

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

ABB INC.,
Petitioner

v.

ROBOTICVISIONTECH, INC.,
Patent Owner

Case IPR2023-01426
U.S. Patent No. 8,095,237

**DECLARATION OF THOMAS R. KURFESS, PH.D.,
IN SUPPORT OF PATENT OWNER'S PRELIMINARY RESPONSE**

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RoboticVisionTech EX2001
ABB v. RoboticVisionTech
IPR2023-01426

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I, Thomas R. Kurfess, hereby declare as follows.

I. INTRODUCTION

1. I have been retained as an expert witness on behalf of Patent Owner RoboticVisionTech, Inc. (“Patent Owner”) for the above-captioned *inter partes* review (“IPR”). I am being compensated for my time in connection with this IPR at a rate of \$650 per hour. My compensation is not contingent in any way on the content of my analysis or the outcome of this proceeding.

2. I understand that this Declaration accompanies Patent Owner’s Preliminary Response filed in this IPR involving U.S. Patent No. 8,095,237 (“the ’237 patent”) (EX1001), which resulted from U.S. Patent Application No. 10/634,874 (“the ’874 application”), filed on August 6, 2003, which claims the benefit of a Canadian patent application filed on January 31, 2002. I understand that Petitioner asserts the “earliest possible effective filing date of the ’237 Patent claims is January 31, 2002.” Pet., 4. I refer to this date throughout this declaration.

3. In preparing this Declaration, I have reviewed the ’237 patent and each of the documents cited herein, in light of general knowledge in the art before January 31, 2002. In formulating my opinions, I have relied upon my experience, education, and knowledge in the relevant art. In formulating my opinions, I have also considered the viewpoint of a person of ordinary skill in the art (“POSITA”) (as discussed further below in Section V) in the timeframe of January 31, 2002.

II. MY BACKGROUND AND QUALIFICATIONS

4. I received my Ph.D. in 1989 from Massachusetts Inst. of Tech. (“MIT”) in Mechanical Engineering. Prior to that, I received dual S.M. degrees in Electrical Engineering & Computer Science in 1988 and Mechanical Engineering in 1987. I received my S.B. in Mechanical Engineering in 1986, also from MIT. I have extensive experience in academia, governmental organizations, and private industry.

5. I am currently a Professor and the HUSCO/Ramirez Distinguished Chair in Fluid Power and Motion Control at the Georgia Institute of Technology (“Georgia Tech”), a title which I have held since 2013. I am also the Chief Manufacturing and Energy Officer for the CyberSecurity Manufacturing Innovation Institute (“CyManII”), a national network whose goal is to research, develop, and implement a national vision for manufacturing cybersecurity.

6. Recently, I completed a three-year leave of absence to serve as the Chief Manufacturing Officer for Oak Ridge National Laboratory (“ORNL”). During that time, I also served as the Founding Division Director of the Manufacturing Science Division at ORNL. My responsibility at ORNL was to develop and execute a long-range plan for advanced manufacturing as it applies to ORNL, national laboratories, and the United States.

7. My primary research areas include Manufacturing and Automation

and Mechatronics, advanced automation, precision manufacturing, metrology, and technology policy. I focus on the design and development of advanced systems targeting complex product production and optimization. My focus spans a wide array of technologies, including high precision manufacturing and metrology systems, as well as national and international manufacturing policy issues.

8. I began my academic career at Carnegie Mellon University where I rose to the rank of Associate Professor. In 1994, I moved to Georgia Tech and was appointed Associate Professor in the George W. Woodruff School of Mechanical Engineering. In 2000, I was promoted to the rank of Professor in Mechanical Engineering at Georgia Tech. In 2005, I was named Professor and BMW Chair of Manufacturing in the Department of Mechanical Engineering at Clemson University's International Center for Automotive Research. In 2012, I returned to Georgia Tech as a Professor of Mechanical Engineering and the HUSCO/Ramirez Distinguished Chair in Fluid Power and Motion Control.

9. During 2012–2013, I took leave from Georgia Tech to serve as the Assistant Director for Advanced Manufacturing at the Office of Science and Technology Policy in the Executive Office of the President of the United States of America. In this position, I had responsibility for engaging the Federal sector and the greater scientific community to identify possible areas for policy actions related to manufacturing. In that role, I coordinated Federal advanced manufacturing

R&D, addressing issues related to technology commercialization, identifying gaps in current Federal R&D in advanced manufacturing, and developing strategies to address these gaps.

10. Additionally, I have served as a special consultant of the United Nations to the Government of Malaysia in the area of applied mechatronics and manufacturing, and as a participating guest at the Lawrence Livermore National Laboratory in their Precision Engineering Program.

11. I served on the Board of Directors for the Society of Manufacturing Engineers (“SME”) and was President of SME in 2018. I currently serve on the Board of Directors for the National Center for Manufacturing Sciences and the National Center for Defense Manufacturing and Machining. I also serve on the Board of Trustees of the MTConnect Institute.

12. I have worked on a variety of mechatronic or robotic systems in my career that involve computer and machine vision, including vision-guided object manipulation. For example, my graduate work at MIT involved force control of a robotic weld bead grinding system. The lateral control of the robot was accomplished by using a vision system that tracked the weld bead that was being ground. In this instance, the lateral motion of the robot along the weld bead path was guided by a vision system. *See* EX2005, 5 (“Verification of a Dynamic Grinding Model”). This work was published as early as 1988 in the Proceedings of

ASME Manufacturing International 88. Further work in this area was published in ASME Journal of Dynamic Systems, Measurement, and Control in 1990. *See* EX2005, 5 (“Development and Control of an Automated Robotic Weld Bead Grinding System”).

13. Another example of my experience with vision being integrated with robotic operations is in the body shop of an automotive production facility, where multiple robots are working together to weld the frame of a vehicle. These robots are typically guided by multiple vision systems. I have also used vision-guided robots in vehicle assembly to accomplish tasks such as aligning and placing windshields on automobiles. Today, my team typically uses vision systems to guide robots in picking up components to be used in assembly and guiding the robot to place the component into the final assembly or subassembly. At a high level, the vision systems are used for fine adjustments in the robot’s trajectory to address misalignment of the components to be grasped or misalignment of the assembly into which the component is to be placed.

14. I have also authored several different book chapters and papers that discuss vision-guided robotic systems and their implementation. For example, I have written or edited portions of multiple CRC handbooks, including the CRC Robotics and Automation Handbook and the CRC Mechatronics Handbook. *See* EX2005, 4–5. I have taught engineering courses at both the undergraduate and

graduate level on the topics of control theory, robotics, advanced dynamics, and real-time signal processing and control, all of which are applicable to vision-guided robotics. Vision systems are often used to identify defects on parts such as castings, and then robots are guided to the defects to remove them and repair them with grinding and welding operations. Such a defect detection system is described, for example, in my paper in Manufacturing Letters published in 2017. *See* EX2005, 16 (“Surface Defect Identification and Measurement for Metal Castings by Vision System”).

15. Further details of my background and qualifications are provided in my CV, which I understand has been submitted as EX2005.

III. LIST OF DOCUMENTS CONSIDERED

16. I have considered the following documents listed below in addition to any other documents cited in this declaration. To the best of my knowledge, these documents are true and accurate copies of what they purport to be. An expert in the field would reasonably rely on them to formulate opinions such as those set forth in this declaration.

Paper No.	Description
1	Petition for <i>Inter Partes</i> Review of U.S. Patent No. 8,095,237

Exhibit No.	Description
1001	U.S. Patent No. 8,095,237 (“the ’237 Patent”)
1002	File History of U.S. Patent No. 8,095,237
1003	Declaration of Seth Hutchinson, Ph.D. Regarding Invalidity of U.S. Patent No. 8,095,237
1004	Peter I. Corke, Visual Control of Robots: High-Performance Visual Servoing (Aug. 1996) (“Corke”)
2006	Rizzi A., et al., “Preliminary Experiments in Spatial Juggling,” International Symposium on Experimental Robotics (1991), 17 pages.
2007	“Navigation of a Mobile Robot using Mono-Vision and Mono-Audition,” <i>IEEE International Conference on Systems, Man, and Cybernetics</i> (1999), pp. 686-91.
2008	Henry, N., “Understanding Robot Coordinate Frames and Points,” SolisPLC, accessible at https://www.solisplc.com/tutorials/robot-coordinate-frames-and-points (last accessed December 22, 2023)
2009	Stevenson, K., “Breaking the Toolhead Barrier with MedUSA,” Fabbaloo.com, accessible at https://www.fabbaloo.com/news/breaking-the-toolhead-barrier-with-medusa (last accessed December 27, 2023)
2010	“Robots Combine for Faster Metal 3D Printing,” MedUSA Video, accessible at https://www.youtube.com/watch?v=FR5X0t7-g6M (last accessed January 2, 2024)
2011	Liu, B., et al., “A Rapid Coordinate Transformation Method Applied in Industrial Robot Calibration Based on Characteristic Line Coincidence,” <i>Sensors</i> , vol. 16, no. 2 (2016), 16 pages.
2012	Xi, F., et al., “Framework on robotic percussive riveting for aircraft assembly automation,” <i>Advances in Manufacturing</i> , vol. 1 (2013), pp. 112-22.

Exhibit No.	Description
2013	Roth, M., et al., “A Real-time World Model for Multi-Robot Teams with High-Latency Communication,” <i>Proceedings of the 2003 IEEE/RSJ International Conference on Intelligent Robots and Systems</i> (2003), pp. 2494-99.
2014	Zhao, G., “Construction of Vision-based Manipulation System for 3D Industrial Objects,” <i>Proceedings of the 2009 IEEE International Conference on Robotics and Biomimetics</i> (2009), pp. 1051-56.

IV. LEGAL UNDERSTANDING

A. My Understanding of Claim Construction

17. I understand that during an *inter partes* review proceeding, claims are to be construed in light of the specification as would be read by a person of ordinary skill in the relevant art at the time the application was filed. I understand that claim terms are given their ordinary and customary meaning as would be understood by a person of ordinary skill in the relevant art in the context of the entire disclosure. A claim term, however, will not receive its ordinary meaning if the patentee acted as his or her own lexicographer and clearly set forth a definition of the claim term in the specification. In this case, the claim term will receive the definition set forth in the patent.

B. My Understanding of Obviousness

18. I understand that a patent claim is invalid if the claimed invention would have been obvious to a person of ordinary skill in the art at the time the

application was filed. I understand that this means that even if all of the requirements of the claim cannot be found in a single prior-art reference that would anticipate the claim, the claim can still be invalid.

19. To obtain a patent, a claimed invention must have been, as of its priority date, nonobvious in view of the prior art in the field. I understand that a patent claim is obvious when the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art.

20. I understand that to prove that prior art or a combination of prior art renders a patent claim obvious, it is necessary to: (1) identify the particular references that, singly or in combination, render the patent claim obvious; (2) specifically identify which elements of the patent claim appear in each of the asserted references; and (3) explain how the prior-art references could have been combined in order to create the inventions claimed in the patent claim.

21. I also understand that when considering the obviousness of a patent claim, one should consider whether a teaching, suggestion, or motivation to combine the references exists so as to avoid impermissibly applying hindsight when considering the prior art. I understand this test should not be rigidly applied, but that the test can be important to avoiding such hindsight.

22. I understand that certain objective indicia can be important evidence as to whether a patent is obvious or nonobvious. Such indicia include:

(1) commercial success of products covered by the patent claims; (2) a long-felt need for the invention; (3) failed attempts by others to make the invention; (4) copying of the invention by others in the field; (5) unexpected results achieved by the invention as compared to the closest prior art; (6) praise of the invention by the infringer or others in the field; (7) the taking of licenses under the patent by others; (8) expressions of surprise by experts and those skilled in the art at the making of the invention; and (9) the patentee proceeded contrary to the accepted wisdom of the prior art.

23. I also understand that “obviousness” is a legal conclusion based on the underlying factual issues of the scope and content of the prior art, the differences between the claimed invention and the prior art, the level of ordinary skill in the pertinent art, and any objective indicia of non-obviousness. For that reason, I am not rendering a legal opinion on the ultimate legal question of obviousness. Rather, my testimony addresses the underlying facts and factual analysis that would support a legal conclusion of obviousness or non-obviousness, and when I use the term obvious, I am referring to the perspective of one of ordinary skill at the time of invention.

C. My Understanding of a Person Having Ordinary Skill in the Art

24. I understand that a POSITA is presumed to be aware of all pertinent art, thinks along conventional wisdom in the art, and is a person of ordinary creativity.

25. I understand that the following should be considered when deciding the level of ordinary skill in the art that someone would have had at the time the claimed invention was made:

- the levels of education and experience of persons working in the field;
- the types of problems encountered in the field; and
- the sophistication of the technology.

26. My opinion below explains how a POSITA would have understood the technology described in the references I have identified herein around the timeframe of January 31, 2002.

27. Regardless if I use “I” or a “POSITA” during my technical analysis below, all of my statements and opinions are always to be understood to be based on how a POSITA would have understood or read a document at the time of the invention.

V. PERSON OF ORDINARY SKILL IN THE ART

28. I understand Dr. Hutchinson alleges that “a POSITA would have had

a Bachelor's degree in robotics, mechanical engineering, computer science, electrical engineering, or an equivalent, and at least three years of professional experience working in the field of computer vision or three years of graduate level education, including a focus on computer vision applications." EX1003, ¶77.

Dr. Hutchinson further alleges that "[t]he POSITA would have knowledge about machine vision and camera calibration techniques." EX1003, ¶77.

29. For purposes of this declaration, I have been told to assume Dr. Hutchinson's definition of a POSITA. As detailed with respect to my background and qualifications, I qualified as a POSITA under this definition as of January 31, 2002.

VI. THE '237 PATENT

A. Overview of the '237 Patent

30. The '237 patent provides "a method of three-dimensional object location and guidance to allow robotic manipulation of an object with variable position and orientation using a sensor array which is a collection of one or more sensors capable of forming a single image." EX1001, Abstract. As the patent notes, prior "camera systems [] have used laser triangulation which involves expensive specialized sensors, must be rigidly packaged to maintain geometric relationships, require sophisticated inter-tool calibration methods and tend to be susceptible to damage or misalignment when operating in industrial environments." EX1001,

1:32–37. The '237 patent provides techniques for enabling robotic manipulation of objects “using only standard video camera equipment” in a way “that is capable of providing the level of accuracy and repeatability required for vision guidance of robots as well as other applications requiring 3D pose information of objects.”

EX1001, 1:47–52.

31. The '237 patent provides an exemplary process for “calibration of the camera” in Figure 5, reproduced below. EX1001, 2:36–37.

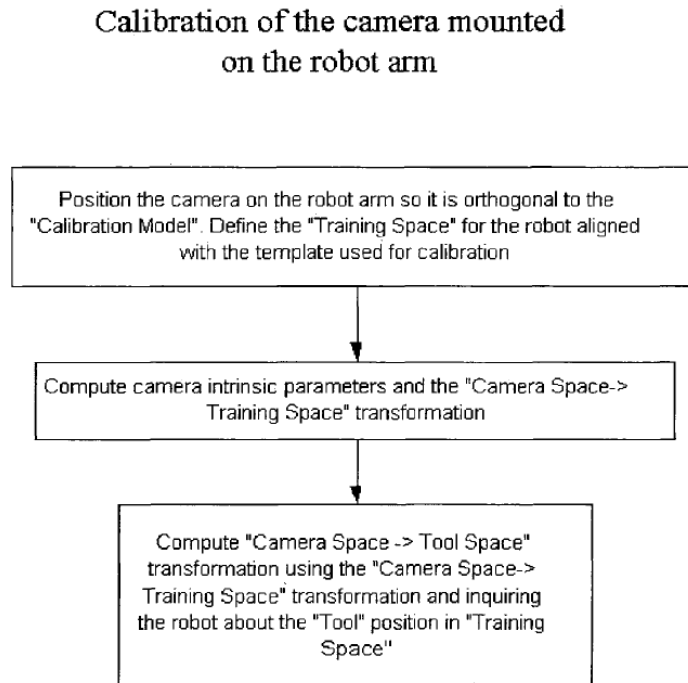


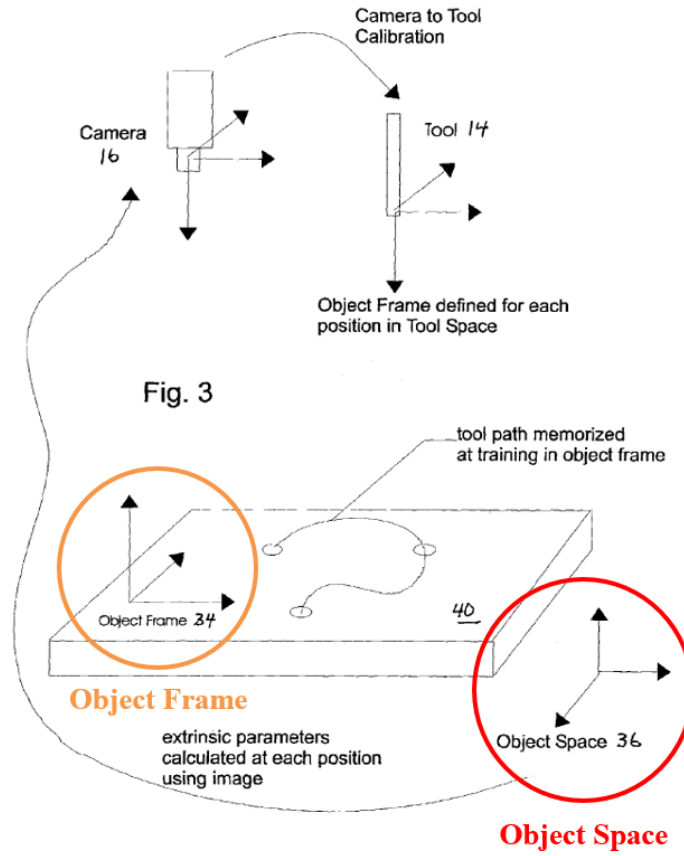
FIG. 5

EX1001, FIG. 5.

32. As the '237 patent explains: “The calibration process involves: i) finding the camera intrinsic parameters and ii) the position of the camera relative to

the tool of the robot ('hand-eye' calibration). The position of the camera in the 'Training Space', which is a space rigid to the place where the object will be trained is also determined." EX1001, 3:36–41. The calibration process involves determinations of transformations between training space, camera space, and tool space, which in turn allows for vision-guided object handling. EX1001, 1:56–2:21, 4:32–42.

33. To enable the robotic manipulation techniques of the '237 patent, the '237 patent defines specific coordinate spaces and frames as part of its processes. EX1001, 3:1–34. For example, the patent defines a three-dimensional "Object Space," which refers to "a reference frame defined with respect to, and therefore rigid to, the object," and an "Object Frame," which refers to "a reference frame defined with respect to a point on, and therefore rigid to, the object." EX1001, 3:25–28. I have annotated Figure 3 of the '237 patent below to show these frames as described in the patent.



EX1001, FIG. 3 (annotated).

34. The '237 patent explains that the "Object Space is defined such that it is identical to the Training Space but is rigid to the object and moves with the object." EX1001, 5:29–31. The '237 patent further explains: "Also an Object Frame will be defined with a constant relationship to the object, in a position selected by the user." EX1001, 5:32–33. For the robot to "find this frame position, the transformation from Object Space to Camera Space is used, then from Camera Space to Tool Space." EX1001, 5:37–40. By employing a coordinate space and frame that is rigid to the object, the '237 patent enables "teaching robots and handling of objects by robots in three dimensions" using at least one camera,

where “[t]he objects need not be fixtured and can be placed anywhere within the workspace of the robot.” EX1001, 7:50–8:10.

35. The inventors of the ’237 patent recognized benefits to defining an object space and object frame, especially for certain industrial object handling and high-speed manufacturing applications—in contrast to Corke (as I discuss below), which is not directed to high-speed manufacturing. In particular, the ’237 patent discloses that the “‘Object Frame’ inside ‘Object Space’ is defined to be used for teaching the intended operation path” of the robot. EX1001, 5:65–67; *see also* EX1001, 10:38–42 (disclosing “creating a new frame called the ‘Object Frame’ that is in constant relationship with the ‘Object Space’ and sending the ‘Object Frame’ to the robot and training the intended operation path relative to the ‘Object Frame’”). By training the intended operation path of the robot relative to the object frame—as opposed to training the operation path with respect to a fixed “world” frame—a robot is able to manipulate multiple objects and/or interact with multiple points on those objects in the same way, without needing to account for variations in the position or orientation of objects in the robot’s working area.

36. Put simply, the use of an object space to guide a robot manipulator is fundamentally different from the use of a fixed “world” coordinate system for guidance. When using an object space as disclosed in the ’237 patent, the absolute positions and orientations of the robot and object become irrelevant—the robot is

able to manipulate the object in a repeatable manner using a computed object space to camera space transformation. EX1001, 1:47–52, 5:67–6:5. In contrast, when using a fixed “world” space, as in Corke (discussed further below), the positions of the robot and object within the fixed coordinate space are used for guiding the robot’s operation path. While both techniques might be used to accomplish similar tasks, the inventors of the ’237 patent recognized that use of an object space can help to “provide the accuracy and repeatability required by industrial applications.” EX1001, 1:46–52.

B. Claim Construction

37. I understand that Petitioner and Dr. Hutchinson have applied the following definitions:

- “object space”¹: “a reference frame defined with respect to, and therefore rigid to, the object.”
- “training space”: a reference frame defined with respect to a point on the calibration template, and aligned to its main axis.”

Pet., 8; EX1003, ¶86.

38. For purposes of this declaration, I have been instructed to apply these definitions in my analysis. For all other claim terms, unless otherwise noted herein,

¹ Underlining is used throughout my declaration to denote language that appears in the ’237 patent claims.

I apply the ordinary and customary meaning of the term as would have been understood by a POSITA as of January 31, 2002.

VII. DR. HUTCHINSON’S PROPOSED OBVIOUSNESS GROUNDS

39. I understand Dr. Hutchinson opines that “a POSITA would have found Claims 1–4, 6–10, 17–20, and 24–28 of the ’237 Patent to be obvious over Corke in view of the knowledge of a POSITA.” EX1003, ¶92. For this declaration, I have been asked to opine on certain aspects of Corke’s disclosure as they relate to Dr. Hutchinson’s opinions.

A. Corke’s techniques employ a world space coordinate system—not an “object space” as the ’237 patent describes.

40. Corke (EX1004) appears to be a copy of a book written by Peter I. Corke, titled “Visual Control of Robots: High-Performance Visual Servoing.” EX1004, Cover. Corke describes that the “book is about the application of high-speed machine vision for closed-loop position control, or visual servoing, of a robot manipulator.” EX1004, ix. In other words, visual servoing refers to controlling the movement of a robot using information derived from images or video.

41. To enable visual servoing of a robot manipulator, Corke first discusses “[c]amera calibration techniques.” EX1004, 139. As Corke explains, “[c]amera calibration is the process of determining the internal camera geometric and optical characteristics (intrinsic parameters) and the 3-D position and

orientation of the camera frame relative to a certain world coordinate system.”

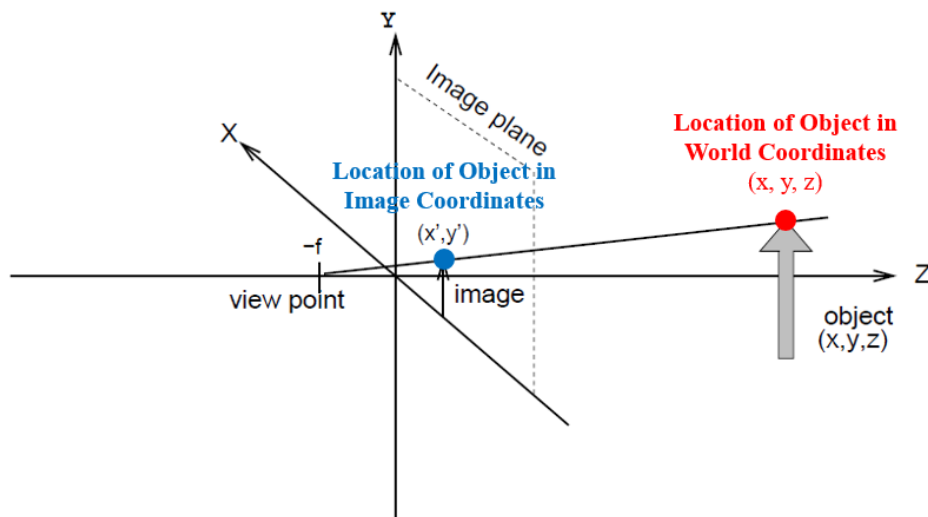
EX1004, 139.

42. The “world coordinate system” used in Corke represents the real world, where the locations of the camera, the robot manipulator, and objects can be specified as three-dimensional coordinates, e.g., (x, y, z). To enable the vision-guidance of the robot, Corke discusses determining a “camera calibration matrix, **C**, [which] contains information about the position of the camera with respect to the world coordinate frame.” EX1004, 143. “**C** represents the relationship between 3-D world coordinates and their corresponding 2-D image coordinates as seen by the computer.” EX1004, 138.

43. I understand that Dr. Hutchinson asserts that “Corke teaches methods for determining the matrix **C** using the position of multiple features in a single image.” EX1003, ¶112 (citing EX1004). Dr. Hutchinson then asserts: “[A] POSITA would have known that if the 3-D coordinates are specified with respect to the object space, then the camera pose obtained by Corke’s algorithm is defined with respect to the object space, and therefore, determines the object space-to-camera space transformation.” EX1004, ¶112.

44. From my review of the portions of Corke cited by Dr. Hutchinson, Corke does not disclose specifying 3-D coordinates with respect to “object space,” or use of an “object space” separate from Corke’s world coordinate system.

Instead, Corke discloses that the location of an object is found in world coordinates, which are related to image coordinates (i.e., “2-D image coordinates as seen by the computer”) by Corke’s camera calibration matrix **C**. EX1004, 137–39. An example of this relationship is shown, for example, in Figure 3.7 of Corke, which I have annotated below.



EX1004, 87 (FIG. 3.7) (annotated).

45. Corke’s world coordinate system is defined independently from the location of any object—as illustrated in the example diagram below, it is simply a three-dimensional reference frame that allows the location of objects (or other items) to be defined in terms of (x, y, z) coordinates. See EX2008, 4–5 (“The WORLD frame is a *fixed* cartesian coordinate frame that ... defines the overall world for the robot” and allows you to “define the location and orientation of an

object in space”).²

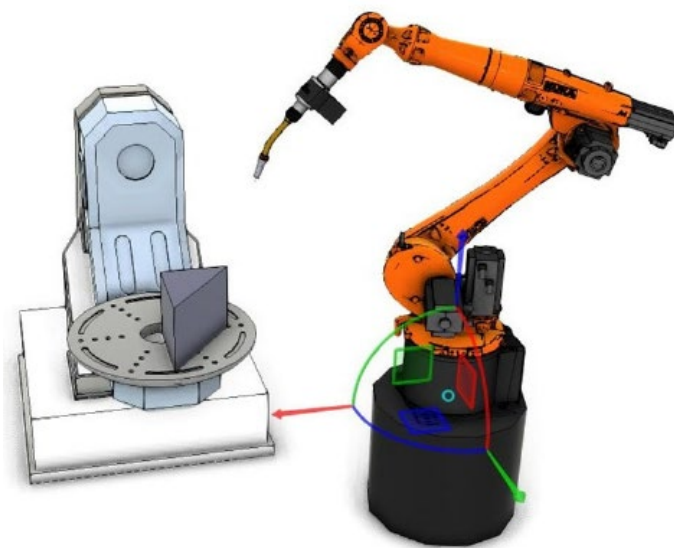


Figure 3 WORLD Frame

EX2008, 4.

46. Corke’s world coordinate system therefore cannot meet Dr. Hutchinson’s definition of “object space” because nowhere does Corke disclose that its world coordinate system is “defined with respect to, and therefore rigid to, the object.” EX1003, ¶86.

B. A POSITA considering Corke’s techniques would not have sought to employ an “object space.”

47. In addition to Corke disclosing use of a world coordinate system and not an “object space,” there are also reasons why a POSITA would not have modified Corke to use an “object space” in view of Corke’s disclosed techniques. In particular, Corke already provides techniques for enabling vision-guided

² Emphasis added unless otherwise noted.

robotics using fixed “3-D world coordinates,” without the need for an “object space” coordinate system. EX1004, 138.

48. A primary purpose of Corke’s techniques is to provide “a mapping from 3D space to the 2D image plane,” such that “a point on the image plane (i_x, i_y) are related to the world coordinates (x, y, z).” EX1004, 86. This mapping is represented by Corke’s “camera calibration matrix which relates a world coordinate system to the image plane coordinates [] for a given camera position and orientation.” EX1004, 139. Corke can then use this determined relationship as a basis for visual servoing, allowing Corke to “determine the 3D relative pose of an object, ${}^c\mathbf{x}$, from 2D image plane coordinates,” EX1004, 159—that is, Corke’s determined relationship between image coordinates and world coordinates can later be used to estimate the position and orientation of an “object of interest,” EX1004, 152. In my opinion, none of these techniques require or would benefit from the use of an “object space” as the ’237 patent discusses.

49. Corke provides example visual servoing applications that use world space coordinates, consistent with Corke’s disclosed techniques. As one example, Corke provides an application of “visual servoing” in which “[t]hree robot DOF [(degrees of freedom)] are controlled by image features so as to keep the camera at a constant height vertically above a target rotating on a turntable,” as illustrated in Corke’s Figure 8.15. EX1004, 282–83.

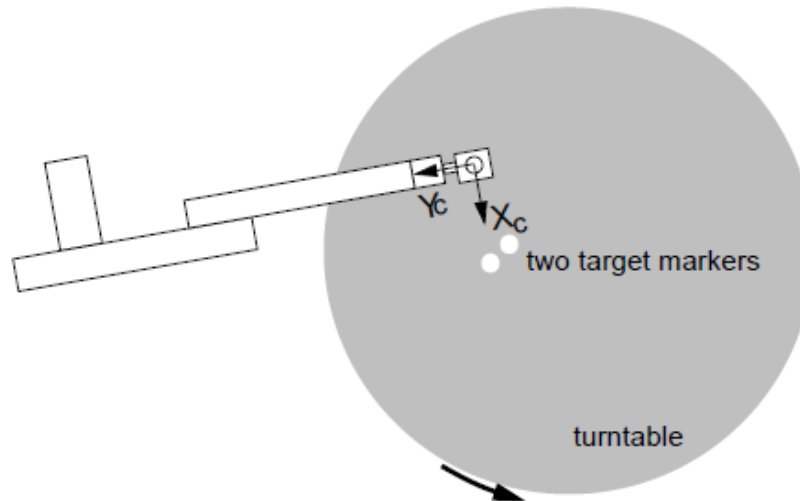


Figure 8.15: Plan view of the experimental setup for translational visual servoing.

EX1004, 283 (FIG. 8.15).

50. Corke explains, “[i]n order to control 3 robot DOF we require 3 ‘pieces’ of information from the image,” including “an X and Y target displacement with respect to the camera and the extra information required is target distance.” EX1004, 283. With this information “[t]he camera coordinate frame can be determined ... which provides the camera pose in *world coordinates* allowing the target position in *world coordinates* to be estimated.” EX1004, 283. Thus, as the object moves around the turntable, the target position in world coordinates can be estimated, and the robot’s camera can be moved such that it remains fixated over the object. EX1004, 282–83.

51. Indeed, a POSITA would have recognized that use of a world coordinate system, rather than an “object space,” is beneficial in numerous applications. For example, a turntable like the one disclosed in Corke can be used

to allow multiple robots to operate on the same object. For instance, I was involved in designing the MedUSA systems at ORNL, which employs three robots situated around a turntable. EX2009, 2. The three robots are capable of working in sync with each other to operate upon one or more parts placed on the turntable, either while the turntable is stationary or rotating. EX2009, 2–3. The video provided as Exhibit 2012 illustrates an example of three welding robots operating on different portions of a part as the turntable rotates the part. *See* EX2010. To facilitate cooperation between the three robots, the MedUSA system uses a fixed world model in which each robot is programmed to operate in a mutually exclusive portion of the world. This fixed world coordinate system thus helps to prevent any potential collisions between robot heads.

52. Corke also discusses additional applications that benefit from the use of a fixed world coordinate system, such as “robotic ping-pong [and] juggling” in which one or more objects are constantly moving. EX1004, 151. For example, one of the papers cited by Corke relates to “research in robotic control of intermittent dynamical tasks” in which the authors “constructed a three degree of freedom robot capable of ‘juggling’ a ball falling freely in earth’s gravitational field.” EX2006, 1. As explained in the paper, “[t]he ‘world’ as seen by the cameras contains only one white ball against a black background.” EX2006, 5. After images are taken by the cameras, “pixel processors [] determine[] the ball location in a pair

of images, [and] stereo triangulation introduced in Section 2.3 *locates the position of the ball in space with respect to a fixed reference coordinate system.*” EX2006,

12. In other words, a fixed world coordinate system is used to track the position of the ball with respect to the robot as the ball moves through space.

53. As another example, Roth (EX2013) discusses use of “a world model in a multi-robot team” finding that “using a world model that incorporates shared information is more successful at tracking a dynamic object in its environment.” EX2013, 2494. Roth specifically used multiple Sony AIBO robots each equipped with their own vision sensor to track the location of a soccer ball on a field. EX2013, 2494–95. Each robots maintains its own “individual world model,” and the “shared world model” is used to facilitate communication of the ball’s position between robots, allowing each robot to maintain the position of the ball even when out of sight of an individual robot. EX2013, 2494–97. This example is consistent with known benefits of using a world model for object tracking—use of an “object space” that is rigid to the object would be illogical because it would provide no information as to the location of the object within the world.

54. Likewise, when an object that remains stationary, the use of an independent, fixed world coordinate system is sufficient to enable vision-guided robotics. In particular, there is no need to define a separate “object space” when Corke already defines a matrix **C** for transforming points between world space and

image space (EX1004, 138) and when the position of the object can be represented in world coordinates. Employing a separate “object space” would require additional computations to keep track of an additional coordinate frame, its relationship to the initial position of the coordinate frame as the object moves, as well as its relationship to other coordinate frames.

55. A POSITA would have sought to reduce the number of computations where possible. *See, e.g.*, EX2007, 686 (disclosing desire to “reduce computational complexities” in vision-guided “Navigation of a Mobile Robot”; “The purpose of the research presented in this paper is to develop a low-cost multi-sensor system and incidental algorithms for autonomous navigation of a mobot.”). Reducing computational complexity allows for less powerful computing requirements, resulting in cost savings in hardware and energy consumption, and the reduction of the system’s carbon footprint. Indeed, Corke itself explains the desire to reduce computations when using the “photogrammetric” techniques that Dr. Hutchinson cites. EX1004, 160 (“The commonly cited drawbacks of the photogrammetric approach are the complex computation...”); EX1003, ¶114 (citing EX1004, 159: Corke’s “Photogrammetric techniques”).

56. Moreover, because Corke’s techniques rely on a fixed world coordinate system, incorporating an “object space” as Dr. Hutchinson suggests (i.e., “if the 3-D coordinates are specified with respect to the object space,”

EX1003, ¶112) would adversely impact the precision of the robot. In particular, to operate on a point “specified with respect to the object space” (EX1003, ¶112), Corke’s system would require performing multiple, chained transformations between object space, Corke’s fixed world space, and Corke’s image space. Although such operation is possible, each coordinate transformation is susceptible to floating point error, which can accumulate across multiple transformations. As Liu explains in a 2015 article:

The transformation of coordinate systems is applied in many fields, especially vision measurement and robotics.... A minor *error introduced by an imprecise coordinate transformation* could cause problems such as the failure of image matching and track breaking. Especially in an error accumulating system such as series industry robots, *the coordinate transformation error would accumulate in each step and thereby decrease the position accuracy of the robot manipulator.*

EX2011, 1. As disclosed, Corke’s techniques require only one transformation between “3-D world coordinates” and “2-D image coordinates.” EX1004, 138. Absent recognition of a particular benefit to doing so, a POSITA would not have sought to increase the number of transformations performed in Corke’s system through the introduction of an “object space.” EX2011, 1.

57. The use of a world coordinate system is also beneficial for numerous manufacturing applications where objects remain stationary and are manipulated

within a defined space. Such techniques are particularly useful when working with large parts and in the assembly of multiple stationary parts, where a world coordinate system captures positions of and relationships between the parts.

58. For example, when making bolt hole patterns or rivet holes on an object (e.g., a car body or aircraft), a world coordinate system allows positions of holes or other pattern features to be specified in a single, universal coordinate system. The camera or sensor used for vision-guidance simply needs to be calibrated such that the relationship between the sensor's coordinate system and the world coordinate system is determined. For example, Xi (EX2012) discusses "a framework for the implementation of a robotic percussive riveting system" in which world coordinates of rivet spots on an aircraft body are determined "according to rivet patterns." EX2012, 112–15. Xi's system uses "a position sensor system" to track the robot and its rivet gun, and then "transfer[s] the coordinates of the rivet spots to those in the robot frame." EX2012, 119. In other words, the locations of the rivet spots are maintained in a fixed reference frame, which can then be transformed to a coordinate frame used by the robot—without the use of any "object space."

59. Similarly, when assembling multiple parts, use of a world coordinate system allows the relative locations of parts to be tracked. As an example from my experience, vision-guided robots can be used to assemble engine blocks, inserting

pistons into cylinder holes. Rather than use an “object space” defined with respect to a piston, using a world coordinate system is more logical in order to track relative positions of all pistons and cylinder holes in the engine block. The operation of the robot can then be programmed to move within the single world coordinate system, instead of needing to track one or more object frames specific to each part being operated upon.

60. Zhao (EX2014), for example, discusses a “vision-based industrial robotic assembly system” in which “sets of automotive parts, such as axletrees, bearings, pistons and pins are grasped from the conveyor and assembled together precisely.” EX2014, 1051. Zhao explains that “it is necessary to precisely figure out the position and orientation of the parts to be grasped” within a “world frame.” EX2014, 1051. In an “off-line stage,” “the base position of the automotive parts to be grasped” is specified, and during operation the system “obtain[s] the corresponding position relationship between the present position and the base position [of the parts] in their images.” EX2014, 1054–55. Once the position and orientation of the parts are determined, the system grasps the parts and assembles them, as illustrated below. EX2014, 1056.

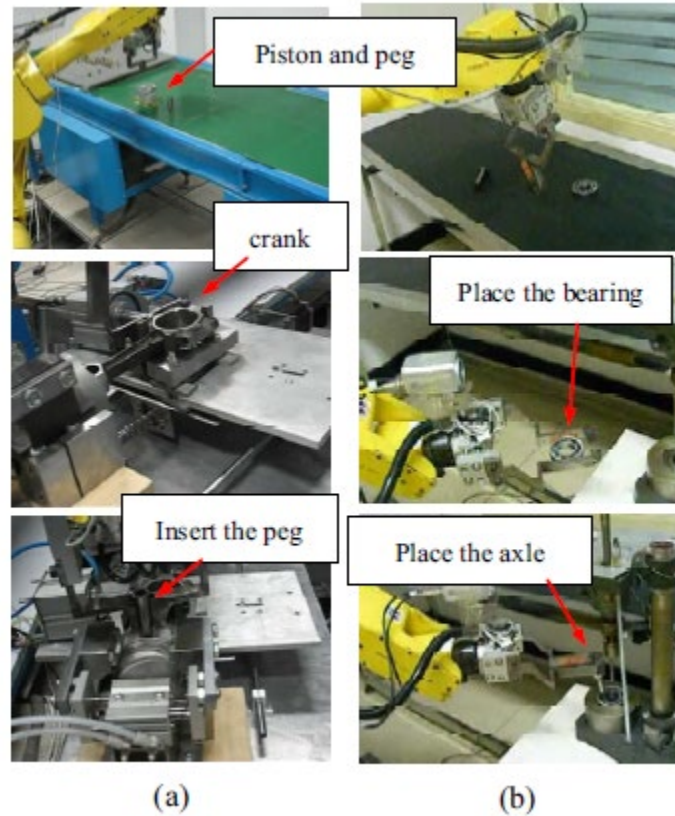


Fig. 8. The axletree-bearing grasping experiments

EX2014, 1056 (FIG. 8).

Thus, as in Zhao, the use of a “world” coordinate system can be used to identify positions and orientations of different work pieces for purposes of assembly.

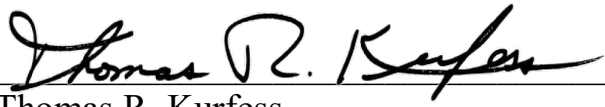
61. For these reasons, it is my opinion that a POSITA would not have sought to use an “object space” with Corke’s disclosed techniques. There would be no need to do so in view of Corke’s calibration techniques, which already define the relationship between world and image coordinates.

VIII. CONCLUSION

In signing this declaration, I recognize that the declaration will be filed as evidence in an *inter partes* review 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, I will appear for cross-examination within the United States during the time allotted.

I hereby 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 1001 of Title 18 of the United States Code.

Executed on this 4th day of January, 2024, in Atlanta, GA.


Thomas R. Kurfess