.-W. Hong, Y.-K. Seo, and W. Singhose, "A New Command Shaper Design for Residual Vibration Reduction in Flexible Systems Using Artificial Mode

- Constraints," in *Int. Conf. on Mechanical, Industrial, and Manufacturing Technologies*, Shenzhen, China, 2012.
- [199] A. Castro, W. Singhose, J. J. Potter, and C. Adams, "Modeling and Experimental Testing of a Two-Wheeled Inverted-Pendulum Transporter " in *ASME Dynamic Systems and Control Conference*, Ft. Lauderdale, FL, 2012.
 - [200] C. Adams, J. Potter, and W. Singhose, "Modeling and Input Shaping Control of a Micro Coaxial Radio-Controlled Helicopter Carrying a Suspended Load," in *Int. Conference on Control, Automation and Systems*, Jeju, Korea, 2012.
 - [201] A. E. Vela, E. Salaun, E. Feron, W. Singhose, and J.-P. Clarke, "Bounds on Controller Taskload Rates at an Intersection for Dense Traffic," in *2011 American Control Conference*, San Francisco, CA, 2011, pp. 2745-51.
 - [202] A. Vela, J. P. Clarke, E. Feron, and W. Singhose, "The relative value of trajectory prediction and conflict-resolution algorithms," in *2011 IEEE/AIAA 30th Digital Avionics Systems Conference* Seattle, WA, 2011: IEEE, in 2011 IEEE/AIAA 30th Digital Avionics Systems Conference (DASC), pp. 6-1.
 - [203] A. Vela, J.-P. Clarke, N. Durand, E. Feron, and W. Singhose, "Determining the Value of Information for Minimizing Controller Taskload: A Graph-Based Approach," in *USA/Europe Seminar on Air Traffic Management Research and Development*, Berlin, Germany 2011.
 - [204] J. Vaughan, A. Karajgikar, and W. Singhose, "A Study of Crane Operator Performance Comparing PD-Control and Input Shaping," in *American Control Conference*, San Francisco, CA, 2011.
 - [205] S. Rangunathan, K. C. C. Peng, W. Singhose, and D. Frakes, "Improving Energy Efficiency of Cranes Driven by Noisy Control Signals," in *Multibody Dynamics Conference*, Brussels, Belgium, 2011.
 - [206] S. Rangunathan, D. Frakes, K. Peng, and W. Singhose, "Filtering Effects on Input-Shaped Command Signals for Effective Crane Control," in *IEEE International Conference on Control and Automation*, Santiago, Chile, 2011.
 - [207] B. Pridgen, E. Maleki, W. Singhose, W. Seering, U. Glauser, and L. Kaufmann, "A Small-Scale Cherrypicker for Experimental and Educational Use," in *American Control Conference*, San Francisco, CA, 2011.
 - [208] J. Potter, W. Singhose, and M. Costello, "Reducing Swing of Model Helicopter Sling Load Using Input Shaping," in *IEEE International Conference on Control and Automation*, Santiago, Chile, 2011.
 - [209] B. Post, A. Mariuzza, W. Book, and W. Singhose, "Faltiness-Based Control of Flexible Motion Systems," in *ASME Dynamic Systems and Control Conference*, Washington, DC, 2011.
 - [210] J. Pasternack *et al.*, "Experimental Analysis for Wind Induced Disturbance Rejection on Bridge Crane Structures," in *ASME Dynamic Systems and Control Conference*, Washington, DC, 2011.

- [211] E. Maleki and W. Singhose, "Control of the Mobile Base of a Small-Scale Boom Crane," in *Multibody Dynamics Conference*, Brussels, Belgium, 2011.
- [212] A. Karajgikar, J. Vaughan, and W. Singhose, "Double-Pendulum Crane Operator Performance Comparing PD-Feedback Control and Input Shaping," in *Multibody Dynamics Conference*, Brussels, Belgium, 2011.
- [213] J. Hongxia, L. Wanli, and W. Singhose, "Using Two-mode Input Shaping to Suppress the Residual Vibration of Cherry Pickers," in *Int. Conf. on Measuring Technology and Mechatronics Automation*, Shanghai, China, 2011.
- [214] D. Fujioka, E. Maleki, and W. Singhose, "Tip-Over Stability of a Portable Cherrypicker," in *Multibody Dynamics Conference*, Brussels, Belgium, 2011.
- [215] A. E. Vela *et al.*, "Determining Bounds on Controller Workload Rates at an Intersection," in *American Control Conference*, Baltimore, MD, 2010.
- [216] A. E. Vela, E. Salaun, P. Burgain, W. Singhose, J.-P. Clarke, and E. Feron, "Predicting Controller Communication Time for Capacity Estimation," in *Int. Conference on Research in Air Transportation*, Budapest, Hungary, 2010.
- [217] A. E. Vela, E. Feron, W. Singhose, and J.-P. Clarke, "Control of Holding Patterns for Increased Throughput and Recovery of Operations," in *Digital Avionics Systems Conference*, Salt Lake City, UT, 2010.
- [218] A. Vela, E. Salaün, S. Solak, E. Feron, W. Singhose, and J.-P. Clarke, "Maximizing Throughput at an Intersection under Constrained Maneuvers," in *IEEE Conference on Decision and Control*, Atlanta, GA, 2010, pp. 1207-1214.
- [219] J. Vaughan and W. Singhose, "Reducing Multiple Modes of Vibration by Digital Filtering and Input Shaping," in *Dynamic Systems and Control Conference*, Cambridge, MA, 2010.
- [220] J. Vaughan, E. Maleki, and W. Singhose, "Advantages of Using Command Shaping Over Feedback for Crane Control," in *American Control Conference*, Baltimore, MD, 2010.
- [221] D. C. Ujueta, K. C. C. Peng, W. Singhose, and D. Frakes, "Determination of Control Parameters for a Radio-Frequency Based Crane Controller " in *IEEE Conf. on Decision and Control*, Atlanta, GA, 2010.
- [222] W. Singhose, J. d. J. Márquez, J. Vaughan, and B. Pridgen, "Use of Tele-Robotic Cranes in International Collaborative Education," in *IASTED Int. Conference on Robotics and Applications*, Cambridge, MA, 2010.
- [223] B. Pridgen and W. Singhose, "Comparison of Polynomial Cam Profiles and Input Shaping for Vibration Reduction," in *International Congress on Sound and Vibration*, Cairo, Egypt, 2010.
- [224] B. Pridgen, K. Bai, and W. Singhose, "Slosh Suppression by Robust Input Shaping," in *IEEE Conf. on Decision and Control*, Atlanta, GA, 2010.
- [225] J. J. Potter, K. L. Sorensen, and W. E. Singhose, "Efficient Method for Generating Pick-and-Place Trajectory Over Obstacles," in *IASTED Int. Conference on Robotics and Applications*, Cambridge, MA, 2010.

- [226] K. C. C. Peng, K. Sorensen, and W. Singhose, "Sway Control of a Relay-Driven Crane with Asymmetrical Acceleration and Deceleration," in *IASTED Conf. on Robotics and Applications*, Cambridge, MA, 2010.
- [227] K. C. C. Peng and W. Singhose, "A Vision-Based Predictive Hook-Tracker for Industrial Cranes," in *International Congress on Sound and Vibration*, Cairo, Egypt, 2010.
- [228] E. Maleki, W. Singhose, and S. Srinivasan, "Positioning and Control of Boom Crane Luffing with Double-Pendulum Payloads," in *IEEE Conference on Control Applications*, Yokohama, Japan, 2010.
- [229] E. Maleki and W. Singhose, "Dynamics and Zero Vibration Input Shaping Control of a Small-Scale Boom Crane," in *American Control Conference*, Baltimore, MD, 2010.
- [230] E. Maleki and W. Singhose, "Operator Performance Studies on a Small-Scale Mobile Boom Crane," in *International Congress on Sound and Vibration*, Cairo, Egypt, 2010.
- [231] E. Maleki, B. Pridgen, J. Q. Xiong, and W. Singhose, "Dynamic Analysis and Control of a Portable Cherry picker," in *Dynamic Systems and Control Conference*, Cambridge, MA, 2010.
- [232] J. Yoon, W. Singhose, M. D. Kim, G. Ramirez, and S. K. Tawde, "Dynamics and Control of Bouncing and Tilting Crane Payloads," in *ASME IDETC*, San Diego, CA, 2009.
- [233] A. Vela, S. Solak, W. Singhose, and J.-P. Clarke, "A Mixed Integer Program for Flight-Level Assignment and Speed Control for Conflict Resolution," in *IEEE Conference on Decision and Control*, Shanghai, China, 2009.
- [234] A. Vela, S. Solak, E. Feron, K. Feigh, W. Singhose, and J.-P. Clarke, "A Fuel Optimal and Reduced Controller Workload Optimization Model for Conflict Resolution," in *Digital Avionics Systems Conference*, Orlando, Florida, 2009.
- [235] A. Vela, E. Salaun, S. Solak, E. Feron, W. Singhose, and J.-P. Clarke, "A Two-Stage Stochastic Optimization Model for Air Traffic Conflict Resolution under Wind Uncertainty," in *Digital Avionics Systems Conference*, Orlando, Florida, 2009.
- [236] J. Vaughan, A. Smith, and W. Singhose, "Using a Predictive Graphical User Interface to Improve Tower Crane Performance," in *IASTED Int. Conference on Robotics and Applications*, Cambridge, MA, 2009.
- [237] J. Vaughan and W. Singhose, "Input Shapers for Reducing Overshoot in Human-Operated Flexible Systems," in *American Control Conference*, St. Louis, MO, 2009.
- [238] J. Vaughan and W. Singhose, "Reducing Vibration and Providing Robustness with Multi-Input Shapers," in *American Control Conference*, St. Louis, MO, 2009.

- [239] W. Singhose, A. Vela, and D. Kim, "Comparison of Residual-Vibration and Energy-Minimizing Control Methods for Command Generation," in *IEEE Conference on Decision and Control*, Shanghai, China, 2009.
- [240] W. Singhose, J. Vaughan, and R. Mayor, "Use of Design Competitions in Mechatronics Education," in *IEEE International Conference on Mechatronics*, Malaga, Spain, 2009.
- [241] K. C. C. Peng, W. Singhose, S. Gessesse, and D. Frakes, "Crane Operation Using Hand-Motion and Radio Frequency Identification Tags," in *IEEE Int. Conference on Control and Automation*, Christchurch, New Zealand, 2009.
- [242] K. C. C. Peng, W. Singhose, and J. Fonseca, "Crane Operation using Hand Motion and Machine Vision," in *ASME Dynamic Systems and Control Conference*, Hollywood, CA, 2009.
- [243] K. C. C. Peng and W. Singhose, "Crane Control Using Machine Vision and Wand Following," in *IEEE International Conference on Mechatronics*, Malaga, Spain, 2009.
- [244] J. d. J. Márquez, D. Kim, and W. Singhose, "An Examination of the Trajectories Traveled by Two-Mode Flexible Systems," in *IASTED Int. Conference on Robotics and Applications*, Cambridge, MA, 2009.
- [245] E. Maleki and W. Singhose, "Initial Experiments with a Small-Scale Mobile Boom Crane," in *IASTED Int. Conference on Robotics and Applications*, Cambridge, MA, 2009.
- [246] D. Fujioka, A. Rauch, W. Singhose, and T. Jones, "Stability Analysis of Mobile Boom Cranes with Double-Pendulum Payloads," in *American Control Conference*, St. Louis, MO, 2009.
- [247] M. Freese, S. Singh, W. Singhose, E. Fukushima, and S. Hirose, "Terrain Modeling and Following Using a Compliant Manipulator for Humanitarian Demining Applications," in *Int. Conference on Field and Service Robots*, Cambridge, MA, 2009.
- [248] A. Dhanda, J. Vaughan, and W. Singhose, "Optimal Input Shaping Filters for Non-Zero Initial States," in *American Control Conference*, St. Louis, MO, 2009.
- [249] J. Vaughan, A. Yano, and W. Singhose, "Performance Comparison of Robust Negative Input Shapers," in *American Control Conference*, Seattle, WA, 2008.
- [250] J. Vaughan and W. Singhose, "Comparison of Command Filtering Methods for Vibration Reduction in Automated Manufacturing Machines," in *ASME Int. Symposium on Flexible Automation*, Atlanta, GA, 2008.
- [251] J. Vaughan, A. Daftari, and W. Singhose, "The Influence of Input Shaper Duration on Bridge Crane Operator Performance," in *International Conference on Motion and Vibration Control*, Munich, Germany, 2008.
- [252] Y.-G. Sung and W. Singhose, "Deflection-Limiting Commands to Slew Flexible Systems with Velocity Limits," in *International Conference on Control, Automation and Systems*, Seoul, Korea, 2008.

- [253] K. L. Sorensen, J. Danielson, and W. E. Singhose, "Anti-Sway and Positioning Control For An Industrial Bridge Crane With Multi-Mode Dynamics," in *ASME International Symposium on Flexible Automation*, Atlanta, GA, 2008.
- [254] K. Sorensen and W. Singhose, "A Multi-Operational-Mode Anti-Sway & Positioning Control for an Industrial 30-Ton Bridge Crane," in *IFAC World Congress*, Seoul, Korea, 2008.
- [255] W. Singhose, J. Vaughan, J. Danielson, and J. Lawrence, "Use of Cranes in System Dynamics and Controls Education," in *IFAC World Congress*, Seoul, Korea, 2008.
- [256] A. Rauch and W. Singhose, "Stability Analysis of Mobile Boom Cranes," in *International Conference on Motion and Vibration Control*, Munich, Germany, 2008.
- [257] R. Manning, D. Kim, and W. Singhose, "Reduction of Distributed Payload Bridge Crane Oscillations," in *WSEAS International Conference on Automatic Control, Modeling, and Simulation*, Istanbul, Turkey, 2008.
- [258] S. W. Hong, S. W. Park, and W. E. Singhose, "A method of input shaper design for residual vibration reduction using virtual mode concept," in *International Congress on Sound and Vibration*, Daejeon, Korea, 2008, pp. 1712-1718.
- [259] U. Glauser, L. Widler, R. Weiss, J. Vaughan, and W. Singhose, "Conducting International Research Projects Using Undergraduate Thesis Projects," in *International Symposium on Flexible Automation*, Atlanta, GA, 2008.
- [260] J. Danielson, J. Vaughan, W. Singhose, L. Widler, and U. Glauser, "Design of a Mobile Boom Crane for Research and Educational Applications," in *International Conference on Motion and Vibration Control*, Munich, Germany, 2008.
- [261] P. Andersch, K. Sorensen, and W. Singhose, "Effects of Rate Limiting on Common Input Shaping Filters," in *WSEAS Int. Conf. on Automatic Control, Modelling, and Simulation*, Istanbul, Turkey, 2008.
- [262] J. Vaughan, A. Yano, and W. Singhose, "Performance Comparison of Robust Input Shapers," in *IEEE International Conference on Control and Automation*, Guangzhou, China, 2007.
- [263] J. Vaughan, W. Singhose, P. Debenest, E. Fukushima, and S. Hirose, "Initial Experiments on the Control of a Mobile Tower Crane," in *ASME IMECE*, Seattle, WA, 2007.
- [264] J. Suter, D. Kim, W. Singhose, K. Sorensen, and U. Glauser, "Evaluation and Integration of a Wireless Touchscreen Into a Bridge Crane Control System," in *IEEE/ASME Int. Conf. on Advanced Intelligent Mechatronics*, Zürich, Switzerland, 2007, p. 4412586.
- [265] Y.-G. Sung and W. Singhose, "Closed-Form Specified-Fuel Commands for Two-Mode Systems," in *IEEE International Conference on Control and Automation*, Guangzhou, China, 2007.

- [266] Y.-G. Sung and W. Singhose, "Two-State Actuator Commands for Moving Two-Mode Flexible Systems," in *IASTED Intelligent Systems and Control*, Boston, MA, 2007.
- [267] K. L. Sorensen, J. B. Spiers, and W. E. Singhose, "Operational Effects of Crane Interface Devices " in *IEEE Conference on Industrial Electronics and Applications*, Harbin, China, 2007.
- [268] K. L. Sorensen and W. E. Singhose, "Oscillatory Effects of Common Hard Nonlinearities on Systems Using Two-Impulse ZV Input Shaping," in *American Control Conference*, New York, NY, 2007.
- [269] K. L. Sorensen, P. W. Cross, W. E. Singhose, and S. Prakash, "Analysis and Mitigation of Dead-Zone Effects on Systems Using Two-Impulse ZV Input Shaping," in *ASME Int. Design Engineering Technical Conferences*, Las Vegas, NV, 2007.
- [270] W. Singhose, J. Vaughan, J. Danielson, and J. Lawrence, "The Use of Tele-operated Cranes for Advanced Controls Education," in *ASME IMECE*, Seattle, WA, 2007.
- [271] W. Singhose and K. Sorensen, "Manipulation of Flexible Space Structures: Effects of Command Shaping and Human Interfaces," in *2007 ICRA Workshop on Space Robotics*, Rome, Italy, 2007.
- [272] W. Singhose and D. Kim, "Manipulation with Tower Cranes Exhibiting Double-Pendulum Oscillations," in *IEEE Int. Conf. on Robotics and Automation*, Rome, Italy, 2007.
- [273] S. W. Park, S. W. Hong, H. S. Choi, and W. E. Singhose, "A Study on Dynamic Performance of Precise XY Stages Using Real-Time Input Shaping," in *Int. Symp. on Measurement Technology and Intelligent Instruments*, Sendai, Japan, 2007.
- [274] D. Kim and W. Singhose, "Studies of Human Operators Manipulating Double-Pendulum Cranes," in *European Control Conference*, Kos, Greece, 2007, p. WeC10.1.
- [275] D. Kim and W. Singhose, "Human Operator Learning On Double-Pendulum Bridge Cranes," in *ASME IMECE*, Seattle, WA, 2007.
- [276] M. Freese, E. Fukushima, S. Hirose, and W. Singhose, "Endpoint Vibration Control of a Mobile Mine-Detecting Robotic Manipulator," in *American Control Conference*, New York, NY, 2007.
- [277] J. Danielson, J. Lawrence, and W. Singhose, "Command Shaping for Flexible Systems with Constant Acceleration," in *IEEE Conference on Industrial Electronics and Applications*, Harbin, China, 2007.
- [278] J. Vaughan and W. Singhose, "Modeling and Control of a Mobile Tower Crane," in *Int. Conf. on Advances in Mechanical Engineering and Mechanics*, Hammamet, Tunisia, 2006.

- [279] J. Vaughan and W. Singhose, "ARLISS: A Multidisciplinary Extracurricular Design Project for Undergraduates," in *American Society for Engineering Education Annual Conf.*, Chicago, IL, 2006.
- [280] A. Timm, M. Robertson, W. Singhose, and K. Fujiwara, "Control of Elastic Tethers During Spin Up For Artificial Gravity," in *Third Asian Conference on Multibody Dynamics*, Tokyo, Japan, 2006.
- [281] W. Singhose, "Crane Oscillation Control: Applications and Educational Uses," in *XVIII International Conference on Material Handling, Constructions and Logistics*, Belgrade, Serbia, 2006.
- [282] M. Robertson and W. Singhose, "Robust Analytic Deflection-Limiting Commands," in *American Control Conference*, Minneapolis, MN, 2006.
- [283] J. Lawrence, W. Singhose, R. Weiss, A. Erb, and U. Glauser, "An Internet-Driven Tower Crane for Dynamics and Controls Education," in *IFAC Symp. on Control Education*, Madrid, Spain, 2006.
- [284] J. Lawrence, J. Danielson, and W. Singhose, "Design and Analysis of Input Shapers for Systems with a Braking Nonlinearity," in *Int. Symp. on Flexible Automation*, Osaka, Japan, 2006.
- [285] D. Kim and W. Singhose, "Reduction of Double Pendulum Crane Oscillations," in *Int. Conf. on Motion and Vibration Control*, Daejeon, Korea, 2006.
- [286] J. Huey *et al.*, "Remote Manipulation of Cranes via the Internet," in *Int. Conference on Motion and Vibration Control*, Daejeon, Korea, 2006.
- [287] K. Hekman, C. Stäheli, K. Sorensen, and W. Singhose, "Measuring Crane Payload Swing Angle Through Computer Vision," in *Int. Symp. on Flexible Automation*, Osaka, Japan, 2006.
- [288] K. Hekman and W. Singhose, "Suppression of Crane Payload Oscillation Using On-Off Commands," in *American Control Conference*, Minneapolis, MN, 2006.
- [289] J. Fortgang, W. Singhose, and V. Patrangenaru, "Scheduling of Input Shaping and Transient Vibration Absorbers for High-Rise Elevators," in *American Control Conference*, Minneapolis, MN, 2006.
- [290] T. Bradley, T. Hall, Q. Xie, W. Singhose, and J. Lawrence, "Input Shaping for Nonlinear Drive Systems," in *ASME Int. Mechanical Engineering Congress & Exposition*, Chicago, IL, 2006.
- [291] D. Blackburn *et al.*, "Advanced Input Shaping Algorithm for Nonlinear Tower Crane Dynamics," in *Int. Conference on Motion and Vibration Control*, Daejeon, Korea, 2006.
- [292] K. Sorensen, W. Singhose, and S. Dickerson, "A Controller Enabling Precise Positioning and Sway Reduction in Cranes with On-Off Actuation," in *IFAC World Congress*, Prague, Czech Republic, 2005.
- [293] M. Robertson, J. Vaughan, W. Singhose, M. Pastirik, M. Usselman, and D. Llewellyn, "Involving High School Students in a University-Level Mechanical Engineering Design Competition " in *American Society for Engineering Education*

- Annual Conference*, Portland, Oregon, 2005: American Society for Engineering Education, Chantilly, VA, pp. 9039-9049.
- [294] M. Robertson, A. Timm, and W. Singhose, "Evaluation of Command Generation Techniques for Tethered Satellite Retrieval," in *AAS/AIAA Space Flight Mechanics Conference*, Copper Mountain, CO, 2005.
 - [295] M. Robertson and W. Singhose, "Evaluation of Analytic Deflection-Limiting Commands," in *IFAC World Congress*, Prague, Czech Republic, 2005.
 - [296] M. Robertson and W. Singhose, "Closed-Form Deflection-Limiting Commands," in *American Control Conference*, Portland, OR, 2005, vol. 3: IEEE, Piscataway, NJ, pp. 2104-9.
 - [297] J. Lawrence and W. Singhose, "Design of Minicrane for Education and Research," in *6th Int. Conference on Research and Education in Mechatronics*, Annecy, France, 2005.
 - [298] H. Kojima and W. Singhose, "Adaptive Deflection Limiting Control for Slewing Flexible Space Structures," in *56th Int. Astronautical Congress*, Fukuoka, Japan, 2005, vol. IAC-05-C2.7.02.
 - [299] J. R. Huey and W. Singhose, "Experimental Verification of Stability Analysis of Closed-Loop Input Shaping Controllers," in *IEEE/ASME Int. Conf. on Advanced Intelligent Mechatronics*, Monterey, CA, 2005, pp. 1587-1592.
 - [300] J. Huey and W. Singhose, "Stability Analysis of Closed-Loop Input Shaping Control," in *IFAC World Congress*, Prague, Czech Republic, 2005.
 - [301] S.-W. Hong, H. Seomoon, V. Patrangenaru, W. Singhose, and S. Sprigle, "An Efficient Method for Identification of Human-Generated Forces During Extensor Thrust," in *IASTED International Conference on Biomedical Engineering*, Innsbruck, Austria, 2005.
 - [302] S.-W. Hong, V. Patrangenaru, W. Singhose, and S. Sprigle, "Motion Measurement and Force Determination During Unconstrained Extensor Thrust," in *Rehabilitation Engineering and Assistive Technology Society of North America Annual Meeting*, Atlanta, GA, 2005.
 - [303] J. Fortgang, W. Singhose, and J. d. J. Márquez, "Command Shaping for Micro-Mills and CNC Controllers," in *American Control Conference*, Portland, OR, 2005.
 - [304] J. Fortgang and W. Singhose, "Input Shaping for Continuum Beams under Longitudinal Vibration," in *IEEE/ASME International Conference on Advanced Intelligent Mechatronics*, Monterey, CA, 2005.
 - [305] E. Biediger, J. Lawrence, and W. Singhose, "Improving Trajectory Tracking for Systems with Unobservable Modes Using Command Generation," in *American Control Conference*, Portland, OR, 2005, vol. 1: IEEE, pp. 513-18.
 - [306] J. Vaughan, W. Singhose, and N. Sadegh, "Examination of Variable Damping for Payload Compensation in Heavy Machinery," in *Seventh International Conference on Motion and Vibration Control*, St. Louis, MO, 2004.

- [307] M. Robertson and W. Singhose, "Command Generation for Tether Retrieval," in *14th AAS/AIAA Space Flight Mechanics Conference*, Maui, Hawaii, 2004.
- [308] J. d. J. Márquez, J. Fortgang, W. Singhose, and J. M. Perez, "Optimizacion del proceso de microfresado mediante el empleo de tecnicas de reduccion activa de vibraciones," in *XVI National Conference of Mechanical Engineering (Spain)*, Leon, Spain, Dec. 15-17, 2004 2004, pp. 2709-2714.
- [309] J. Lawrence, W. Singhose, and K. Hekman, "Robust Friction-Compensating Input Shapers," in *8th Cairo Univ. Int. Conf. on Mechanical Design and Production*, Cairo, Egypt, 2004.
- [310] J. Lawrence, M. Falkenberg, W. Singhose, and G. Peláez, "Input Shaping for a Flexible, Nonlinear, One-link Robotic Arm with Backlash," in *Japan–USA Symposium on Flexible Automation*, Denver, Colorado, 2004.
- [311] H. Kojima, H. Fukudome, T. Watanabe, M. Robertson, and W. Singhose, "Adaptive Input Shaping Control for Slewing Flexible Space Structures," in *24th Int. Symp. on Space Technology and Science*, Miyazaki, Japan, 2004, pp. 474-479.
- [312] S. Klooster, K. Kozak, J. Vaughan, P. Sanders, and W. Singhose, "Fluid Power Control of a Hyper-Active Seat for Low-Frequency Vibration Suppression," in *IFAC Symposium on Advances in Automotive Control*, Salerno, Italy, 2004.
- [313] A. Khalid, W. Singhose, J. Huey, J. Lawrence, and D. Frakes, "Study of Operator Behavior and Performance Using an Input-Shaped Bridge Crane," in *IEEE Conference on Control Applications*, Taipei, Taiwan, 2004, vol. 1: IEEE, pp. 759-64.
- [314] J. Huey and W. Singhose, "Design of Flexible Systems for Use with Input Shaping," in *Seventh International Conference on Motion and Vibration Control*, St. Louis, MO, 2004.
- [315] K. Hekman, W. Singhose, and J. Lawrence, "Using Input Shaping to Suppress Controller and Structural Oscillations," in *Mechatronics 2004 9th Mechatronics Forum*, Ankara, Turkey, 2004.
- [316] K. Hekman, W. Singhose, and J. Lawrence, "Input Shaping with Coulomb Friction Compensation on a Solder Cell Machine," in *American Control Conference*, Boston, MA, 2004, vol. 1: IEEE, pp. 728-33.
- [317] J. Fortgang and W. Singhose, "Improving Trajectory Following Through Input Shaping of Internal Deflections," in *Seventh International Conference on Motion and Vibration Control*, St. Louis, MO, 2004.
- [318] J. Fortgang, J. d. J. Marquez, and W. Singhose, "Application of Command Shaping on Micro-Mills," in *Japan – USA Symposium on Flexible Automation*, Denver, Colorado, 2004.
- [319] J. Vaughan, W. Singhose, and N. Sadegh, "Use of Active Suspension Control to Counter the Effects of Vehicle Payloads," in *IEEE Conf. on Control Applications*, Istanbul, Turkey, 2003.

- [320] W. Singhose, J. Huey, J. Lawrence, and D. Frakes, "Input Shaping Curriculum: Integrating Interactive Simulations And Experimental Setups," in *11th Mediterranean Conference on Control Automation*, Rhodes, Greece, 2003, pp. IV 11-05.
- [321] W. Singhose, E. Biediger, H. Okada, and S. Matunaga, "Control of Flexible Satellites Using Analytic On-Off Thruster Commands," in *AIAA Guidance, Navigation, & Control Conf.*, Austin, TX, 2003: AIAA-2003-5333.
- [322] K. Kozak, J. Huey, and W. Singhose, "Performance Measures for Input Shaping," in *IEEE Conf. on Control Applications*, Istanbul, Turkey, 2003.
- [323] S. Klooster and W. Singhose, "A Study of Passenger Seat Parameters as a Basis for Active Seat Control," in *11th Mediterranean Conference on Control Automation*, Rhodes, Greece, 2003.
- [324] J. Huey and W. Singhose, "Effect of Vertical Acceleration on the Frequency of a Pendulum: Impact on Input Shaping," in *IEEE Conference on Control Applications*, Istanbul, Turkey, 2003.
- [325] J. Brogan, J. Fortgang, and W. Singhose, "Experimental Verification of Vibration Absorbers Combined with Input Shaping for Oscillatory Systems," in *American Control Conference*, Denver, CO, 2003.
- [326] E. Biediger, W. Singhose, H. Okada, and S. Matunaga, "Trajectory Planning for Coordinating Satellites using Command Generation," in *10th International Space Conference of Pacific-basin Societies*, Tokyo, Japan, 2003.
- [327] R. Thomas, J. Fortgang, and W. Singhose, "Optimization of Lightly Damped Pick-and-Place Processes Using Optimal Dynamic Vibration Absorbers," in *6th International Conference on Motion and Vibration Control*, Saitama, Japan, 2002.
- [328] J. Smith, K. Kozak, and W. Singhose, "Input Shaping for a Simple Non-Linear System," in *American Control Conference*, Anchorage, AK, 2002, vol. 1, pp. 821-6.
- [329] T. Singh and W. Singhose, "Tutorial on Input Shaping/Time Delay Control of Maneuvering Flexible Structures," in *American Control Conference*, Anchorage, AK, 2002.
- [330] G. Peláez, W. Singhose, and A. Vizan, "Shaping Tool Head Pneumatic Actuator Commands to Reduce Cut Car Letters Machine Vibration," in *WSEAS Int. Conf. on Signal Processing, Robotics and Automation*, 2002, pp. 54-59.
- [331] G. Peláez and W. Singhose, "Implementation of Input Shaping on Flexible Machines with Integer Controllers," in *IFAC World Congress on Automatic Control*, Barcelona, Spain, 2002, doi: 10.3182/20020721-6-ES-1901.01474.
- [332] J. Lawrence and W. Singhose, "Decreasing Effects of Coulomb Friction in Precision Positioning Using Input Shaping: Experimental Verifications," in *Japan-USA Symp. on Flexible Automation*, Hiroshima, Japan, 2002.

- [333] T. Kurfess, W. Singhose, and J. Fortgang, "Genesis and Evolution of an Undergraduate Mechatronics Course," in *Second IFAC Conf. of Mechatronic Systems*, Berkeley, CA, 2002.
- [334] J. Huey and W. Singhose, "The Application of Input Shaping to Wire-Driven Mechanisms," in *6th International Conference on Motion and Vibration Control*, Saitama, Japan, 2002.
- [335] K. Hekman, J. Lawrence, and W. Singhose, "Input Shaping for a PD Position Controller Under Coulomb Friction," in *IFAC World Congress on Automatic Control*, Barcelona, Spain, 2002.
- [336] J. Fortgang and W. Singhose, "Concurrent Design of Input Shaping and Vibration Absorbers," in *American Control Conference*, Anchorage, AK, 2002.
- [337] R. Eloundou and W. Singhose, "Justification for Using Step-Function Reference Commands: Comparison to S-Curves," in *2nd IFAC Conference on Mechatronic Systems*, Berkeley, CA, 2002: Elsevier Ltd., Oxford, UK
- [338] R. Eloundou and W. Singhose, "Saturation Compensating Input Shapers for Reducing Vibration," in *6th Int. Conference on Motion and Vibration Control*, Saitama, Japan, 2002, vol. 2: Japan Soc. Mechanical Eng., Tokyo, Japan, pp. 625-30.
- [339] U. Andresen and W. Singhose, "A Simple Cam Design Procedure for Automatic Screw Machines with Flexible Dynamics," in *Japan-USA Symp. on Flexible Automation*, Hiroshima, Japan, 2002.
- [340] M. Robertson and W. Singhose, "Multi-level Optimization Techniques for Designing Digital Shapers," in *American Control Conference*, Pittsburgh, PA, 2001.
- [341] K. Kozak, I. Ebert-Uphoff, and W. Singhose, "Analysis of Varying Natural Frequencies and Damping Ratios of a Sample Parallel Manipulator Throughout its Workspace using Linearized Equations of Motion," in *ASME Design Engineering Technical Conferences*, Pittsburgh, PA, 2001.
- [342] K. Hekman, J. Lawrence, and W. Singhose, "Use of Input Shaping to Decrease the Effects of Stiction," in *5th IFAC Symposium on Nonlinear Control Systems*, St. Petersburg, Russia, 2001.
- [343] J. Fortgang and W. Singhose, "Design of Vibration Absorbers for Step Motions and Step Disturbances," in *ASME Int. DETC 18th Biennial Conf. on Mechanical Vibration and Noise*, Pittsburgh, PA, 2001.
- [344] C. Forest, D. Frakes, and W. Singhose, "Input-Shaped Control of Gantry Cranes: Simulation and Curriculum Development," in *ASME DETC 18th Biennial Conf. on Mechanical Vibration and Noise*, Pittsburgh, PA, 2001: DETC2001/VIB-21522.
- [345] M. Kenison and W. Singhose, "A Parameter-Based Method for Designing Input Shapers for Flexible Robotic Systems," in *Seventh Mechatronics Forum International Conference*, Atlanta, GA, 2000.

- [346] D. Frakes, K. Grosser, J. Fortgang, and W. Singhose, "Simulating Motion of an Operator-Controlled Gantry Crane in a Cluttered Work Environment," in *IMECE Conference*, Orlando, FL, 2000.
- [347] W. Singhose and B. Mills, "Command Generation Using Specified-Negative-Amplitude Input Shapers," in *American Control Conference*, San Diego, CA, 1999, vol. 1: IEEE, Piscataway, NJ, pp. 61-65.
- [348] W. Singhose and B. Mills, "Vibration Reduction with Specified-Swing Input Shapers," in *Conference on Control Applications*, Kohala, Hawaii, 1999, vol. 1: IEEE, Piscataway, NJ, pp. 533-538.
- [349] W. Singhose and K. Grosser, "Limiting Excitation of Unmodeled High Modes with Negative Input Shapers," in *IEEE Conference on Controls Applications*, Kohala, Hawaii, 1999.
- [350] M. Kenison and W. Singhose, "Input Shaper Design for Double-Pendulum Planar Gantry Cranes," in *IEEE Conference on Control Applications*, Kona, Hawaii, 1999, pp. 539-44.
- [351] W. Singhose and S. Towell, "Double-Pendulum Gantry Crane Dynamics and Control," in *IEEE Conf. on Control Applications*, Trieste, Italy, 1998.
- [352] R. Masterson, W. Singhose, and W. Seering, "Input Shaping for Constant-Velocity Scanning with Flexible Sensors," in *IEEE Conf. on Control Applications*, Trieste, Italy, 1998.
- [353] W. E. Singhose, L. J. Porter, and W. P. Seering, "Input Shaped Control of a Planar Gantry Crane with Hoisting," in *American Control Conf.*, Albuquerque, NM, 1997.
- [354] W. E. Singhose, B. W. Mills, and W. P. Seering, "Closed-Form Methods for On-Off Control of Multi-Mode Flexible Structures," in *IEEE Conf. of Decision and Control*, San Diego, CA, 1997, vol. 2: IEEE, New York, NY, pp. 1381-6.
- [355] W. Singhose, T. Singh, and W. Seering, "On-Off Control of Flexible Spacecraft with Specified Fuel Usage," in *American Control Conf.*, Albuquerque, NM, 1997.
- [356] W. Singhose and W. Seering, "Analytic Methods for Slewing Undamped Flexible Structures with On-Off Actuators," in *AIAA Guidance, Navigation, and Control Conf.*, New Orleans, LA, 1997.
- [357] W. E. Singhose, W. P. Seering, and A. K. Banerjee, "Limiting Deflection During the Slewing of Flexible Spacecraft Using Deflection Sampling," in *AIAA Guidance, Navigation, and Control Conf.*, San Diego, CA, 1996.
- [358] W. E. Singhose, L. Y. Pao, and W. P. Seering, "Time-Optimal Rest-to-Rest Slewing of Multi-Mode Flexible Spacecraft Using ZVD Robustness Constraints," in *AIAA Guidance, Navigation, and Control Conf.*, San Diego, CA, 1996.
- [359] W. Singhose, W. Seering, and N. Singer, "Input Shaping for Vibration Reduction with Specified Insensitivity to Modeling Errors," in *Japan-USA Sym. on Flexible Automation*, Boston, MA, 1996, vol. 1: ASME, pp. 307-13.

- [360] W. Singhose and L. Pao, "Comparison of Input Shaping Techniques for Speed-Critical Multi-Mode Flexible Systems," in *IEEE Conf. on Control Applications*, Dearborn, MI, 1996.
- [361] L. Pao and W. Singhose, "Unity Magnitude Input Shapers and Their Relation to Time-Optimal Control," in *IFAC World Congress*, San Francisco, CA, 1996, pp. 385-390.
- [362] E. A. Crain, W. E. Singhose, and W. P. Seering, "Derivation and Properties of Convolved and Simultaneous Two-Mode Input Shapers," in *IFAC World Congress*, San Francisco, CA, 1996, pp. 441-6.
- [363] E. A. Crain, W. E. Singhose, and W. P. Seering, "Evaluation of Input Shaping on Configuration Dependent Systems," in *Japan-USA Symp. on Flexible Automation*, Boston, MA, 1996.
- [364] W. Singhose, L. Porter, and N. Singer, "Vibration Reduction Using Multi-Hump Extra-Insensitive Input Shapers," in *American Control Conference*, Seattle, WA, 1995, vol. 5, pp. 3830-34.
- [365] W. Singhose, K. Bohlke, and W. Seering, "Fuel-Efficient Shaped Command Profiles for Flexible Spacecraft," in *AIAA Guidance, Navigation, and Control Conf.*, Baltimore, MD, 1995.
- [366] L. Y. Pao and W. E. Singhose, "On the Equivalence of Minimum Time Input Shaping with Traditional Time-Optimal Control," in *IEEE Conference on Control Applications*, Albany, NY, 1995, pp. 1120-5.
- [367] L. Y. Pao and W. E. Singhose, "A Comparison of Constant and Variable Amplitude Command Shaping Techniques for Vibration Reduction," in *IEEE Conference on Control Applications*, Albany, NY, 1995, pp. 875-81.
- [368] W. Singhose, N. Singer, and W. Seering, "Design and Implementation of Time-Optimal Negative Input Shapers," in *International Mechanical Engineering Congress and Exposition, DSC 55-1*, Chicago, IL, 1994: ASME, pp. 151-7.
- [369] W. Singhose, S. Derezinski, and N. Singer, "Extra-Insensitive Shapers for Controlling Flexible Spacecraft," in *AIAA Guidance, Navigation, and Control Conf.*, Scottsdale, AZ, 1994.
- [370] W. Singhose, S. Derezinski, and N. Singer, "Input Shapers for Improving the Throughput of Torque-Limited Systems," in *IEEE Conf. on Control Applications*, Glasgow, Scotland, 1994.
- [371] W. E. Singhose, W. P. Seering, and N. C. Singer, "Shaping Inputs to Reduce Vibration: A Vector Diagram Approach," in *IEEE Int. Conference on Robotics and Automation*, Cincinnati, OH, 1990, vol. 2, pp. 922-927.
- [372] W. Singhose, C. Adams, R. Martinez, A. Rana, D. Kim, and W. Li, "Semi-Automated Mining of Customer Reviews to Identify Design Problems of Cantilever-Style Bassinets," in *ASME Int'l Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, Washington, D.C., 2024.

- [373] T. Rome, C. Adams, and W. Singhose, "Dynamic Model for Improved Controller Design in Tower Crane Disassembly," in *IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM)*, Boston, MA, July 15-18 2024.

Invited papers

- [374] W. Singhose, "Shaping Inputs to Reduce Vibration: A Vector Diagram Approach," MIT Artificial Intelligence Lab Memo No. 1223, March 1990. [Online]. Available: invited
- [375] W. Singhose and W. Seering, "Generating Vibration-Reducing Inputs with Vector Diagrams," in *IFTToMM Eighth World Congress on the Theory of Machines and Mechanisms*, Prague, Czechoslovakia, 1991, vol. 1, pp. 315-318. [Online]. Available: invited. [Online]. Available: invited
- [376] A. K. Banerjee and W. E. Singhose, "Slewing and Vibration Control of a Nonlinearly Elastic Shuttle Antenna," in *AIAA/AAS Astrodynamics Specialists Conf.*, Scottsdale, AZ, 1994. [Online]. Available: invited. [Online]. Available: invited
- [377] W. Singhose and N. Singer, "Initial Investigations into the Effects of Input Shaping on Trajectory Following," in *American Control Conference*, Baltimore, MD, 1994, vol. 3, pp. 2526-32. [Online]. Available: invited. [Online]. Available: invited
- [378] W. E. Singhose and N. C. Singer, "Improving Coordinate Measuring Machine Repeatability with Input Shaping," in *NSF Design and Manufacturing Grantees Conf.*, Cambridge, MA, 1994, pp. 467-8. [Online]. Available: invited. [Online]. Available: invited
- [379] A. K. Banerjee and W. E. Singhose, "Minimum Time Fuel Efficient Maneuver of Flexible Spacecraft with Vibration Amplitude Constraint," in *AAS Astrodynamics Specialist Conf.*, Halifax, Nova Scotia, 1995, vol. AAS 95-318. [Online]. Available: invited. [Online]. Available: invited
- [380] W. Singhose and T. Chuang, "Reducing Deviations From Trajectory Components With Input Shaping," in *American Control Conference*, Seattle, WA, 1995, vol. 1, pp. 929-33. [Online]. Available: invited. [Online]. Available: invited
- [381] W. Singhose, W. Seering, and N. Singer, "The Effect of Input Shaping on Coordinate Measuring Machine Repeatability," in *IFTToMM Ninth World Congress on the Theory of Machines and Mechanisms*, Milan, Italy, 1995, vol. 4, pp. 2930-2934. [Online]. Available: invited. [Online]. Available: invited
- [382] W. Singhose, N. Singer, and W. Seering, "Comparison of Command Shaping Methods For Reducing Residual Vibration," in *Third European Control Conf.*, Rome, Italy, 1995, vol. 2, pp. 1126-1131.
- [383] N. Singer, L. Pao, W. Singhose, and W. Seering, "An Efficient Algorithm for the Generation of Multi-Mode Input Shaping Sequences," in *IEEE Int. Conf. on*

- Control Applications*, Dearborn, MI, 1996. [Online]. Available: invited. [Online]. Available: invited
- [384] W. E. Singhose, W. P. Seering, and A. Banerjee, "An Evaluation of Fuel-Efficient On-Off Input Shaping with Deflection Limiting," in *AIAA/AAS Astrodynamics Specialist Conf.*, San Diego, CA, 1996. [Online]. Available: invited. [Online]. Available: invited
 - [385] A. K. Banerjee and W. E. Singhose, "Command Shaping in Tracking Control of a Two-Link Flexible Manipulator," in *AIAA Astrodynamics Conf.*, Sun Valley, ID, 1997, vol. AAS 97-721. [Online]. Available: invited. [Online]. Available: invited
 - [386] H. J. S. Feder, W. E. Singhose, and W. P. Seering, "Input Shaping for Collision Avoidance with Robotic Manipulation of Suspended Payloads," in *11th Symposium on Structural Dynamics and Control*, Blacksburg, VA, 1997. [Online]. Available: invited. [Online]. Available: invited
 - [387] N. Singer, W. Singhose, and E. Krikkku, "An Input Shaping Controller Enabling Cranes to Move Without Sway," in *ANS 7th Topical Meeting on Robotics and Remote Systems*, Augusta, GA, 1997, vol. 1, pp. 225-231. [Online]. Available: invited. [Online]. Available: invited
 - [388] W. Singhose, I. Villanueva, and W. Seering, "Use of Neural Networks for Generation of On-Off Commands for Flexible Systems," in *12th IEEE Int. Symp. on Intelligent Control*, Istanbul, Turkey, 1997.
 - [389] W. E. Singhose, "Command Generation for Flexible Systems," Ph.D. Thesis, Mechanical Engineering, Massachusetts Institute of Technology, 1997.
 - [390] B. W. Mills, W. E. Singhose, and W. P. Seering, "Closed-Form Generation of Specified-Fuel Commands for Flexible Systems," in *American Control Conference*, Philadelphia, PA, 1998, vol. 5: IEEE, Piscataway, NJ, pp. 2632-6.
 - [391] A. Banerjee and W. Singhose, "Vibration Reduction for Flexible Spacecraft Following Momentum Dumping with/without Slewing," in *AAS/AIAA Astrodynamics Specialist Conference*, Girdwood, AK, 1999. [Online]. Available: invited. [Online]. Available: invited
 - [392] L. French, W. Singhose, and W. Seering, "An Expert System for the Design of Input Shapers," in *IEEE Conference on Control Applications*, Kohala, Hawaii, 1999. [Online]. Available: invited. [Online]. Available: invited
 - [393] K. Grosser and W. Singhose, "Command Generation for Flexible Telerobotic Arms," in *International Symposium on Motion and Vibration Control in Mechatronics*, Tokyo, Japan, 1999. [Online]. Available: invited. [Online]. Available: invited
 - [394] E. Ooten and W. Singhose, "Time-Optimal Commands for Sequential Motions of Flexible Systems with Numerator Dynamics," in *International Symposium on Motion and Vibration Control in Mechatronics*, Tokyo, Japan, 1999. [Online]. Available: invited. [Online]. Available: invited

- [395] M. Robertson and W. Singhose, "Initial Guess Schemes for Generating Deflection-Limiting Commands," in *AAS/AIAA Astrodynamics Specialist Conference*, Girdwood, AK, 1999. [Online]. Available: invited. [Online]. Available: invited
- [396] K. Grosser, J. Fortgang, and W. Singhose, "Limiting High Mode Vibration and Rise Time in Flexible Telerobotic Arms," in *Conf. on Systemics, Cybernetics, and Informatics*, Orlando, FL, 2000.
- [397] M. Kenison and W. Singhose, "Concurrent Design of Input Shaping and Feedback Control for Insensitivity to Parameter Variations," in *Sixth Int. Workshop on Advanced Motion Control*, Nagoya, Japan, 2000.
- [398] E. Ooten and W. Singhose, "Command Generation with Sliding Mode Control for Flexible Systems," in *Sixth International Workshop on Advanced Motion Control*, Nagoya, Japan, 2000. [Online]. Available: invited. [Online]. Available: invited
- [399] D. Frakes and W. Singhose, "Geometrically Constrained Optical-flow Based Tracking for the Extraction of Kinematic Data from Video," in *Fifth Int. Symp. on Computer Methods in Biomechanics and Biomedical Engineering*, Rome, Italy, 2001.
- [400] K. Kozak, I. Ebert-Uphoff, P. A. Voglewede, and W. Singhose, "Concept Paper: On the Significance of the Lowest Linearized Natural Frequency of a Parallel Manipulator as a Performance Measure for Concurrent Design," in *Workshop on Fundamental Issues and Future Research Directions for Parallel Mechanisms and Manipulators*, Quebec City, Quebec, Canada, 2002.
- [401] E. Ooten-Biediger and W. Singhose, "Command Generation for Trajectory Planning of Coordinating Satellites," in *University Space Systems Symposium*, Honolulu, HI, 2002.
- [402] M. Robertson and W. Singhose, "Deflection-Limiting Control of Flexible Spacecraft Using On-Off Thrusters," in *University Space Systems Symposium*, Honolulu, HI, 2002.
- [403] E. Biediger and W. Singhose, "Formation Flying Satellite Control Utilizing Input Shaping," in *AIAA/AAS Astrodynamics Specialist Conf.*, Big Sky, Montana, 2003.
- [404] E. Biediger, W. Singhose, D. Frakes, M. Kashiwa, and S. Matunaga, "An Investigation of Video Tracking on a Formation Flying Satellite Testbed," in *AIAA/AAS Astrodynamics Specialist Conf.*, Big Sky, Montana, 2003.
- [405] W. Singhose, M. Robertson, T. Watanabe, H. Kojima, and A. Banerjee, "Tether-Based Actuators for Space Applications," in *2003 International Workshop on Advanced Sensors, Structural Health Monitoring, and Smart Structures*, Yokohama, Japan, 2003.
- [406] T. Watanabe, T. Makida, H. A. Fujii, H. Kojima, and W. Singhose, "An Application of Input Shaping for Electrodynamic Tether System," in *AIAA/AAS Astrodynamics Specialist Conference*, Providence, Rhode Island, 2004.

- [407] A. Banerjee, W. Singhose, and D. Blackburn, "Orbit Boosting of an Electrodynamic Tethered Satellite with Input-Shaped Current," in *AAS/AIAA Astrodynamics Specialist Conference*, Lake Tahoe, CA, 2005.
- [408] W. Singhose and D. Kim, "Robustness of Command-Shaping Control on Flexible Systems," in *Spring Research Conference on Statistics in Industry and Technology*, Chicago, IL, 2011.

D. Presentations

Keynote and Plenary Lectures

- 6/8/23 "Hazard Analysis of Mobile Juvenile Products," International Forum on Automotive and Mechanical Engineering (MECHFORUM2023)
- 9/23/15 "Dynamics and Control of Crane Payload Lift-off and Lay-Down Operations," XXI Triennial Int. Conference on Material Handling, Constructions, and Logistics, Vienna, Austria
- 10/27/14 "Using Mechatronics to Improve Human Operation of Complex Dynamic Systems," International Conference on Mechanics and Control Engineering, Asheville, NC
- 10/18/12 "Improving Human Operation of Oscillatory Dynamic Systems," International Conference on Control, Automation and Systems, Jeju, South Korea
- 10/19/06 "Crane Oscillation Control: Applications and Educational Uses," International Conference on Material Handling, Constructions, and Logistics, Belgrade, Serbia

Other Invited Lectures

- 3/2/20 "Legal Considerations of Sensor use in Emerging Technology," Google, Mountain View, CA
- 4/24/19 "Ethical Considerations of Sensor Use," Stanford University, Palo Alto, CA
- 11/29/18 "Killer Robots: Why You Will not be Owning a Self-Driving Car," Stanford University, CA
- 10/12/18 "Georgia Tech ARLISS Team", University of Oregon, Eugene, OR
- 2/26/18 "Command Generation for Flexible Systems," University of California, Berkeley, Berkeley, CA
- 10/3/16 "Oscillation Control Using Input Shaping Technology," Hankyong University, Anseong, South Korea
- 9/29/16 "Input Shaping Control Technologies", Shanghai Jiao Tong University, Shanghai, China
- 4/21/16 "Improving Manufacturing Machines with Command Shaping," Mercedes Manufacturing Facilities, Vance, AL
- 1/25/16 "Commercialization of University-Developed Technology," University of Chicago Booth School of Business, Chicago, IL
- 9/25/15 "Applications of Input Shaping Control Methods," Czech Technical University, Prague, Czech Republic

3/25/15 “Oscillation Control of Suspended Loads Using Command Shaping,” Boeing BR&T – Vertical Lift, Mesa, AZ

1/22/15 “Building a Culture of Active Learning in Mechatronics,” Kumoh National Institute of Technology, Gumi, South Korea

1/19-1/23/15 “Special Lectures on Mechatronics by Foreign Distinguished Professor,” Kumoh National Institute of Technology, Gumi, South Korea

9/26/14 “Building a Culture of Active Learning”, Georgia Tech Zeigler Lecture

8/4/14 “NI myRIO Design Real Systems, Fast: 2014 Student Project Success”, Panelist, NI Week, Austin, TX

3/19/14 “Input Shaping for Oscillation Reduction in the Digital World”, Auburn University

11/16/13 “Improving Machine Motion with Command Shaping”, Wuxi Zhong Ding Logistics, Wuxi, China

11/14/13 “Improving Manufacturing Machines with Command Shaping”, HUST-Wuxi Research Institute, Wuxi, China

11/13/13 “Analyzing Accident Videos of Inverted-Pendulum Human Transporters”, Huazhong University of Science and Technology, Wuhan, China

4/15/13 “Control of Large Flexible Spacecraft, Robots, and Cranes”, Budapest University of Technology and Economics, Budapest, Hungary

4/15/13 “Recue Robot: An International Student Design Collaboration”, University of Patras, Patras, Greece

10/17/12 “Active Learning Methods for Mechanical Engineering”, Yeungnam College, Daegu, South Korea

6/26/12 “Command-Shaping Control of Flexible Aerospace Systems”, Beijing Institute of Technology Beijing, China

6/18-21/12 “Introductory Creative Decision and Design Tools for Mechatronics”, Huazhong University of Science and Technology, Wuhan, China

11/8/11 “Advanced Crane Control to Improve Safety and Ergonomics”, Boeing Research and Technology Ergonomics Road Show, Everett, WA

5/6/11 “Creative Decisions and Design: An Innovative Design Course at Georgia Tech”, Aalto University, Helsinki, Finland

4/25/11 “Creative Decisions and Design: An Innovative Design Course at Georgia Tech”, Chosun University, Gwangju, Korea

4/21/11 “Controlling Large Flexible Structures with Command Shaping”, Konkuk University, Seoul, Korea

4/19/11 “Command Shaping Control of Large Flexible Structures”, Shanghai Maritime University, Shanghai, China

4/18/11 “Creative Decisions and Design: An Innovative Design Course at Georgia Tech”, Huazhong University of Science and Technology, Wuhan, China

4/18/11 “Controlling Large Flexible Structures with Command Shaping”, Huazhong University of Science and Technology, Wuhan, China

4/1/11 “Command Shaping Control of Large Flexible Systems”, University of Parma, Parma, Italy

7/12/10 “Command Shaping Control of Large Flexible Systems”, University Carlos III, Madrid, Spain

6/18/10 “Advanced Crane Control Lab at Georgia Tech”, KoneCranes, Hyvinkää, Finland

5/3/10 “Command Shaping Control of Flexible Systems”, University Castilla-La Mancha, Ciudad Real, Spain

12/16/09 “Control of Cranes and Spacecraft using Command Shaping”, University of Sydney, Sydney, Australia

11/25/09 “The ASU Experience: Interfacing with the Machines“, Arizona State University, Tempe, AZ

11/25/09 “Interfaces and Control Systems for Intuitive Crane Control”, Arizona State University, Tempe, AZ

10/6/09 “Using Competitions in Mechatronics Engineering Education at Georgia Tech”, Chosun University, Kwangju, Korea

4/20/09 “Advanced Command Shaping Control of Cranes, Robots, and Spacecraft”, Instituto Automatico de Industriales, Madrid, Spain

11/25/08 “Command Shaping Control of Cranes, Robots, and Spacecraft”, Kyung Hee University, Suwon, Korea.

11/24/08 “Command Shaping Control of Cranes, Robots, and Spacecraft”, Seoul National University, Seoul, Korea.

11/21/08 “Command Shaping Control of Cranes, Robots, and Spacecraft”, Korean Atomic Energy Research Institute, Deajon, Korea.

11/20/08 “Control of Tip-Over Instability”, Kumoh National Institute of Technology, Gumi, Korea.

8/10/08 “Engineering Teaching Methods at Georgia Tech”, Shandong Jianzhu University, Jinan, China.

8/10/08 “Using Command Shaping to Control Robots, Spacecraft, and Cranes”, Shandong Jianzhu University, Jinan, China.

8/8/08 “Control of Robots, Spacecraft, and Cranes Using Command Shaping”, Northeastern Forest University, Harbin, China.

8/7/08 “Engineering Teaching Methods at Georgia Tech”, Northeastern Forest University, Harbin, China.

8/4/08-8/8/08 “Command Shaping for Dynamic Systems”, Harbin Institute of Technology, Harbin, China.

5/28/07, "A Design Course at Georgia Tech: Creative Decisions & Design", Center of Excellence in Robotics, Kumoh National Institute of Technology, Gumi, Korea.

5/24/07, "Making Robots and Cranes Move Very Fast with Command Shaping", Northwest Forest University, Harbin, China.

5/23/07, "Making Robots and Cranes Move Very Fast with Command Shaping", Harbin Institute of Technology, Harbin, China.

3/19/07, "Crane Dynamics and Control: Applications and Educational Uses", Center of Excellence in Robotics, Tokyo Tech, Tokyo, Japan.

9/1/2006, "Crane Oscillation Control by Command Shaping", Ishikawajima Harima Heavy Industries, Yokohama, Japan.

4/20/06, "High-Speed Motion Control Using Command Shaping", Toshiba Corporate Research & Development Center, Tokyo, Japan.

1/25/2006, "Command Shaping for Cranes and Other Flexible Systems", University of Tokyo, Tokyo, Japan.

1/18/06, "Research Topics for Gantry Robots", Kumoh National Institute of Technology, Gumi, South Korea.

12/13/05, "An Introduction to Command Shaping for Flexible Systems", Center of Excellence in Robotics, Tokyo Tech, Tokyo, Japan.

8/12/05, "Advanced Command Shaping for Nonlinear Systems and On-Off Actuators", Kumoh National Institute of Technology, Gumi, South Korea.

8/11/05, "An Introduction to Command Shaping for Flexible Systems", Kumoh National Institute of Technology, Gumi, South Korea.

8/10/05, "An Introduction to Command Shaping for Flexible Systems", Korea Institute of Machinery & Materials, Deajon, South Korea.

8/9/05, "Command Shaping for Flexible Systems", Pusan National University, Busan, South Korea.

11/29/04, "Improving Machine Speed and Accuracy by Command Shaping", Metz, France.

10/27/04 – "Improving the Speed of Cranes, Robots, and Micro Mills by Command Shaping", Instituto Automatico de Industriales, Madrid, Spain

4/15/04 – "Undergraduate Research in Mechanical Engineering", Meeting of Congressional Staffers, Georgia Tech Conference Center, Atlanta, GA.

3/10/04 – "Design of Physical Mechanisms to Reduce Unwanted Dynamics", Nihon University, Tokyo, Japan.

1/29/04 – "Georgia Tech CanSat Team", Southeastern Space Grant Consortia Director's Meeting, Atlanta, GA.

10/23/03 - "Control of Flexible Spacecraft Using Command Shaping ", Georgia Tech IEEE meeting Atlanta, GA.

8/7/02 - "Rapid Motion of Crane-Like Structures", Tsukuba University, Tsukuba, Japan.

10/15/02 - "Designing Commands to Reduce Vibration in Mechanical Systems", ETSII de Madrid, Madrid, Spain.

10/14/02 - "Designing Commands to Reduce Vibration in Mechanical Systems", University of Vigo, Vigo, Spain.

8/13/02 - "Command Shaping for Flexible Structures", Tokyo Metropolitan Institute of Technology, Tokyo, Japan.

7/29/02 - "Controlling Flexible Spacecraft through Command Shaping", ISAS Astrodynamics Symposium Invited Speaker, Sagamihara, Japan.

7/13/02- "Using Input Shaping with On/Off Actuators", Laboratory for Space Systems, Tokyo Institute of Technology, Tokyo, Japan.

7/6/02- "Tutorial on Input Shaping for Moving Flexible Structures", Laboratory for Space Systems, Tokyo Institute of Technology, Tokyo, Japan.

3/18/02 - "Command Shaping Overview and Application to Hard Disk Drive Servo Control", Hitachi Corporation, Odawara, Japan.

3/15/02 - "Command Shaping for Vibration Reduction: Overview and Application to Hard Disk Drive Servo Control", IEE Committee Meeting for Mass Storage Servo, Nagoya, Japan.

10/27/00 - "Robotics Research at Georgia Tech." Waseda University, Tokyo, Japan.

10/24/00 - "Robotics Research at Georgia Tech." Tokyo Institute of Technology, Tokyo, Japan.

10/23/00 - "Robotics Research at Georgia Tech." Kyushu University, Fukuoka, Japan.

10/16/00 - "How to Properly Motivate Robots." MIT Club of Atlanta, Georgia Tech.

2/27/99 - "Making Machines Move Very Fast With Command Generation." American University in Cairo, Cairo, Egypt.

E. Grants and Contracts

A. As PI or Co-PI

Private Sources

"Crane Safety Research Center", Wang-Wong Foundation, December, 2023, \$5,000,000.

Government Sources

"Input Shaping Mobile Crane Controllers", Georgia Research Alliance, October 2018, \$49,965.

"I-Corps: Reducing Oscillation of Systems Driven by Stepper Motors and On-Off Actuators", National Science Foundation, April 2016, \$50,000.

"Rocket Rescue Robot", Georgia Space Grant Consortium, August 2014, \$6,000.

"Designing a Rocket-Launched Target-Seeking Rescue Robot", Georgia Space Grant Consortium, May 2013, \$3,762.

"Hopping Rotochute Micro Satellite Design Project", Georgia Space Grant Consortium, July 2012, \$2,275.

“International DDEP: Control of Complex Tower Crane Motion Using Low-Cost Cameras”, National Science Foundation, September 2011-December 2012, \$13,930.

"Input Shaping for Rotorcraft Sling Load Operation", National Rotorcraft Technology Center (NRTC), Jan. 2011 – May 2013, \$120,000. **Co-PI (Singhose: \$56,875)**

"Georgia Tech Student CanSat Team", Georgia Space Grant Consortium, Jan. 2006 - May 2010, \$19,708.

“International DDEP: Development of Aircraft Conflict Resolution Algorithms”, National Science Foundation, May 2008-September 2008, \$9,950.

“Approaches to Traffic Flow Management in the Presence of Uncertainty”, NASA, October 2006-September 2008, \$706,366. **Co-PI (Singhose: \$120,056)**

“International DDEP: Experimental Evaluation of a Mobile Tower Crane”, National Science Foundation, November 2006-March 2007, \$10,800.

“International DDEP: Experimental and Educational Research with Remotely Operated Cranes”, National Science Foundation, December 2005-March 2006, \$8,100.

“Planning Visit: Large Flexible Space Structures”, National Science Foundation, December 2005, \$12,412.

"Application of Command Generation Techniques to the Control of Space Tether Systems", NASA/Marshall Space Flight Center, July 2005-July 2006, \$24,000.

“Ph.D. Dissertation Enhancement Project: Experimental Evaluation of Low-Contact-Force Machining”, National Science Foundation, January 2004-May 2004, \$9,700.

Support for International Workshop on Advanced Sensors, Structural Health Monitoring, and Smart Structures, Yokohama, Japan, National Science Foundation, November 2003, \$1,334.

"Command Generation and Control of Momentum Exchange Electrodynamic Reboost Tethered Satellite", NASA/Marshall Space Flight Center, August 2003-July 2005, \$48,000.

"Georgia Tech CanSat Development", Georgia Space Grant Consortium, December 2002 - December 2005, \$20,851.

"Experimental Evaluation of Coordinated Flexible Satellite Control", National Science Foundation, November 2002, \$7,995.

"Trajectory Planning for Coordinating Satellites Using Command Generation",
NASA/ Goddard Space Flight Center, August 2002-July 2005, \$72,000.

Industry Sources

"Evolution of Novel Haptic Actuation, Implementation and Test Systems"

Google Inc., Jan. 2022, \$249,869.

"Steady Hoist Swing-Damping Control for Rotocraft Operations," Atlas Devices Inc., March, 2021, \$100,000.

"Development of Advanced Haptic Actuation Structures and Control Methods,"
Google Inc., Jan. 2021, \$246,042.

"Development of Novel Haptic Actuation," Google Inc., Jan. 2020, \$258,488.

"Dynamic Model and Control System Design for Cable-Driven Crane,"
ConcertLab, Jan. 2020, \$27,088.

"Steady Hoist for Rotocraft Operations," Atlas Devices, LLC, Dec. 2019, \$10,000.

"Mobile Vision GT Singhose SOW 5", Google Inc., Nov, 2017, \$105,650.

"Mobile Vision GT Singhose SOW 4", Google Inc., Jan, 2017, \$95,922.

"Development Kits and myRIO Controllers for Undergraduate Controls",
National Instruments, October 2016, \$8,814.

"Mobile Vision GT Singhose SOW 3", Google Inc., August, 2016, \$80,193.

"Mobile Vision GT Singhose SOW 2", Google, Inc. Jan, 2016, \$112,309.

"Automated Large-Area Sanding", Boeing Research and Technology, Jan, 2016, \$50,000.

"Mobile Vision - Design and Evaluation of a Mobile Vision-Based Device for Interactive Writing", Google Inc., June, 2015, \$79,794.

"Automated Large-Area Painting", Boeing Research and Technology, May, 2015, \$50,000.

"Hardware Integration for Large-Area Sensing", Boeing Research and Technology, July, 2014, \$141,632.

"ME6404 Pneumatics project", National Fluid Power Association, November 2014, \$4,520.

"PLC Programming Curriculum for Georgia Tech", Siemens, August 2014, \$27,500.

"Use of Pneumatic Systems in Introductory Mechanical Design Projects",
National Fluid Power Association, November 2013, \$4,720.

“Development of Mechatronics and Robotics Educational Platforms Using Compact Control Units”, National Instruments, May 2013, \$117,000.

“Integration of Zurich University of Applied Sciences Bridge Crane into Georgia Tech Research and Educational Activities”, Siemens, May 2013, \$15,920.

“Manufacturing Technologies for the 21st Century”, Boeing Research and Technology, Jan. 2013, \$185,700.

“Multi-National Collaborative Design of Target-Seeking Robots”, Boeing Research and Technology, Nov. 2012, \$60,864.

“Multi-National Collaborative Design Tools”, Boeing Research and Technology, Nov. 2012, \$62,711.

“Input Shaping Analysis and Design Support”, Space Systems Loral, August 2012, \$47,086.

“Material Handling Dynamic Load Oscillation Suppression”, Boeing Research and Technology, Jan. 2012, \$100,000.

“Material Handling Dynamic Load Oscillation Suppression”, Boeing Research and Technology, Jan. 2011, \$100,000.

“A Balloon Hoist Experimental Setup to Evaluate National Instruments Products”, National Instruments, March 2011, \$38,665.

“Design & Development of a Pediatric Personal Transporter for Children with Disabilities”, International Diversified Products, December 2010, \$5,500. Co-PI (Singhose: \$2,750)

“Siemens Automation – Cherrypicker Crane Project”, Siemens Industry, August 2010, \$44,732.

“Investigation of Commercial Personal Transporters”, International Diversified Products, June 2010, \$6,000. Co-PI (Singhose: \$3,000)

“Material Handling Dynamic Load Oscillation Suppression”, Boeing Research and Technology, Jan. 2010, \$100,000.

“Sponsorship of Georgia Tech Curriculum Improvements”, British Petroleum, Nov. 2009, \$7,500.

“Development of a Cherrypicker Aerial Lift for Use in Local and Remote Laboratories”, Siemens Energy and Automation, Sept. 2009, \$38,000.

“Pneumatic Powered Advertisement Dispenser”, Diastone Corporation, May 2009, \$8,800.

“Material Handling Dynamic Load Oscillation Suppression”, Boeing Research and Technology, Jan. 2009, \$100,000.

“Integrating Pneumatics Into Introductory Mechanical Design”, National Fluid Power Association, May 2008, \$4,960.

“Material Handling Dynamic Load Oscillation Suppression”, Boeing Research and Technology, Jan. 2008, \$75,000.

“Expansion of Pneumatic Systems in ME2110: Creative Decisions and Design”, National Fluid Power Association, March 2006, \$4,000.

“Pneumatic Equipment and Supplies for ME2110: Creative Decisions and Design”, Festo Corporation, March. 2005, \$6,898.

“Introduction of Pneumatic Systems into ME2110: Creative Decisions and Design”, National Fluid Power Association, Nov. 2004, \$5,000.

“Feedback and Command Shaping Control of Bridge Cranes”, CAMotion, Inc. Jan. 2004 - August 2008, \$98,168.

“Prototype Controller for Elastic Spacecraft”, Northrop Grumman, January 2004 – December 2004, \$44,415.

Support for University Space System Symposium, Jet Propulsion Laboratory, November 2002-5, \$5,528.

“Control of Sloshing Liquid Demonstration Unit”, National Instruments, March 2001, \$1,500.

International Sources

“International Design and Construction of Quadrotors”, Kumoh National Institute of Technology, December 2015, \$6,000.

“International Cooperative Education in Engineering Design”, Chosun University, November 2013, \$9,000.

“Development of Educational Tasks in an Introductory Design Course”, Chosun University, November 2011, \$9,600.

“Development of a Mobile Mechatronic Device”, Chosun University, June 2011, \$9,600.

“Development of Educational Tasks in an Introductory Design Course”, Chosun University, November 2010, \$2,400.

“Research on Mobile Mechatronics Machine”, Chosun University, November 2010, \$3,600.

“Mechanical Manipulators Control, Education and Research”, Ministerio de Ciencia e Innovacion de España, Dec. 2009, 18,000 Euro (\$25,767).

“Environmentally-Friendly Automotive Parts - Human Resources Development Center”, Chosun University, Dec. 2009, \$6,000.

“Versatile Command Shaping Controllers for Industrial Cranes”, Kumoh National Institute of Technology, June 2006, \$50,829

“Development of Vibration Reduction Scheme for XY Stages Using Input Shaping”, Top Engineering Co., Center for Nano and Precision Technology, Kumi, Korea, December 2005, \$5,000.

“Command Generation for Flexible Systems”, Kumoh National Institute of Technology and Pusan National University, August 2005, 3300000 Won (\$3,210).

“Enhanced Trajectory Tracking of Flexible Systems Using Command Generation”, Japan Ministry of Education, Culture, Sports, Science and Technology (MEXT), and Tokyo Metropolitan Institute of Technology (TMIT), \$11,500 **Co-PI** (Singhose: \$5,750).

“Generación De Órdenes De Movimiento Que No Inducen Vibración En Maquinas Con FaltaDe Rigidez”, University of Vigo, October 2002, 900 Euros.

“Experimental Investigation of Deflection-Limiting Satellite Thruster Control for Multiple Flexible Satellites”, Japan Society for the Promotion of Science, June 2002, \$17,245.

Internal Sources

“An International Collaborative Student Space Robot Design Initiative”, Denning Global Engagement Seed Fund, 2014, \$15,000.

GTRC travel grant to Serbia, July, 2014, \$1,458.

“Interactive Tablet Computers for Introductory Mechanical Design”, Georgia Tech Technology Fee Grant, 2013, \$22,896.

“Power Analyzer for Energy-Efficient Student Design Projects”, Georgia Tech Technology Fee Grant, 2013, \$17,104.

GTRC travel grant to Turkey, July, 2013, \$1,500.

GTRC travel grant to Lithuania, July, 2012, \$750.

“Siemens Cherrypicker and Conference Paper Support” Manufacturing Research Center, July 2010, \$6,750.

GTRC travel grant to Egypt, July, 2010, \$750.

“Siemens Conference Paper Support” Manufacturing Research Center, September 2009, \$3,200.

GTRC travel grant to Spain, April, 2009, \$1,500.

“The Influence of Input Shaper Duration on Bridge Crane Operator Performance” Aayush Daftari, President's Undergraduate Research Travel Award, August 2008, \$1,000.

“Dynamics of Orbit Boosting of an Electrodynamic Tethered Satellite with Input-Shaped Current” Adrit Lath, President's Undergraduate Research Award, July 2008, \$1,500.

“Robustness of Negative Input Shaping” Aika Yano, President's Undergraduate Research Travel Award, May 2008, \$1,000.

“Generator for Mobile Boom Crane”, Materials, Supplies, & Travel Grants for Undergraduate Research, April. 2008, \$1,500.

GTRC travel grant to Turkey, April, 2008, \$1,500.

“Comparison of Command Filtering Methods for Vibration Reduction in Mechanical Systems”, Anderson Smith, President's Undergraduate Research Awards, March. 2008, \$1,500.

“Development of Input Shapers for Mobile Cranes”, Adrit Lath, President's Undergraduate Research Awards, Nov. 2007, \$1,500.

“Effect of Input Shaper Duration on Crane Operator Performance”, Aayush Daftari, President's Undergraduate Research Awards, Nov. 2007, \$1,500.

“Robust Input Shaper Evaluation”, Aika Yano, President's Undergraduate Research Awards, May 2007, \$1,500.

GTRC travel grant to China, May, 2007, \$1,500.

“Conference Travel Funding: Reduction of Double Pendulum Crane Oscillations”, Dooroo Kim, President's Undergraduate Research Awards, August 2006, \$1,000.

GTRC travel grant to Serbia, October, 2006, \$1,278.

“Reduction of Double Pendulum Crane Oscillations”, Dooroo Kim, President's Undergraduate Research Awards, December 2005, \$1,500.

“Development and Testing of a Command Shaping Compensator for Nonlinear Drives”, Jon Danielson, President's Undergraduate Research Awards, December, 2005, \$1,000.

“Space Tethered Satellite Control”, Andrew Timm, President's Undergraduate Research Awards, May, 2005, \$1,500.

GTRC travel grant to IFAC (Czech Republic) & REM (France), June, 2005, \$1,500.

“Use of Fluid Power to Cancel Low Frequency Vibrations”, Varun Sharma,

President's Undergraduate Research Awards, Jan. 2005, \$1,500.

"The Effects of Input Shaping on a Flexible Nonlinear Robotic Arm with Backlash", Matthew Falkenberg, President's Undergraduate Research Awards, Jan. 2005, \$1,500.

"Study of Operator Behavior and Performance Using an Input-Shaped Bridge Crane", Attir Khalid, President's Undergraduate Research Awards, April 2004, \$1,000.

"Fluid Power Control of a Hyper-Active Seat for Low-Frequency Vibration Suppression", Earl Lewis, President's Undergraduate Research Awards, December 2003, \$960.

GTRC travel grant to IEEE CCA (Turkey) & IEEE MED (Greece), June, 2003, \$1,500.

"Vibration Reduction for High-Rise Elevators", Vlad Patrangenaru, President's Undergraduate Research Awards, April 2003, \$800.

"Experimental Verification of Input Shaping Combined with Vibration Absorbers for Oscillatory Systems", President's Undergraduate Research Awards, April 2003, \$900.

"Experimental Investigation of Input Shaping with Friction on a Solder Cell Machine", President's Undergraduate Research Awards, December 2002, \$900.

"CanSat Project", President's Undergraduate Research Awards, December 2002, \$500.

Georgia Tech Foundation Travel Grant to Spain, October 2002, \$764.

GTRC travel grant to NCOLS 2001 (Russia), April 2001, \$1,406.

"Experimental Apparatus for Input-Shaped Cam Profiles", President's Undergraduate Research Awards, July 2001, \$1,250.

GTRC travel grant for Japan lecture tour, October 2000, \$1,231.

GTRC travel grant to Advanced Motion Control 2000, February 2000, \$1,250.

Other Sources

SURE & SHARP student support (Marie Cox, April Pritchard, Nathan Mauch, Adam Vela, Dwayne Bobb, Timothy Melano, Rory Thomas, Kimberly Sheafe)
May 1999 – August 2004, \$4,000.

B. As Investigator

RERC on Wheeled Mobility in Everyday Life. PI Dr. Stephen Sprigle. Funding for salary, graduate student support, materials and supplies. November 2003 - October 2008. \$134,725. Total project budget \$4,750,000.

In-Line Optical Measurement of MicroElectroMechanical Systems (MEMS) Devices During Production. PI Dr. Thomas Kurfess. Funding provided to train high school teacher for mechatronics curriculum transfer from Georgia Tech to Cedar Grove High School. June 2003-August 2003. \$6,000.

MARC Siemens - Automation and Drives. PI Dr. Steven Danyluk. Funding provided for graduate and undergraduate student support, hardware development, installation of oscillation controller on the MARC crane and development of portable bridge and tower cranes. August 2002 – August 2012, \$889,429.

HUSCO/Ramirez Laboratories for Fluid Power and Motion Control. PI Dr. Wayne Book. Funding for graduate student support, hardware development, and travel. August 2002-July 2004. \$42,775.

F. Other Scholarly and Creative Accomplishments

Patents

- [1] W. Singhose, N. Singer, W. Rappole, S. Derezinski, and K. Pasch, "Methods and Apparatus for Minimizing Unwanted Dynamics in a Physical System," US Patent US 5,638,267, June 10, 1997, 1997.
- [2] R. Eloundou and W. Singhose, "Command Generation Combining Input Shaping and Smooth Baseline Commands," Patent US 6,920,378, July 19, 2005, 2005.
- [3] K. L. Sorensen, W. Singhose, and S. Dickerson, "Combined feedback and command shaping controller for multistate control with application to improving positioning and reducing cable sway in cranes " Patent US 7,970,521, June 28, 2011, 2011.
- [4] W. Singhose and D. Kim, "Methods and Systems for Double-Pendulum Crane Control," Patent US 8,235,229, August 7, 2012, 2012.
- [5] W. Singhose and K. Peng, "Crane Control Systems and Method," US Patent US9,132,997 Patent Appl. 13/642,075, Sept. 15, 2015.
- [6] W. Singhose and J. Vaughan, "Methods and Systems for Improving Positioning Accuracy," US Patent US 8,975,853 B2 Patent Appl. 2011/0298409 A1, 2015.
- [7] K. L. Sorensen, W. Singhose, and S. Dickerson, "Crane Motion Control," Patent US 9,776,838, October 3, 2017, 2017.

G. Other Professional Conferences Organized

NSF Planning Visit: Large Flexible Space Structures, Tokyo Japan, 12/11-12/15/2005.

Siemens Automation and Drives Conference at Georgia Tech Lorraine, 11/29-11/30/04.

Conference Sessions Organized

“Command Shaping in Mechatronics.” 7th Mechatronics Forum International Conference, 2000, Atlanta, GA.

“Tutorial: Input Shaping and Time Delay Control of Maneuvering Flexible Structures.” 2002 American Controls Conference, Anchorage, AK.

Conference Sessions Chaired

2007 American Control Conference, New York, NY

2006 ICAMEM, Tunis, Tunisia

2004 Japan-USA Symposium on Flexible Automation, Denver, CO.

2004 American Control Conference, Boston, MA.

2003 American Control Conference, Denver, CO.

2002 2nd IFAC Conference on Mechatronic Systems, Berkeley, CA.

2002 6th International Conference on Motion and Vibration Control, Saitama, Japan

2002 Japan-USA Symposium on Flexible Automation, Hiroshima, Japan.

2002 American Control Conference, Anchorage, AK.

1999 IEEE Conference on Control Applications, Kona, HA.

1998 IEEE Conference on Control Applications, Trieste, Italy.

1995 IFToMM Ninth World Congress on the Theory of Machines and Mechanisms, Milan, Italy.

V. Education

B. Individual Student Guidance

B1. Ph.D. Students

B1.a. Graduated Ph.D. Students

- 1) Kris Kozak. Started Fall '99. Passed qualifier examination Fall '00. Ph.D. awarded May '03, "Investigation of Input Shaping for Parallel Manipulators." Currently at Southwestern Research Institute. (coadvised with Dr. Ebert-Uphoff).
- 2) Erika Biediger-Ooten. Started Fall '98. M.S. Dec. '00. Passed qualifier examination Fall '01. Ph.D. awarded May '05, “Vibration Reduction Using Command Generation in Formation Flying Satellites.” Currently Engineer at Exxon-Mobil.
- 3) Mike Robertson. Started Fall '98. M.S. May '01. Passed qualifier examination Spring '02. Ph.D. awarded May '05, “Command Generation for Tethered Satellite Systems”. Currently Professor at the Naval Academy
- 4) Joel Fortgang. Started Fall '99. M.S. May '02. Passed qualifier examination Spring '02. Ph.D. awarded May '06. “Combined Mechanical and Command Design for Micro-Milling Machines”.

- 5) John Huey. Started Fall '01. M.S. August '03. Passed qualifier examination Fall '03. Ph.D. awarded August '06. "Concurrent Design of Feedback and Command Shaping Control". Currently Controls Engineer - GE Aviation.
- 6) Jason Lawrence. Started Fall '00. M.S. August '02. Passed qualifier examination Fall '03. Ph.D. awarded August '06. "Control of Tower Cranes", Currently Mechanical Engineer at Lexmark.
- 7) Joshua Vaughan. Started Fall '02. M.S. May '04, Ph.D. awarded August '08 "Dynamics and Control of Mobile Cranes". Currently professor at University of Louisiana-Lafayette.
- 8) Khalid Sorensen. Started Fall '03. M.S. May '05, Ph.D. awarded August '08. "Combined Feedback Control and Command Shaping of a Bridge Crane."
- 9) Adan Vela. Started Fall '06. Ph.D. awarded Dec. '11. "Bounds on Controller Taskload Implementing Conflict-Resolution Algorithms in an Airspace."
- 10) Kelvin Peng, Started Spring '08, Ph.D. awarded Dec. '13, "Methods for Improving Crane Performance and Ease of Use."
- 11) Ehsan Maleki, Started Fall '08, Ph.D. awarded Dec. '13, "Control of Human-Operated Machinery with Flexible Dynamics."
- 12) James Potter, Started Fall '09, Ph.D. awarded Dec. '13, "Input-Shaped Manual Control of Helicopters with Suspended Payloads."
- 13) Arto Kivila, Started Fall '13, Ph.D. awarded Aug. '17, "Modeling, Estimation and Control for Serial Flexible Robot Arms."
- 14) Daichi Fujioka, Started Fall '10, Ph.D. awarded Aug. '17, "Input-Shaped Model Reference Control for Flexible Systems."
- 15) Christopher Adams, Started Fall '12, Ph.D. awarded Dec. '18, "Modeling and Control of Backdrivable Flexible Systems"
- 16) Ali AlSaibie, Started Fall '12, Ph.D. awarded Dec. '18, "Mechatronic Design of Micro Autonomous Underwater Vehicles for Confined Spaces"
- 17) Arnaldo Castro, Started Spring '16, Ph.D. awarded Dec. '19, "Dynamics and Control of Self-Balancing Transporters"

B1.b. In Process Ph.D. Students

- 1) Alison Jenkins, Started Spring '20, Passed Quads Fall 2021
- 2) Tyler Rome, Started Spring '21, Passed Quads Fall 2022

B2. M.S. Students (Indicate Thesis Option for Each Student)

B2.a. Graduated M.S. Students

- 1) Mike Kenison. Graduated Dec. '99 - "Command Generation in Control System Design for Systems with Parameter Variations." Currently Development Engineer, Schlumberger.
- 2) Karen Grosser. Graduated May '00 - "Input Shaping for Telerobotic Manipulators." Currently Development Engineer, Schlumberger.

- 3) Erika Ooten. Graduated Dec. '00 - "Command Generation for Flexible Systems Using Numerator Dynamics and Sliding Mode Control." Currently Engineer at Exxon-Mobil.
- 4) Kris Kozak. Graduated Aug. '01 - "Dynamic Analysis of Parallel Manipulators and Digital Input Shaper Computation Using Linear Optimization." Currently a Post-doc at Tsinghua University.
- 5) Mike Robertson. Graduated May '01. "Methods for Generating Deflection-Limiting Commands." Currently Post-doc at Air Force Research Lab.
- 6) Joel Fortgang. Graduated May '02 - "Concurrent Design of Input Shaping and Vibration Absorbers."
- 7) Jason Lawrence. Graduated August '02 - "Using Input Shaping to Optimize Point-to-Point Motions in PD Controlled Systems with Coulomb Friction."
- 8) Raynald Eloundou. Graduated August '02 - "Investigation of Various Reference Commands for Vibration Reduction." Currently Mechanical Engineer at Hitachi.
- 9) John Huey. Graduated August '03. "Dynamics and Vibration Control of Large Area Manipulators."
- 10) Sam Klooster. Graduated Spring '04. "Design of an Active Safety Seat." Currently mechanical engineer at Lockheed Martin.
- 11) Joshua Vaughn. Graduated Spring '04. "Active and Semi-Active Control to Counter Vehicle Payload Variation." (coadvised with Dr. Nader Sadegh)
- 12) Khalid Sorensen. Graduated Spring '05. "A Combined Feedback and Command Shaping Controller for Improving Positioning and Reducing Cable Sway in Cranes"
- 13) Vlad Patrangenaru. Graduated Spring '06. "Design of Active Wheelchair Seats to Compensate for Extensor Tone in Children."
- 14) Azeem Meruani, Spring '06. "Tweel Technology Tires for Wheelchairs and Instrumentation for Measuring Everyday Wheeled Mobility"
- 15) David Blackburn. Graduated Summer '06. "Control of Space Tethers."
- 16) Jim Kitchen. Graduated Summer '06. "Design of an Dynamic Wheelchair Seat."
- 17) Ray Manning. Graduated Spring '08 "Improving the Control of Two-Mode Flexible Systems with Input Shaping"
- 18) Jon Danielson. Graduated Summer '08 "Mobile Boom Crane Dynamics and Control"
- 19) Andreas Rauch, Graduated Summer '08 "Stability Analysis of Mobile Boom Cranes"
- 20) Daichi Fujioka, Graduated Summer '10, "Dynamic Stability of Mobile Boom Cranes"
- 21) Kelvin Peng, Graduated Fall '09, "Interfaces and Control Systems for Intuitive Crane Control"
- 22) Ehsan Maleki, Graduated Summer '10, "Dynamics and Control of a Small-Scale Mobile Boom Crane"

- 23) Brice Pridgen, Graduated May '11, "Comparison of Polynomial Profiles and Input Shaping for Industrial Applications"
- 24) Arnolando Castro, Graduated Summer '12, "Modeling and Dynamic Analysis of a Two-Wheeled Inverted-Pendulum"
- 25) Christopher Adams, Graduated Summer '12, "Modeling and Control of Helicopters Carrying Suspended Loads"
- 26) Eileen Hernandez, Graduated Fall '12, "Dynamic Characterization and Analysis of Aerial Lifts"
- 27) Arto Kivila, Graduated Aug. '13, "Touchscreen Interfaces for Machine Control and Education"
- 28) Alex Miller, Graduated Dec. '13, "Dynamics and Control of Dual-Hoist Cranes Moving Distributed Payloads"
- 29) Athony Garcia, Graduated Dec. '14, "Improved Friction, Contact and Dynamic Simulation Model to Study the Behavior of Payloads During Off-Centered Crane Lifts"
- 30) John Harber, Graduated May '16, "A Dual Hoist Robot Crane for Large Area Sensing"
- 31) Sima Rishmawi, Graduated May '16, "Tip-Over Stability Analysis of Crawler Cranes in Heavy Lifting Applications"
- 32) Yujia Yang Graduated May '17, "Automated Longitudinal Payload Lift-up Using Bridge Cranes"
- 33) Nickolas Johnson, Graduated May'17, "Control of a Folding Quadrotor with a Slung Load Using Input Shaping."
- 34) Franziska Schlagenhauf, Graduated Aug. '17, "A Kinematic Upper Body Model for Evaluating Clothing"
- 35) Xiaoshu Liu, Graduated Dec. '17, "Numerical Investigation of Affordable 2D Lidar Sensors for Autonomous Driving Under a Specially-Structured Driving Environment"
- 36) Luk, Henry, Graduated May '20, Non-thesis Master's, Project: Dynamics of LRA Devices Within Wrist Bands
- 37) Lyman, Colin, Graduated August '21, Non-thesis Master's, Project: Development of Multi-LRA Devices
- 38) Ravishankar, Praveen, Graduated August '21, Non-thesis Master's, Project: Development of Haptic Signals for Multi-LRA Devices
- 39) Schmidt, Ryan, Graduated August '22, Non-thesis Master's, Project: Sensing of LRA Back EMF

B2.b. In Process M.S. Students

- 1) William Barclay
- 2) Eemil Harkonen
- 3) Sae Sholapurkar

B3. Undergraduate Students

Kanako Abe, Hafeez Alam, Ulf Andresen, Derek Bastien, Fernando Bazerghi, Esteban Benero (SURE), Dustin Bergman, Dwayne Bobb (SURE - Morehouse College), Carrie Boles, Justis Brogan, Jeff Clement, Maria Cox (SURE), Jon Danielson, Chuck Devane, Raynald Eloundou, Adrian Erb (Swiss), Matthew Falkenberg (PURA), Brian Fatkin, Jonathon Fonseca, Craig Forest, Damien Gaudry, Terry Hall, Samir Idnani, Walker Inman, Taft Jones (SURE), Paul Jurek, Attir Khalid, Dooroo Kim, Jae-Hyung Kim, Nathan Knight, Prerana Kumar, Bumsoo Lee, Caitlyn Leksana, Earl Lewis, Alan Martin, Timothy Melano (SURE – Berkeley), Ben Myers, Chad Nicholson, Noav Nossenson (SURE), Patrick Opdenbosch, Adnan Pandjou, Tejan Poage, Jessica Powell, April Pritchard (SURE), Devshan Renganathan, Caroline Rhee, Nathan Ritz, Nick Sabogal, Prachi Sahoo, Dushyant Sharma, Varun Sharma (PURA), Kimberly Sheafe (SURE – Stanford), Anderson Smith (PURA), Jonathon Smith, Josh Spiers, Christoph Stäheli (Swiss), Lee Stokes, Ethan Stone (PURA), Art Terdpravat, Brandon Terrell, Rory Thomas (SURE – John Hopkins), Andrew Timm, Adam Vela (SURE), Rolf Weiss (Swiss), Amber Welsh, Kevin Yang, Aika Yano, Jieun Yoo.

B5. Mentorship of Postdoctoral Fellows or Visiting Scholars

B5.a. Postdoctoral Fellows

- 1) Dr. Kris Kozak. June 2003-Dec. 2003, “Development of a Hyperactive Seat.”
- 2) Dr. Joshua Vaughan. Jan. 2010–August 2012, “Development of an Aerospace Manufacturing Center.”
- 3) Dr. Christopher Adams. Jan. ’19-present, “Input Shaping Mobile Crane Controllers”

B5.b. Visiting Scholars

- 1) Prof. Seong-Wook Hong, Kumoh National University, Kumi, Korea, Feb. 2004-Feb. 2005.
- 2) Prof. Juan de Juanes Marquez, Escuela Tecnica Superior de Ingenieros Industriales (ETSII), Madrid, Spain, June 2005-Dec. 2005.
- 3) Prof. Yoon-Gyeong Sung, Chosun University, Gwangju, Korea, July 2006-August 2007.
- 4) Prof. Mingxiao Dong, Shandong Jianzhu University, China, Dec 2007-May 2008
- 5) Ji Sup Joon, Division Director, Advanced Fuel Cycle System Eng., Korea Atomic Energy Research Institute, Korea, September 2008-September 2009
- 6) Prof. Zhang Yizhuo, North East Forestry University, Harbin, China, Dec. 2009 – Dec. 2010
- 7) Prof. Youmin Hu, Huazhong University of Science & Technology, Wuhan, China, Jan. 2010-Jan 2011

- 8) Prof. Kyoungseok Park, Kumoh National Institute of Technology, Gumi, Korea, June 2010-June 2011
- 9) Prof. Jie Huang, Beijing Institute of Technology, August 2014-July 2015
- 10) Prof. Dongjoo Kim, Kumoh National Institute of Technology, Gumi, Korea, Feb. 2016 - Feb. 2017
- 11) Stanislao Grazioso, Università degli Studi di Napoli "Federico II", Napoli, Italy, August 2016-Dec. 2016
- 12) Dr. Ali AlSaibie, Kuwait University, July-August 2023

C. Educational Innovations and Other Contributions

a) New Course Development

ME 6404 - Advanced Control System Design and Implementation. Course was completely overhauled, updated, and expanded for the Fall of 2001. The result was essentially a new course. A book, *Command Generation for Dynamic Systems*, was written to compliment the course curriculum. A portable robotic bridge crane was constructed so that this course could be taught at Georgia Tech Lorraine in the fall of 2004. Siemens sponsored the crane construction and also a two-day conference at GTL that centered on the crane and the associated curriculum development: <http://singhose.marc.gatech.edu/SiemensGTL/>. A portable tower crane was also constructed for the course. The tower crane was used at Tokyo Tech for 2 years. Students conducted remote operation tests via the internet. The course was also taught at MIT during the fall of 2010 in conjunction with Professor Warren Seering of MIT. The course was expanded in the fall of 2011 to include a distance learning curriculum that uses remote-operated labs.

ME 4863 – Emerging Technology Law. Course was designed to educate engineering students about legal constructs that effect engineering activities in the area of emerging technology. The course is cross listed as BME4853. The course has two main components: Product Liability and Intellectual Property. In addition to weekly lectures, the course includes weekly studio sessions and mock trials.

b) Laboratory Experiments Developed: The new version of Advanced Control System Design and Implementation has a major laboratory component. An entire sequence of laboratory projects were developed for the course using the large bridge crane in the MARC building and hardware in the Love Building hydraulics laboratory. The crane in the MARC building has been equipped with oscillation-reducing technology that is taught in ME6404. The crane was also used as a testbed in the senior-level experimental engineering course, ME4055. Several laboratory projects were developed for ME2110, Creative Decisions and Design. A paper describing these developments was presented at the 2nd IFAC Conference on Mechatronic Systems. A

two-week curriculum on PLC programming was developed along with PLC workstations to conduct laboratory activities. Hands-on control experiments for ME4452 (Control Systems) were developed to utilize the NI MyRIO controller along with a flexible-beam experimental setup.

- c) Interactive Instructional Materials Developed:** Dr. Singhose has developed interactive textbooks for both introductory mechanical design (with an emphasis on mechatronics) and advanced control system implementation (with an emphasis on command-shaping control). Features of interactive textbooks include: embedded videos that can be viewed with the tap of a finger, picture slideshows, user-controlled simulations, and interactive charts that accept user input and provide immediate feedback. Dr. Singhose has also developed a series of remote-operated experimental cranes and aerial lifts that have been used extensively in educational activities.

VI. Service

A. Professional Contributions

Journals

Int. Journal of Control, Automation, and Systems (IJCAS), Editorial Board Member, 2005-Present

Mechatronics, Associate Editor, 2008

Control Engineering Practice, Designated Editor, 2007-2010

Conferences

Asian Control Conference, Associate Editor of Contributed Papers, 2017

Int. Symposium on Flexible Automation, Program Chair, 2008

IEEE/ASME Int. Conference on Advanced Intelligent Mechatronics, Program Committee, 2007

Int. Symposium on Flexible Automation, Program Committee, 2006

Advanced Intelligent Mechatronics Program Committee, member, 2005

International Conference on Motion and Vibration Control Program Committee, member, 2004

American Control Conference Program Committee, member, 2004

Japan-USA Symposium on Flexible Automation Program Committee, member, 2004

Reviews

National Science Foundation, Division of Design Manufacturing and Industrial Innovation, proposal reviewer

National Science Foundation, Sensors and Sensor Systems, proposal reviewer

AIAA Journal of Guidance, Control, and Dynamics, reviewer

AIAA Journal of Spacecraft and Rockets, reviewer

AIAA Guidance, Navigation, and Control Conference, reviewer

American Control Conference, reviewer

ASME Journal of Dynamic Systems, Measurement, and Control, reviewer

ASME Design Engineering Technical Conferences, reviewer
ASME Journal of Vibration and Acoustics, reviewer
Automatica, reviewer
Control Engineering Practice, reviewer
Control Systems Technology, reviewer
IEEE/ASME Transactions on Mechatronics, reviewer
IEEE Transactions on Systems, Man, and Cybernetics, reviewer
IEEE Conference on Control Applications, reviewer
IEEE Int. Conference on Robotics and Automation, reviewer
Industrial & Engineering Chemistry Research, reviewer
Journal of the Franklin Institute, reviewer
Journal of Sound and Vibration, reviewer
Mechatronics, reviewer
Mechatronics 2000, Panel reviewer
Industrial Project Advising
Milliken Summer Faculty Challenge – 2000

B. Public and Community Service

Standards Committees

IEEE Virtual Reality and Augmented Reality Standards Working Group, 2018-2019
ASTM F15.18 - Cribs, Toddler Beds, Play Yards, Bassinets, Cradles and Changing Tables, 2018-2019
ASTM D13-Textiles, D13.66 – Sewn Product Automation subcommittee member, 2017-2019
ASTM F08.52, F08.67 - Pole Vault Pole Testing and Pole Vault Landing Pads subcommittee, member, 2000-2006
USA Track & Field Pole Vault Equipment Task Force, member.

Legislative Testimony

Washington State Legislature, Senate Labor & Commerce Committee, SB5900 – Construction Crane Safety, 1/11/24
Washington State Legislature, House Labor and Workplace Standards Meeting, HB2022 – Construction Crane Safety, 1/12/24

C. Institute Contributions

Organized and supervised Georgia Tech Rescue Robot Team, 2013-present
Organized and supervised Georgia Tech CanSat Team, 2002-2012
ASME Student Group, Faculty Advisor, 2007-2012
SME Student Group, Faculty Advisor, 2001-2007
Pole vault coach for Georgia Tech track and field team (1998-2000)
2009 Chair of Director of Design Search Committee

2015 Chair of Zeigler Woodruff School Outstanding Educator Award Committee

Woodruff School Committee member:

2023 Zeigler Outstanding Educator Award Committee

2022 Zeigler Outstanding Educator Award Committee

2021-23 RPT

2019-21 Graduate Student Development

2015-16 RPT

2016-17 PPR

2013-16 Undergraduate

2012 Director of Design Search Committee

2008 HR Director Search Committee

2006-07 Undergraduate

2003-04 Faculty Awards

2001-03 Undergraduate

2000 Faculty Recruiting

1999 Graduate

1998 Undergraduate

APPENDIX B

Dr. William Singhose
Expert Witness Testifying Experience
2020-2025

1. Wong et al. v. Morrow Equipment et al.
7/2019-3/2022
Civil Action No. 19-2-33286-7 SEA
Swanson, Gardner, and Meyers
Depositions: 1/3/22, 1/31/22
Court Testimony: 1/31-2/1/22, 3/2/22
2. Guntert and Zimmerman v. Gomaco
5/20-10/21
C.A. No. 5:20-cv-4007
Finnegan Henderson
Analysis of construction machines and patents
Deposition: 8/21/20
3. Coleman Co. vs. Team Worldwide Corp.
5/2020-1/23
Civil Action No. 2:20cv351-RGD-RJK
Meunier Carlin & Curfman LLC
Analysis of air mattresses and patents
Deposition: 8/18/21
4. Gamevice v. Nintendo
6/20-12/20
Certain Portable Gaming Console Systems with Attachable Handheld Controllers and Components Thereof
ITC Investigation No. 337-TA-1197
Finnegan Henderson
Analysis of gaming consoles and patents
Depositions: 9/29/20, 10/2/20; Trial Testimony: 12/10/20, 12/14/20
5. Gomaco v. Guntert and Zimmerman
9/2020-7/2021
IPR2020-01698, IPR2021-00050, IPR2021-00136, IPR2021-00234
Finnegan Henderson
Analysis of construction machine patents US9,708,020 & US10,196,101 & US10,029,749 & US9,908,57
Deposition: 7/21/21 & 7/23/21
6. Unicorn Global v. GoLabs
11/2020-7/2021
Civil Action No. 3:20-cv-02023
Offit Kurman, P.A.

Analysis of hoverboards and patents
Deposition: 3/31/21

7. Courkamp v. Fisher Price

2/26/20-10/22

No. CV-19-02689-PHX-GMS

US District Court for the Northern District of Arizona

Goldberg & Osborne LLP

Analysis of infant incline sleepers

Deposition: 9/14/21, 9/27/21

8. iRobot v. SharkNinja

6/20-1/21

Certain Robotic Floor Cleaning Devices and Components Thereof

ITC Investigation No. 337-TA-1252

Finnegan Henderson

Analysis of robotic cleaners and patents

Deposition: 10/6/21

Court Testimony: 1/10-1/12/22

9. DJI v. Textron

9/21-10/22

IPR2022-00162 and IPR2022-00162

Finnegan Henderson

Analysis of drone patents

Deposition: 8/11/22, 10/7/22

10. Caterpillar Paving Products v. Wirtgen America

12/21-7/23

IPR2022-01264, IPR2022-01277, IPR2022-01278, IPR2022-01310

Finnegan Henderson

Analysis of construction machine patent US9879390, US9879391, US8424972

Deposition: 4/6/23, 4/12/23

11. Opex v. HC Robotics

1/22-12/22

Certain Automated Put Walls and Automated Storage and Retrieval Systems, Associated Vehicles, Associated Control Software, and Component Parts Thereof

ITC Investigation No. 337-TA-1293

Desmarais

Analysis of factory automation and mobile robot patents

Deposition: 9/22/22

Court Testimony: 12/1/22

12. Bissell v. Tineco

- 2/22-12/22
Certain Wet Dry Surface Cleaning Devices
ITC Investigation No. 337-TA-1304
Quinn Emanuel
Analysis of wet/dry cleaning devices and patents
Deposition: 10/27/22
Court Testimony: 12/5/22 and 12/9/22
13. LightGuide v. Amazon
3/23-12/23
IPR2023-01423
Hueston Hennigan LLP
Analysis of assembly system patents US10528036, US9658614, and US7515981
Deposition: 10/20/23
14. Juul v. NJOY
9/23-Present
ITC Investigation No. 337-TA-1368
IPR2024-00223
Weil, Gosthal and Manges
Analysis of vaporizer patent US10709173
Deposition: 2/27/24
Court Testimony: 5/3, 5/8/24
15. Lenovo v. Asus
2/24-Present
ITC Investigation No. 337-TA-1382
DLA Piper
Analysis of computer hinges and US8687354
Deposition: 7/9/24
Court Testimony: 9/21, 9/22, 9/24
16. Juul v. NJOY
6/24-Present
IPR2024-00160, IPR2024-00161
Weil, Gosthal and Manges
Analysis of vaporizer patents 11,497,864 and US10,334,881
Deposition: 10/24/24
17. US Conec v. Senko
7/24-8/24
ITC Inv. No. 33-TA-1399
Certain Fiber-Optic Connectors, Adapters, Jump Cables, Patch Cords, Products Containing
The Same, and Components Thereof
Alston & Bird
Analysis of Fiber-Optic Equipment and Patents

Deposition: 8/6/24