

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

ABB INC.,

Petitioner, ~~v.~~

~~- vs. -~~

ROBOTICVISIONTECH,

INC.,

Patent Owner

~~Case: IPR2023-1426~~

~~U.S. Patent No.~~

EXPERT DECLARATION OF SETH HUTCHINSON,
PH.D. IN SUPPORT OF ~~8,095,237~~

PETITION FOR *INTER PARTES*

REVIEW OF U.S. PATENT NO. ~~8,095,237~~

~~8,095,237~~

RoboticVisionTech EX2002
ABB v. RoboticVisionTech
IPR2023-01426

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I, Seth Hutchinson, hereby declare as follows:

I. INTRODUCTION AND QUALIFICATIONS

1. I have been retained on behalf of ABB Inc. (“ABB” or “Petitioner”) to provide my technical review, analysis, insights, and opinions concerning the validity of claims 1–10 and 12–28 of U.S. Patent No. 8,095,237 (“the ’237 Patent”) (EX1001) entitled “Method and apparatus for single image 3D vision guided robotics.” I understand that the ’237 Patent is assigned to RoboticVISIONTech, Inc. (“RVT”).

2. I am a Professor and KUKA Chair for Robotics at the School of Interactive Computing at the Georgia Institute of Technology (“Georgia Tech”). I have held that position since 2018. At Georgia Tech, I have taught and developed the courses: Robot Motion Planning, Mobile Manipulation, and Introduction to Perception and Robotics. At Georgia Tech, I have advised six Ph.D. students.

3. I also serve as the Executive Director of the Institute for Robotics and Intelligent Machines (“IRIM”) at Georgia Tech. I have held that position since 2019. Previously, I held the position of Associate Director at IRIM. IRIM is a center for robotics research and education at Georgia Tech. IRIM conducts research on mechanics, control, perception, artificial intelligence and cognition, interaction, and systems, including on field and service robots and human-centered robotics. This includes research on manipulation and locomotion, safe and resilient autonomy, and

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sensing and perception. IRIM hosts more than 80 faculty members, 150 graduate students, and 40 robotics labs.

4. I was previously employed at the University of Illinois at Urbana-Champaign (the “University of Illinois”) from 1990 to 2018, where I still hold the position of Professor Emeritus of Electrical and Computer Engineering. During my time at the University of Illinois, I worked in the Electrical and Computer Engineering Department. From 1990 to 1996, I was an Assistant Professor of Electrical and Computer Engineering and a Research Assistant Professor at the Beckman Institute and Coordinated Science Laboratory. From 1996 to 2003, I was an Associate Professor of Electrical and Computer Engineering and a Research Associate Professor at the Beckman Institute and Coordinated Science Laboratory. From 2001 to 2007, I was the Associate Head for Undergraduate Affairs for Electrical and Computer Engineering. From 2003 to 2017, I was a Professor of Electrical and Computer Engineering and a Research Professor at the Beckman Institute and Coordinated Science Laboratory.

5. At the University of Illinois, I taught and developed the courses: Introduction to Robotics, Robot Sensing, Introduction to Robotics, Advanced Robotic Planning, Control Systems, Control System Theory and Design, Introduction to Optimization, Senior Design Laboratory, Introduction to Computing Systems, Analog Signal Processing, Computer Engineering I, Probability with

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Engineering Applications, Logic Design, and Engineering Ethics. I also advised 18 Ph.D. students in their thesis research.

6. I have also been a visiting professor at various institutions between 1989 and 2017, including Purdue University, Ecole Nationale Supérieure des Télécommunications, The Australian National University, Tecnológico de Monterrey, Université de Rennes I, L’Institut Français Mécanique Avancée, and Università di Roma “La Sapienza.”

7. I have conducted various tutorials and short courses since 1993, including several courses on Visual Servo Control. I have also taught short courses on Path Planning, Robot Motion Planning, Multisensor Fusion Under Uncertainty, Underactuated Robots, Probabilistic Methods in Robotics, and Robotics and Computer Vision.

8. I attended Purdue University, where I received a Ph.D. in electrical engineering in 1988, an M.S. degree in electrical engineering in 1984, and a B.S. degree in electrical engineering in 1983.

9. A large part of my research work has involved machine vision and robotics. My research interests include vision-based control, motion planning and control, planning under uncertainty, pursuit-evasion, localization and mapping, locomotion, and bio-inspired robotics.

10. I have served on the advisory and editorial boards for multiple journals since 1997, including the International Journal of Robotics Research, the Journal of Intelligent Service Robotics, Transactions on Robotics, Transactions on Robotics and Automation, and the IEEE Robotics and Automation Society.

11. I have published three textbooks on Robot Modeling and Principles of Robot Motion. I am an author on over 75 articles on similar topics. According to Google Scholar, my work has been cited more than 27,000 times.

12. I am very involved in the Robotics and Automation Society of IEEE, including serving as its President until 2021.

13. Attached as Exhibit 1012 is my curriculum vitae, which includes a more detailed list of my qualifications. My work on this case is being billed at a rate of \$500 per hour, with reimbursement for actual expenses. I have no direct financial interest in the dispute between the Petitioner and RVT, and my compensation is not contingent upon the outcome of this *inter partes* review.

14. I have not testified as an expert at trial or by deposition during the previous 4 years.

II. UNDERSTANDING OF THE GOVERNING LAW

a. Invalidity by Obviousness

15. I understand that a claim may be invalid under 35 U.S.C. § 103 if the subject matter described by the claim as a whole would have been obvious to a

POSITA in view of a prior art reference, or in view of a combination of references at the time the claimed invention was made. I understand that obviousness is analyzed from the perspective of a POSITA at the time of the alleged invention. I also understand that a POSITA is presumed to have been aware of all pertinent prior art at the time of the alleged invention.

16. I understand that an obviousness analysis involves comparing a claim to the prior art to determine whether the claimed invention as a whole would have been obvious to a POSITA in view of the prior art, and in light of the general knowledge in the art at the time the invention was made. I also understand that the invention may be deemed obvious when a POSITA would have reached the claimed invention through routine experimentation.

17. I understand that obviousness can be established by combining or modifying the disclosures of the prior art to achieve the claimed invention. It is also my understanding that where there is a reason to modify or combine the prior art to achieve the claimed invention, there must also be a reasonable expectation of success in so doing to render the claimed invention obvious. I understand that the reason to combine prior art references can come from a variety of sources, not just the prior art itself or the specific problem the patentee was trying to solve. I also understand that the references themselves need not provide a specific hint or suggestion of the

alteration needed to arrive at the claimed invention; the analysis may include recourse to logic, judgment, and common sense available to a POSITA.

18. I understand that when there is some recognized reason to solve a problem, and there are a finite number of identified, predictable solutions, a POSITA has good reason to pursue the known options within his or her technical grasp. If such an approach leads to the anticipated success, it is likely the product not of innovation but of ordinary skill and common sense. In such a circumstance, when a patent simply arranges old elements with each performing the same function it had been known to perform and yields no more than one would expect from such an arrangement, I understand that the combination is obvious.

19. I understand that when considering the obviousness of an invention, one should also consider whether there are any objective indicia that support the non-obviousness of the invention. I further understand that objective indicia of nonobviousness include failure of others, copying, unexpected results, information that “teaches away” from the claimed subject matter, perception in the industry, commercial success, and long-felt but unmet need. I also understand that in order for objective indicia of non-obviousness to be applicable, the indicia must have some sort of nexus to the subject matter in the claim that was not known in the art. I understand that such nexus includes a factual connection between the patentable subject matter of the claim and the objective indicia alleged. I also understand that

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an independently made invention that is made within a comparatively short period of time is evidence that the claimed invention was the product of ordinary skill.

20. Finally, I understand that patent examiners at the U.S. Patent and Trademark Office (“USPTO”) rely upon certain exemplary rationales in reviewing patent applications to understand whether the subject matter of the claims is obvious. I understand that the following is the list of exemplary rationales relied upon by patent examiners at the USPTO:

- a. Combining prior art elements according to known methods to yield predictable results;
- b. Simple substitution of one known element for another to obtain predictable results;
- c. Use of a known technique to improve similar devices, methods, or products in the same way;
- d. Applying a known technique to a known device, method, or product ready for improvement to yield predictable results;
- e. “Obvious to try” – Choosing from a finite number of identified, predictable solutions, with a reasonable expectation of success;
- f. Known work in one field of endeavor may prompt variations of it for use in either the same field or a different one based on design incentives

or other market forces if the variations are predictable to one of ordinary skill in the art; and

g. Some teaching, suggestion, or motivation in the prior art that would have led one of ordinary skill to modify the prior art reference or to combine prior art reference teachings to arrive at the claimed invention.

b. Interpreting Claims Before the Patent Office

21. I understand that *inter partes* review is a proceeding before the USPTO for evaluating the validity of issued patent claims. I understand that, in an *inter partes* review, a claim term is interpreted in a manner consistent with the standard used in patent litigation, as set forth in *Phillips v. AWH Corp.*, 415 F.3d 1303 (Fed. Cir. 2005) (en banc). I understand that such standard generally construes the claims according to their “ordinary and customary” meaning in view of the claim language, specification, and file history, and where applicable, other relevant evidence.

22. I understand that a patent’s “specification” includes all the figures, discussion, and claims within the patent. I understand that the USPTO will look to the specification and prosecution history to see if there is a definition for a given claim term, and if not, will apply the ordinary and customary meaning from the perspective of a POSITA at the time in which the alleged invention was made.

c. Materials Relied on in Forming My Opinions

23. In forming my opinions expressed in this declaration, I have relied on my own knowledge, experience, and expertise, as well as the knowledge of a POSITA in the relevant timeframe. In addition, I have reviewed and relied upon all documents referenced in this declaration including the following materials. I understand the documents have been given the following exhibit numbers in this proceeding:

- U.S. Patent No. 8,095,237 (“the ’237 Patent”) (EX1001);
- Prosecution History of the ’237 Patent (EX1002);
- “Visual Control of Robots: High-Performance Visual Servoing,” by Peter I. Corke (“Corke”) (EX1004);
- Active Self-Calibration Of Robotic Eyes And Hand-Eye Relationships With Model Identification, Guo-Qing Wei at al., IEEE Transactions on Robotics and Automation (“Wei-I”) (EX1005);
- Multisensory Visual Servoing by a Neural Network, Guo-Qing Wei and Gerd Hirzinger, IEEE Transactions on Systems, Man and Cybernetics (“Wei-II”) (EX1006).
- U.S. Patent No. 4,146,924 to Birk et al. (“Birk”) (EX1008); and
- U.S. Patent No. 5,959,425 to Bieman et al. (“Bieman”) (EX1009).

III. BACKGROUND OF THE ART

a. Camera Calibration and Single Image Three-Dimensional Vision

Guided Robotics Were Well-Known Long Before the '237 Patent

24. The '237 Patent relates to “a method and apparatus for single image three dimensional vision guided robotics.” EX1001, 1:13-15. As the '237 Patent recognized, “machine vision [was] increasingly being used to guide robots in their tasks.” *Id.*, 1:20-22. 3D vision guidance systems for robots were also known, including those mentioned in the various patents disclosed in the Background of the '237 Patent. *Id.*, 1:25-30. Such systems “typically involved using two or more cameras.” *Id.*, 1:26-30; *see also* EX1008, 4:41-42.

25. Having only one camera decreased cost and took up less space, so it was viewed as “preferable.” EX1001, 1:30-32. In many single camera prior art systems, two or more 2D images from “different perspectives” were “used to convert the two-dimensional image data” to determine 3D location. EX1009, 3:37-49. These systems were not without problems. Some used laser triangulation and required “rigidly packaged” and “expensive specialized sensors.” EX1001, 1:32-35. “[S]ophisticated inter-tool calibration methods” were needed and the systems were often “susceptible to damage or misalignment when operating in industrial environments.” *Id.*, 1:35-37.

26. Known techniques to determine the “location in space of the target object using single or multiple cameras” included the use of “[t]arget points.” EX1001, 1:38-40. Some of those methods involved “computing the position of the object relative to a previous position, which requires knowledge of the 3D pose of the object at the starting point.” EX1001, 1:43-46. According to the ’237 Patent, such methods did not provide the accuracy and repeatability required for industrial applications. EX1001, 1:46-47.

27. Certain robotic vision systems were able to determine the 3D pose of an object using a single camera mounted on a robot’s hand. Some systems used a look-and-move structure in an “open-loop fashion” where the camera would capture an image of an object, extract features from the image, determine the pose of the object using the extracted features and previous knowledge about the relationship between those features, and plan the robot’s motion based on that information. EX1004, pp.3, 151-54. Other systems used a visual servoing approach with a “closed” feedback loop where the above process repeated itself such that the robot’s position could be altered while the robot was in motion to increase task accuracy. EX1004, pp.3, 151-55.

28. Robotic machine vision is the ability of a computerized robot to see and interact with the 3D world around it. At the time the application leading to the ’237 Patent was filed, this vision capability was typically enabled by one or more sensors

connected to a computer to interpret the information and provide information back to the robot allowing it to maneuver. The most common type of sensor was a camera, which could either be stationary or affixed to the robot's arm and would capture images of an object of interest.

29. Typically, machine vision involved the “extraction of a small number of generally numeric *features* from the image.” EX1004 at 123. These features would then be used by the machine vision system to gain further information. For instance, these features could be used along with “knowledge of the geometric relationship between feature points” on the object to determine the 3D pose of the object. EX1004 at 152.

30. Many machine vision systems that existed as of the priority date had the ability to determine the 3D pose of an object using a single camera mounted on a moveable part of the robot. Some of these systems were of the “look and move” variety whereby the camera would capture an image of an object, extract features from the image, determine the pose of the object using previous knowledge about the relationship of those features to each other, plan the robot's motion based on the pose information, and then await further instruction. EX1004 at 151-54.

31. Broadly speaking, visual servoing “involves the use of one or more cameras and a computer vision system to control the position of the robot's end-effector relative to the workplace.” EX1004, p.1. As of the earliest effective

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filing date, there were two classifications of visual servoing: position-based and image-based. In position-based visual servoing, a video camera captures images of a target that the system would process one at a time (at the camera's frame rate) such that "features are extracted from the image and used in conjunction with a geometric model of the target to determine the pose of the target with respect to the camera." EX1004, p.153 (the "camera frame rate" is "essentially the sample rate in a visual servo system"). The system sent the pose information to the robot to alter the robot's motion, and the process would start again with the next image. EX1004, p.155. Image-based visual servoing was similar but lacked pose estimation. EX1004, p.155.

32. The functionality of these two systems is shown in Figures 5.4 and 5.5 of Corke:

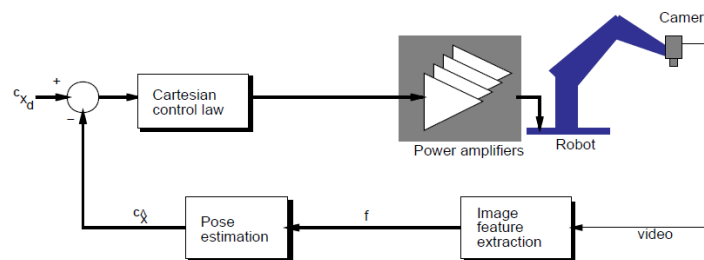
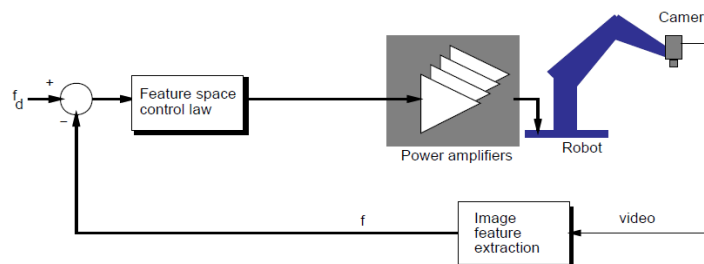


Figure 5.4: Position-based visual servo (PBVS) structure as per Weiss.



EX1004, p.155.

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As

TABLE OF AUTHORITIES

Cases	Page(s)
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<i>Becton, Dickinson & Co. v. B. Braun Melsungen AG</i> , IPR2017-01586, Paper 8 (P.T.A.B. Dec. 15, 2017)	81
<i>Bristol Myers Squibb Co. v. Ben Venue Lab'ys, Inc.</i> , <u>33. 246 F.3d 1368 (Fed. of the priority date, many robotic vision systems</u> <u>required calibration. There were three main types of calibration: intrinsic, extrinsic,</u> <u>and hand-eye.</u>	

34. Intrinsic calibration estimates the internal parameters of an image sensor and can be used to adjust for lens distortions and other imperfections that affect image quality and vision accuracy. EX1004, pp.139-46. Extrinsic calibration determines the position and orientation of the camera (specifically, the position and orientation of a 3D coordinate frame that is rigidly attached to the camera) relative to a reference 3D coordinate frame (e.g., the robot base frame, the Object Space, or a world coordinate frame). Together, this position and orientation information define the camera pose, which can be used to map, or “transform,” 3D points in the reference coordinate frame to two 3D points in the camera coordinate frame. Taken together, the intrinsic and extrinsic parameters define exactly the mathematical relationship between points in the robot’s workspace and their locations in the

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camera image. EX1004, pp.139-46. Hand-eye calibration is the process of determining the fixed transformation between the robot's tool and the camera coordinate system, or the robot base and the world (Cartesian) coordinate system, and is typically required when the camera is mounted to the robot's hand. EX1004, p.147. These transformations provide "positioning information" of the object, camera, and tool "directly in Cartesian or task space" (EX1004, p.3)—with the task

or training space being a Cartesian coordinate frame “defined with respect to a point on the calibration template.” EX1001, 3:1-34.

IV. OVERVIEW OF THE ’ 237 PATENT

<u>Specification</u> ~~Cir. 2001~~)	11
<i>Harris Corp. v. Ericsson Inc.</i> , 417 F.3d 1241 (Fed. ~~Cir.~~ 2005)	8
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PETITIONER'S EXHIBIT LIST

Exhibit	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, <i>Visual Control of Robots: High-Performance Visual Servoing</i> (Aug. 1996) (“Corke”)~~
~~1005~~	~~Guo-Qing Wei, et al., “Active Self-calibration of Robotic Eyes and Hand-eye Relationships with Model Identification,” TRANSACTIONS ON ROBOTICS AND ANIMATION, vol. 14, No. 1, Feb 1998 (“Wei I”)~~
~~1006~~	~~“Multisensory Visual Servoing by a Neural Network,” Guo-Qing Wei et al., IEEE Transactions on Systems, Man and Cybernetics, April 1999 (“Wei II”).~~
~~1007~~	~~<i>RoboticVISIONTech, Inc. v. ABB Inc.</i>, No. 1:22-cv-01257, Summons in a Civil Action (served Sept. 23, 2023).~~
~~1008~~	~~U.S. Patent No. 4,146,924 to Birk et al.~~
~~1009~~	~~U.S. Patent No. 5,959,425 to Bieman et al.~~
~~1010~~	~~Declaration of Sylvia Hall-Ellis, Ph.D.~~
~~1011~~	~~Docket Sheet, <i>RoboticVISIONTech, Inc. v. ABB Inc.</i>, Case No. 1:22-cv-01257-GBW (D. Del.)~~

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~~1012~~	~~Curriculum Vitae of Seth Hutchinson, Ph.D.~~
~~1013~~	~~Scheduling Order, <i>RoboticVISIONTech, Inc. v. ABB Inc.</i>, Case No. 1:22-cv-01257-GBW (D. Del.)~~

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~~I. MANDATORY NOTICES UNDER 37 C.F.R. § 42.8~~

~~A. Real Party in Interest~~

~~ABB Inc. (“ABB”) is the Petitioner and real party in interest.~~

~~B. Related Matters~~

~~U.S. Patent No. 8,095,237 (the “237 Patent”) is asserted in *RoboticVISIONTech, Inc. v. ABB Inc.*, Case No. 1:22-cv-01257-GBW (D. Del.) (“Related Litigation”).~~

~~C. Lead and Back-up Counsel and Service Information~~

~~Lead Counsel~~	~~Backup Counsel~~
~~Andrew R. Sommer USPTO Reg. No. 53,932 Greenberg Traurig, LLP 1750 Tysons Boulevard Suite 1000 McLean, VA 22102 Phone: 703-749-1370 Fax: 703-749-1301 sommera@gtlaw.com~~	~~Benjamin Schladweiler (<i>pro hac vice</i> forthcoming) Greenberg Traurig, LLP 222 Delaware Avenue Suite 1600 Wilmington, DE 19801 Phone: 302-661-7352 Fax: 302-661-7360 schladweilrb@gtlaw.com~~
~~Backup Counsel~~	~~Backup Counsel~~
~~Trenton A. Ward USPTO Reg. No. 59,157 Greenberg Traurig, LLP 333 Piedmont Road NE Suite 250 Atlanta, GA 3035 Phone: 678-553-2100 Fax: 678-55302212 Trenton.ward@gtlaw.com~~	~~Kathryn E. Albanese USPTO Reg. No. 78,153 Greenberg Traurig, LLP One Vanderbilt Avenue New York, NY 10017 Phone: 212-801-6533 Fax: 212-801-6200 Katie.albanese@gtlaw.com~~

~~Please address all correspondence to lead and back-up counsel at
Petitioner consents to electronic service.~~

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~~II. — GROUNDS FOR STANDING~~

~~Petitioner certifies that the '237 Patent is available for *inter partes* review and that Petitioner is not barred or estopped from requesting *inter partes* review challenging the claims on the grounds identified in this Petition.~~

~~III. — REQUESTED RELIEF~~

~~Petitioner requests institution of *inter partes* review of Claims 1-10 and 12-28 (“Challenged Claims”) of the '237 Patent, and cancelation of those claims as unpatentable.~~

~~IV. — REASONS FOR THE REQUESTED RELIEF~~

~~For the reasons discussed in this Petition, the Board should institute trial and find the Challenged Claims unpatentable.~~

a. Summary of the '237 Patent

~~15:35.~~ The '237 Patent describes the use of machine vision for 3D pose estimation. The methods of the '237 Patent include three steps: “a) calibration of the camera; b) teaching the features on the object; and c) finding the three - dimensional pose of the object.” and using this information to guide the robot to approach the object to perform any operations (e.g. handling, cutting etc.).” EX1001, 2:60-67.

~~16:36.~~ Figure 1 of the '237 Patent depicts a “vision-guided robot” 10 with a base 22 and manipulating arm 12 on which a camera 16 and tool 14—designed to manipulate a target object—are mounted. EX1001, 2:29, 2:53-59.

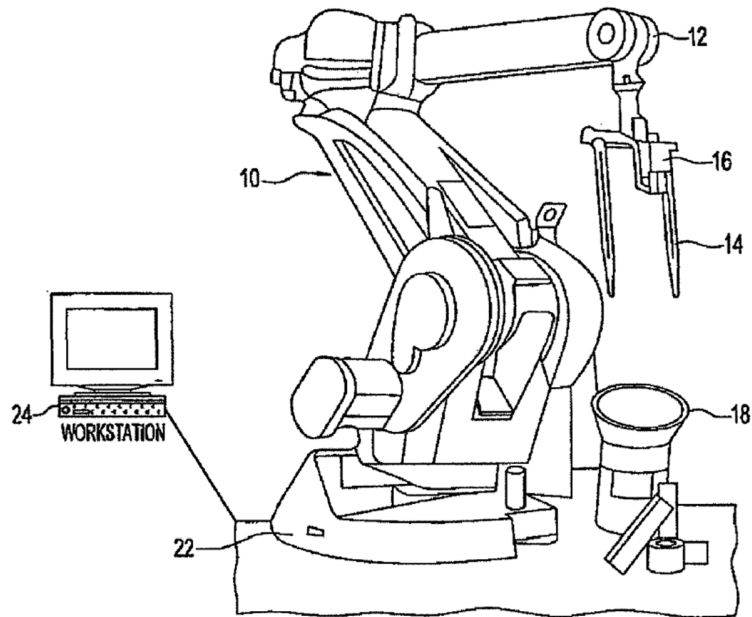


FIG. 1

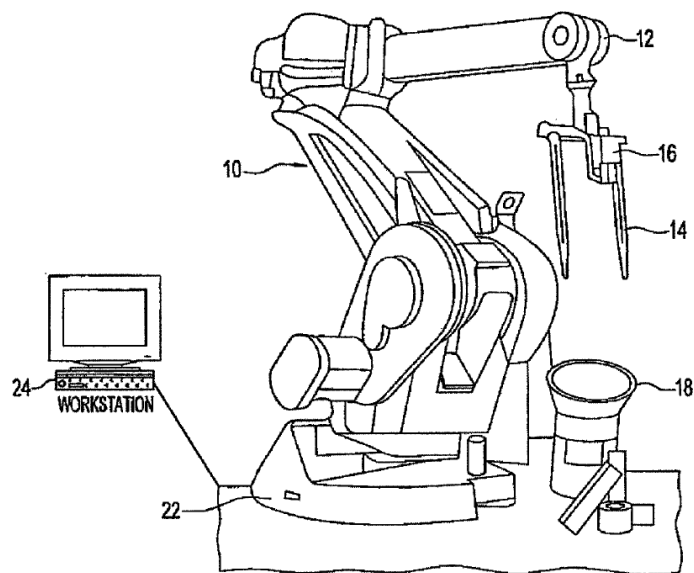


FIG. 1

47.37. The first step is to calibrate the camera. ~~The~~As was known in the art, the '237 Patent describes three well-known types of calibrationcalibrations: (1) intrinsic

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calibration, which involves finding the “camera intrinsic parameters” describing “how the camera forms an image,” including the focal length of the camera, a radial distortion coefficient, coordinates of the center of radial lens distortion, and a scale factor, (2) extrinsic calibration, which involves finding the camera’s position and orientation (*i.e.*, “pose”) in the world coordinate frame by solving the transformation between the Camera Space—“a reference frame defined with respect to a point on, and therefore rigid to, the camera”—and the Training Space—a world coordinate “reference frame defined with respect to a point on the calibration template,” and (3) hand-eye calibration, which involves finding the position and orientation of the

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camera “relative to the tool of the robot.” EX1001, 3:36-38, 3:56-67, 4:1-10, 5:51-65, 7:19-25, 7:48-49, 8:11-14, 8:30-39, 9:25-32, 9:44-65.

38. The “first step” in calibration is to position the camera on the robot arm orthogonally to a calibration template “so the camera’s imaging plane is parallel to the template,” and “defining the ‘Training Space’ for the robot aligned with the template.” EX1001, 4:18-29. The calibration template is an object with a “series of fixed detectable features such as a grid of dots or squares.” EX1001, 4:22-25. Next, the camera is “moved to a plurality of stations,” the camera captures images at each station, and the camera intrinsic parameters (intrinsic calibration), the Camera Space-to-Training Space transformation (extrinsic calibration), and Camera Space-to-Tool Space transformation (hand-eye calibration) are determined. EX1001, 4:32-42; 4:57-5:11. The relevant coordinate spaces and frames are shown in Figure 2 of the ’237 Patent:

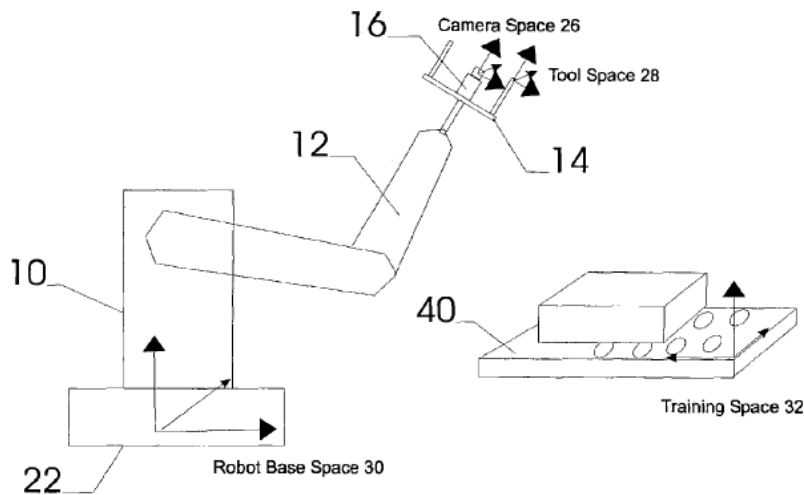
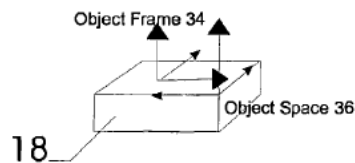


Fig. 2



39. The '237 Patent also describes a process for “teaching” the features of the object, involving placing an object that will be manipulated by the robot in the “Training Space,” taking 2D images of the object, extracting features from the images, and computing “[r]eal world coordinates” for the selected features relative to the “Training Space.” EX1001, 5:12-45, FIG. 6.

40. The '237 Patent discloses that the calibration and teaching steps “can be combined by using a self-calibration of robotic eye and hand-eye relationship with model identification as described in” Wei-I, which provides the “camera intrinsic parameters, hand-eye calibration and position of selected features in camera space.” EX1001, 8:30-39, 6:6-19. This method involves placing a part in front of the

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camera, selecting features from the part, “moving the robot to a set of stations” around the robot’s base, “memorizing the tool position relative to [the] base at each station,” acquiring an image of the part at each station, extracting features from each image, and calculating the position of those features “in a space that suits the application.” EX1001, 6:52-65. Using the method described in Wei-I, the 3D position of the selected features may be determined automatically, “without any prior knowledge about the part,” and the coordinates of those features in camera space “can be transposed in any other space that is related to it, such as training space.” EX1001, 6:6-13, 6:45-48.

41. The independent claims of the ’237 Patent recite a method (Claim 1) and apparatus (Claims 20 and 25) for single image 3D vision guided robotics. EX1001, 1:13-15. The claims recite, for example, a method for pose estimation “with a single camera mounted to a movable portion of a robot” comprising the steps of capturing a 2D image of a target object, locating features in said image, and determining an object space to camera space transformation for the target object based on a position of some of the captured features from a single image. EX1001, 11:54-67. The claims also recite determining intrinsic and extrinsic parameters of the camera from the images of the calibration object, positioning the camera orthogonally to a ruled calibration template, determining a camera space-to-tool space transformation, and training an operation path of the robot. EX1001, 12:1-13,

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12:17-21, 12:53-57, 13:18-21. The claims further recite an apparatus comprising a single camera capable of calibration and pose estimation as described in the method claims. EX1001, 13:51-14:65.

b. The Relevant Claims of the '237 Patent

42. The '237 Patent includes 28 claims, and claims 1, 20, and 25 are independent claims. See EX1001, 11:54-14:65. I have been asked to evaluate the patentability of claims 1–10 and 12–28 of the '237 Patent. Those claims are reproduced in full below.

43. Claim 1 recites:

1. A useful in three-dimensional pose estimation for use with a single camera mounted to a movable portion of a robot, the method comprising:

capturing a two-dimensional image of a volume containing a target object;

locating a number of features in the captured image of the target object; and

determining by a processor an object space-to-camera space transformation for the target object based at least in part on a position of at least some of the located features using only the single captured image and an algorithm that employs a known or determinable physical relationship between at least some of the located features.

EX1001, 11:54-67.

44. Claim 2 recites:

2. The method of claim 1, further comprising:

capturing a number of images of a calibration object by the camera;

determining a set of intrinsic parameters of the camera from at least one of the number of images of the calibration object captured by the camera; and

determining a set of extrinsic parameters of the camera from at least one of the number of images of the calibration object captured by the camera, the set of extrinsic parameters comprising a camera space-to-training space transformation defining a transformation between a camera space reference frame and a training space reference frame.

EX1001, 12:1-13.

45. Claim 3 recites:

3. The method of claim 2, further comprising:

positioning the camera with respect to the calibration object.

EX1001, 12:14-16.

46. Claim 4 recites:

4. The method of claim 3 wherein positioning the camera with respect to the calibration object comprises positioning the camera orthogonally with respect to a ruled template with a number of features, where a known or determinable physical relationship exists between at least some of the features.

EX1001, 12:17-21.

47. Claim 5 recites:

5. The method of claim 3 wherein positioning the camera with respect to the calibration object comprises positioning the camera with respect to a sample of a type of object the robot will manipulate, the sample having a number of features, where a known or determinable physical relationship exists between at least some of the features.

EX1001, 12:22-27.

48. Claim 6 recites:

6. The method of claim 3 wherein capturing a number of images of a calibration object by the camera comprises capturing at least one image at each of a plurality of positions spaced perpendicularly from the calibration object.

EX1001, 12:28-31.

49. Claim 7 recites:

7. The method of claim 3 wherein capturing a number of images of a calibration object by the camera comprises capturing at least one image at each of a plurality of different orientations with respect to the calibration object.

EX1001, 12:32-35.

50. Claim 8 recites:

8. The method of claim 2 wherein determining a set of intrinsic parameters of the camera from the at least one of the number of images of the calibration object captured by the camera comprises determining at least one of a focal length, a first order radial lens distortion coefficient, a set of coordinates of a center of a radial lens distortion, or a

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scale factor indicative of a framegrabber scanline
resampling uncertainty.

EX1001, 12:36-42.

51. Claim 9 recites:

9. The method of claim 2 wherein determining a set of
extrinsic parameters of the camera from at least one of the
number of images of the calibration object captured by the
camera, the set of extrinsic parameters comprising a
camera space-to-training space transformation defining a
transformation between a camera space reference frame
and a training space reference frame comprises
determining a respective translation component along
three orthogonal axes, and a respective rotation
component about the three orthogonal axes.

EX1001, 12:43-52.

52. Claim 10 recites:

10. The method of claim 2, further comprising:

determining a camera space-to-tool space transformation
based at least in part on at least two of the number of
images captured by the camera of the calibration object.

EX1001, 12:53-56.

53. Claim 12 recites:

12. The method of claim 1, further comprising:

capturing an image of a teaching object of a type of object
that will be manipulated by the robot;

selecting a number of features from the captured image of
the teaching object; and

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determining a set of object space coordinates for each of the selected features from the captured image of the teaching object.

EX1001, 12:63-13:3.

54. Claim 13 recites:

13. The method of claim 12 wherein selecting a number of features from the captured image of the teaching object comprises selecting six features from the captured image of the teaching object.

EX1001, 13:4-7.

55. Claim 14 recites:

14. The method of claim 12, further comprising:

determining an object space-to-camera space transformation defining a transformation between an object space reference frame and the camera space reference frame.

EX1001, 13:8-11.

56. Claim 15 recites:

15. The method of claim 14, further comprising:

determining a position and an orientation of an object frame in the tool frame reference frame based at least in part on the object frame-to-camera space and camera space-to-tool space transformations.

EX1001, 13:12-17.

57. Claim 16 recites:

16. The method of claim 15, further comprising:

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providing the position and orientation of the object frame to the robot; and

training an intended operation path inside the object frame.

EX1001, 13:18-21.

58. Claim 17 recites:

17. The method of claim 1, further comprising:

adjusting a position of the movable portion of the robot if the number of features located in the captured image of the target object is determined to be an insufficient number of features; and

capturing another two-dimensional image of the volume containing the target object before determining the object space-to-camera space transformation for the target object.

EX1001, 13:22-30.

59. Claim 18 recites:

18. The method of claim 1, further comprising:

determining at least one movement of the robot that orients the camera orthogonally with respect to the target object based at least in part on the object space-to-camera space transformation.

EX1001, 13:31-35.

60. Claim 19 recites:

19. The method of claim 18, further comprising:

determining a position of the object frame in the tool space reference frame; and

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providing an object frame to the robot.

EX1001, 13:36-40.

61. Claim 20 recites:

20. An apparatus useful in robotics, the apparatus comprising:

a single camera operable to capture a number of images of a calibration object;

means for calibrating the camera, by:

determining a set of intrinsic parameters of the camera from at least one of the number of images of the calibration object captured by the camera; and

determining a set of extrinsic parameters of the camera from at least one of the number of images of the calibration object captured by the camera, the set of extrinsic parameters comprising a camera space-to-training space transformation defining a transformation between a camera space reference frame and a training space reference frame; and

means for estimating a pose of a target object, by:

capturing a two-dimensional image of a volume containing a target object; and

locating at least six features in the captured image of the target object; and

determining an object space-to-camera space transformation based at least in part on a position of at least some of the located features in solely the captured image using an algorithm that employs a known or determinable physical relationship between at least some of the located features.

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EX1001, 13:41-67.

62. Claim 21 recites:

21. The apparatus of claim 20, further comprising:

means for training, comprising:

capturing an image of a teaching object of a type of object that will be manipulated by the robot;

selecting a number of features from the captured image of the teaching object;

determining a set of object space coordinates for each of the selected features from the captured image of the teaching object; and

determining an object space-to-camera space transformation defining a transformation between an object space reference frame and the camera space reference frame.

EX1001, 14:1-13.

63. Claim 22 recites:

22. The apparatus of claim 21 wherein the means for calibrating, the means for estimating a pose, and the means for training comprises at least one programmed computer.

EX1001, 14:14-16.

64. Claim 23 recites:

23. The apparatus of claim 21 wherein the means for calibrating, the means for estimating a pose, and the means for training comprises at least one computer-readable medium storing instructions operating at least one computer.

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EX1001, 14:17-20.

65. Claim 24 recites:

24. The apparatus of claim 20 wherein the pose estimating means estimates the pose of the target object further by:

adjusting a position of the movable portion of the robot if the number of features located in the captured image of the target object is determined to be an insufficient number of features.

EX1001, 14:21-26.

66. Claim 25 recites:

25. An apparatus useful in robotics, the apparatus comprising:

a single camera operable to capture a number of images of a calibration object;

means for calibrating the camera, by:

determining a set of intrinsic parameters of the camera from at least one of the number of images of the calibration object captured by the camera; and

determining a set of extrinsic parameters of the camera from at least one of the number of images of the calibration object captured by the camera, the set of extrinsic parameters comprising a camera space-to-training space transformation defining a transformation between a camera space reference frame and a training space reference frame; and

means for estimating a pose of a target object, by:

capturing a two-dimensional image of a volume containing a target object;

locating at least five features in the captured image of the target object; and

determining an object space-to-camera space transformation based at least in part on a position of at least some of the located features using the captured image without any additional captured images and an algorithm that employs a known or determinable physical relationship between at least some of the located features.

EX1001, 14:27-52.

67. Claim 26 recites:

26. The apparatus of claim 25 wherein the means for calibrating and the means for estimating a pose comprises at least one programmed computer.

EX1001, 14:53-55.

68. Claim 27 recites:

27. The apparatus of claim 25 wherein the means for calibrating and the means for estimating a pose comprises at least one computer-readable medium storing instructions operating at least one computer.

EX1001, 15:56-59.

69. Claim 28 recites:

28. The apparatus of claim 25 wherein the pose estimating means estimates the pose of the target object further by:

adjusting a position of the movable portion of the robot if the number of features located in the captured image of the target object is determined to be an insufficient number of features.

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EX1001, 14:60-65; EX1003, ¶¶24-41.

b.c. The Prosecution History of the '237 Patent

~~18.70.~~ The '237 Patent was filed as U.S. Patent Application No. 10/634,874 (“the '874 Application”) on August 6, 2003~~as~~. EX1001, cover. I understand that the face of the '237 Patent claims the benefit of an earlier priority date through a continuation-in-part of application, Application No. 10/153,680, which claims the benefit of a as well as through Canadian patent application filed on January 31, 2002. EX1001. The Patent Application No. 2,369,845 (“the '845 Application”). I understand that the earliest possible effective priority date for the '874 Application (and thus the '237 Patent) is January 31, 2002, which is the filing date of the '237 Patent claims is January 31, 2002 '845 Application.

~~19.71.~~ ~~I~~ I understand that in over eight years of prosecution, the Office rejected the claims in six different Office Actions. During prosecution, ~~Patentee canceled~~ I understand that the original claims were canceled and ~~presented~~ new claims 33-61. were presented. EX1002, pp.64-65. ~~These~~ I understand that these claims were rejected as being anticipated by Wei, et al., “Multisensory Visual Servoing by a Neural Network, IEEE (1999) (“Wei-II”).¹ ~~Patentee~~ I understand that the Patent Owner sought to distinguish Wei-II by arguing that: “Importantly...Wei[-II]-......is directed to the use of a stereo pair of cameras” but the claimed invention “is directed to methods and apparatus that employ[s] single camera three-dimensional (3-D) vision for robotic guidance.” EX1002, p.129. I further understand that the

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Patent Owner argued that: “It is the problems associated with stereo vision based

systems and other multi-camera systems which are addressed by

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the various single camera embodiments described in Applicants' specification and claims." EX1002, p.129. PatenteeI understand that the Patent Owner argued that Wei-II's techniques "are not directly applicable" to the claimed "single camera vision based methods and apparatus." EX1002, p.130. I understand that Wei-II also sought to "avoid calibration," and the independent claims of the '237 Patent recited calibration steps. EX1002, p.130. I understand that the Examiner determined that the claims were allowable on this basis. EX1002, p.193.

~~⁺Wei-I and Wei-II were coauthored by Wei fourteen months apart, but disclose completely different methods. Whereas Wei-I discloses a method for "Active Calibration of Robotic Eyes," Wei-II discloses a visual servoing method that "avoids all such calibrations." EX1005, p.1; EX1006, p.276.~~

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72. ~~“single camera vision based methods and apparatus.”~~Instead of allowing the application to issue, I understand that the Patent Owner filed a request for continued examination, submitted additional prior art, and further amended the claims. EX1002, pp.206-217. I understand that the Office rejected many claims based on U.S. Patent No. 7,024,280 to Parker. I understand that Patent Owner distinguished Parker because it, like Wei-II, disclosed a two-camera system while “Applicants’ claims are directed to methods and apparatus that employ single camera three-dimensional (3-D) vision for robotic guidance.” EX1002, p.588.

73. I understand that the Office withdrew the rejection over Parker, but applied Wei-II again in a §102(b) rejection. EX1002, p.611. I understand that Patent Owner again distinguished Wei-II on the basis that it disclosed “two stereo cameras” while the claims recited a “single camera” approach. EX1002, pp.635-643. Based on Patent Owner’s representation that the claims were limited to a “single camera”

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approach, I understand that the anticipation rejection based on Wei-II was withdrawn. EX1002, pp.787-802.

I understand that several other ~~EX1002, p.130. Wei-II also sought to “avoid calibration,” and the ’237 Patent’s independent claims recited calibration steps.~~

~~EX1002, p.130. On this basis, the Examiner allowed the claims. EX1002, p.193.~~

20.74. Several rejections followed, including obviousness rejections based on U.S. Patent No. 4,942,539 to McGee in view of Wei-II, and McGee in view of U.S. Patent Application Publication No. 2002/0159628 to Matusik. Id., pp.858-860. In response to the first of those rejections, I understand that Patent Owner again argued that Wei-II taught away from calibration. EX1002, pp.858-860819-820. In response to the last of those rejections, PatenteeI understand that the Patent Owner argued that for application claim 50, the prior art failed to show “determining an object space-to-camera space transformation for the target object based at least in part on a position of at least some of the located features using only the single captured image.” EX1002, p.945.

~~V. STATUTORY GROUNDS FOR CHALLENGES~~

~~Petitioner presents the following challenges:~~

No.	Claims	Ground	Statute
1	~~1-4, 6-10, 17-20, 24-28~~	~~Obviousness over Peter I. Corke, <i>Visual Control of Robots: High-Performance Visual Servoing</i> (Aug. 1996) (“Corke”) in view of the knowledge of a POSITA~~	~~§103(a)~~

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2	~~5, 12-16, 21-24~~	~~Obviousness over Corke in view of Guo-Qing Wei, et al., “Active Self-calibration of Robotic Eyes and Hand-eye Relationships with Model Identification,” TRANSACTIONS ON ROBOTICS AND ANIMATION, vol. 14, No. 1, Feb 1998 (“Wei I”) and the knowledge of a POSITA~~	~~§103(a)~~
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~~VI. THE CHALLENGES ARE BASED ON PRIOR ART PATENTS AND PRINTED PUBLICATIONS~~

~~Based on the references provided herein, Petitioner assumes, without admitting, that the claims of the '237 Patent are entitled to a filing date of January 31, 2002. Corke² was published in 1996 and was available to those working in the field no later than July 9, 1997 because, at least by this date, Corke was cataloged by subject matter in various databases including the OCLC bibliographic database and accessible to the public in the British Library and the Morgan Library at Colorado State University. EX1010, ¶¶40-45. Corke was distributed and accessible to the public based on (1) the print copy in the Morgan Library and Colorado State at least of July 9, 1997, (2) that it was cataloged by subject matter on or around that date, (3) and was widely held by libraries and was cataloged by subject matter on the OCLC bibliographic database. EX1010, ¶¶40-45. Regardless of which of these dates is the date of first publication, Corke is a prior art printed publication under §102(b). Corke is analogous to the '237 Patent because it is in the same field as the '237 Patent—vision guided robotics. EX1001, 1:13-15; EX1004, p.3 (discussing background of robotic vision).~~

²~~The version of Corke submitted with the Petition was obtained from the Morgan Library at Colorado State University. EX1010, ¶39.~~

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~~Wei I³ was included in the February 1998 edition of *Transactions on Robotics and Animation*. EX1005; EX1010, ¶¶46. Wei I is expressly referenced in the '237 Patent specification and is Applicant Admitted Prior Art. EX1001, 8:30-39, 6:6-7:2. Specifically, the '237 Patent states that its “algorithm is developed using the approach described in” Wei I. EX1001, 6:6-7:2. Wei I was distributed and accessible to the public based on (1) the date stamp on the cover page showing that it was received in the Linda Hall Library on or about February 18, 1998, (2) that it was cataloged by subject matter on or around that date, (3) and was widely held by libraries and was cataloged by subject matter on the OCLC bibliographic database. EX1010, ¶¶47-52. Wei I was thus publicly accessible on or shortly after February 18, 1998, making it prior art under at least §102(b). Wei I is analogous to the '237 Patent because it is in the same field as the '237 Patent—vision guided robotics. EX1001, 1:13-15; EX1005, p.1 (referring to “camera self-calibration” achieved in “robotics and computer vision.”).~~

~~VII. LEVEL OF ORDINARY SKILL IN THE ART~~

75. As I understand that the claims were then allowed with claim 50 becoming issued Claim 1, claim 53 becoming issued Claim 20, and claim 58 becoming issued Claim 25. EX1002, pp.953-959.

d. The Priority Date of the '237 Patent

76. I understand that the earliest-filed patent application to which the '237 Patent claims priority (Canadian Patent Application No. 2,369,845) was filed on

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~~January 31, 2002. I have therefore been asked for purposes of this declaration to~~

~~analyze obviousness as of January 31, 2002.~~

V. STATE OF THE ART PRIOR TO THE '237 PATENT

a. The Person of Ordinary Skill in the Art

The '237 Patent relates to methods for “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, 11:54-67. Based on this, it is my opinion that, as of January 31, 2002, 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

³~~The version of Wei I submitted with the Petition was obtained from the Linda Hall Library of Science, Engineering & Technology. EX1010, ¶46.~~

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21.77. of computer vision or three years of graduate level education, including a focus on computer vision applications. The POSITA would have knowledge about machine vision and camera calibration techniques. ~~EX1003, ¶¶ 77-78.~~

78. As detailed above, I qualify as a POSITA, and also qualified as a POSITA as of January 31, 2002. I have a sufficient level of knowledge, experience, and expertise to provide an expert opinion in the field of the '237 Patent.

b. Corke

79. Corke is a textbook published in 1996 about the “application of high-speed machine vision for closed-loop position control, or visual servoing, of a robot manipulator.” EX1004, p.ix. Corke explains that “visual servoing involves the use of one or more cameras and a computer vision system to control the position of

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the robot's end-effector relative to the workpiece as required by the task." EX1004,

p.1. As shown in Figure 5.4 reproduced below, Corke discloses a robot having a single camera to implement a method for 3D pose estimation:

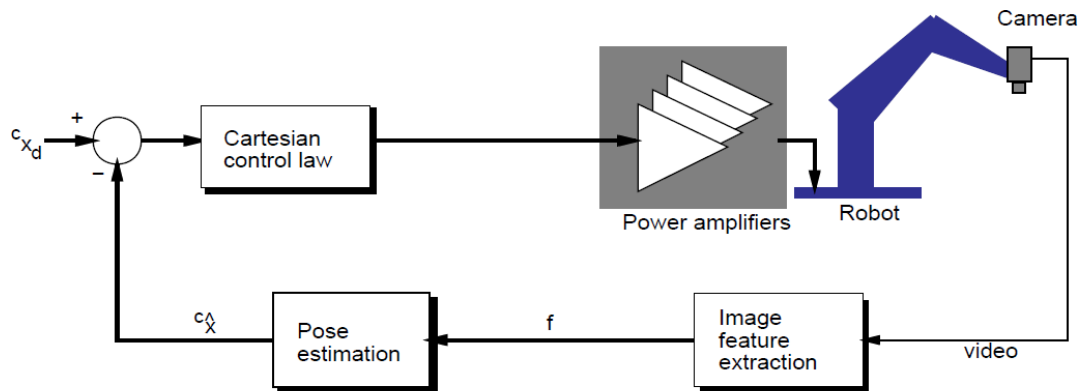


Figure 5.4: Position-based visual servo (PBVS) structure as per Weiss.

EX1004, Figure 5.4.

80. Corke explains that a key component of visual servoing systems is the use of vision sensing and a closed “feedback” loop through which the system (for each video frame) takes an image of the target object, extracts features from the object, determines the “relative pose between the camera and the target” using that single image and “knowledge of the geometric relationship between several feature points on the target,” and sends the pose estimation to the robot, causing the robot to adjust the position of the robot’s end-effector relative to the object. EX1004, pp.3, 152-55. As such, visual servoing uses “visual information” from a single image “to control the pose of the robot’s end-effector relative to a target object or a set of target features.” EX1004, pp.2-3. Corke contrasts visual servoing with “conventional”

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“look-then-move” systems having no “feedback loop” which “alternated between picture taking and moving.” EX1004, pp.2-3.

81. Corke discusses camera calibration techniques to determine “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 (extrinsic parameters).” EX1004, p.139. Corke also teaches techniques to determine “eye-hand calibration,” which is “the fixed transformation between the gripper and the camera coordinate system.” EX1004, p.147.

c. Wei-I

82. Wei-I discloses “a method for self-calibration of robotic hand cameras by means of active motion.” EX1005, p.1. The method involves “tracking a set of world points” on an object “during robot motion” to determine “the camera internal and external parameters” and “hand-eye calibration.” EX1005, pp.1-2. The method involves placing the part in front of the camera, choosing the features on the part to be used, moving the robot to a set of stations around the base, calculating the tool position relative to the base at each station, acquiring an image at each station, extracting the features from each image, and determining the 3D coordinates of each feature in a space that suits the application. EX1005, pp.8-13.

83. The object used to perform self-calibration in Wei-I, termed the “Orbital Replacement Unit (ORU),” was an “octagonal shape[d]” object used in a

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“1993 German Spacelab mission D2” during which it was “grasped in a predefined position by a space robot using telesensor programming.” EX1005, p.279. The ORU is shown in Figure 7 of Wei-I:

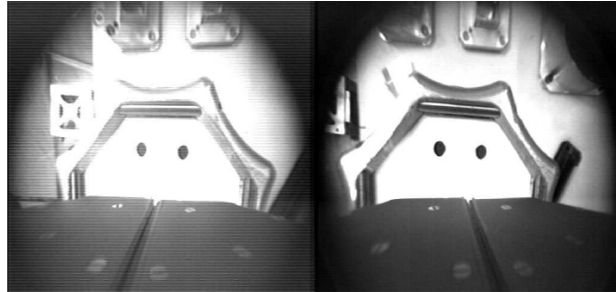


Figure 7: The images of the ORU from the hand cameras. The two black blobs are used as calibration points.

EX1005, p. 15.

4.VI. CLAIM CONSTRUCTION

84. I understand that in *inter partes* review, claims are “construed using the same claim construction standard that would be used to construe the claim in a civil action under 35 U.S.C. 282(b).” 37 C.F.R. § 42.100(b). I understand that claims must be given their ordinary and customary meaning as understood by a POSITA at the time of the invention in light of the specification and the prosecution history. *Id.*; *Phillips v. AWH Corp.*, 415 F.3d 1303, 1312-13 (Fed. Cir. 2015) (en banc); 83 Fed. Reg. 51340, Vol. 83, No. 197 (Oct. 11, 2018). I understand that terms not specifically construed have their plain and ordinary meaning as understood by a POSITA.

85. For purposes of this declaration, unless otherwise noted herein, I apply the ordinary and customary meaning of the claim language as it would have been

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understood by a POSITA as of January 31, 2002 based on the '237 Patent and the prosecution history.

22.86. I have been told that the terms in the Challenged Claims do not require construction to evaluate the prior art in this Petition. For this Petition only, I am told that Petitioner relies upon the definitions provided in column 3, lines 3-34 of the '237 Patent, including for “object space” as “a reference frame defined with respect to, and therefore rigid to, the object” and “training space” as “a reference frame defined with respect to a point on the calibration template, and aligned to its main axis.” EX1001, 3:3-34. I have been instructed to apply these definitions in my analysis.

23.87. Claims 20-28 recite a “means for calibrating the camera” and a “means for estimating a pose of a target object.” EX1001, ~~13:41-14:65. The~~ claims 20-28. I have been told that there is a presumption that these claims are in a form called “means-plus-function-claims,” but that the presumption can be overcome if the claims recite structural, rather than functional, language. *TecSec, Inc. v. Int’l Bus. Machs. Corp.*, 731 F.3d 1336, 1347 (Fed. Cir. 2013). ~~“[I]t is sufficient if the claim term is used in common parlance or by persons of skill in the pertinent art to designate structure.”~~ *Id.* The.” I understand that the Federal Circuit has established that the corresponding structure for a “computer-implemented means-plus-function” is “the algorithm.” *Harris Corp. v. Ericsson Inc.*, 417 F.3d 1241, 1253 (Fed. Cir. 2005).

88. It is my opinion that in the '237 Patent, the functional language provided in independent Claims 20 and 28 for the “means for calibrating the camera” is the calibration algorithm itself, as the claim itself recites “determining a set of intrinsic parameters” and “determining a set of extrinsic parameters” “from at least one of the images of the calibration object,” which results in performing the calibration algorithm recited in the specification. EX1001, ~~Fig. Figure 5; EX1003, ¶88. The~~

89. It is my opinion that the same is true with the ~~recited~~ “means for estimating the pose of a target object” recited in the claims because completing the claimed steps of “capturing a two-dimensional image of a volume containing a target object,” “locating” a number of “features in the captured image,” and “determining an object space-to-camera space transformation,” results in performing the pose estimation algorithm recited in the specification. ~~EX1003, ¶89; EX1001, Fig. 7. Therefore, Claims 20-28 are not means plus function claims and no construction is necessary. A~~EX1001, Figure 7.

~~24.90.~~ It is my opinion that a POSITA reading the specification of the '237 Patent would have understood that Claims 20-28 provide sufficient structure to perform the algorithm cited therein; ~~thus, these terms do not invoke 35 U.S.C. §112(6).~~ EX1003, ¶90.

~~H.VII. STATESUMMARY OF THE PRIOR ARTPOSITIONS~~

~~a. A. Corke~~

~~Corke is a textbook published in 1996 about the “application of high-speed~~

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~~machine vision for closed-loop position control, or visual servoing, of a robot manipulator.” EX1004, p.ix; EX1003, ¶¶ 79-81. Corke explains that “visual servoing involves the use of one or more cameras and a computer vision system to control the position of the robot’s end-effector relative to the workpiece as required by the task.”~~

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~~EX1004, p.1. In Figure 5.4, Corke discloses a robot having a single camera to implement a method for 3D pose estimation:~~

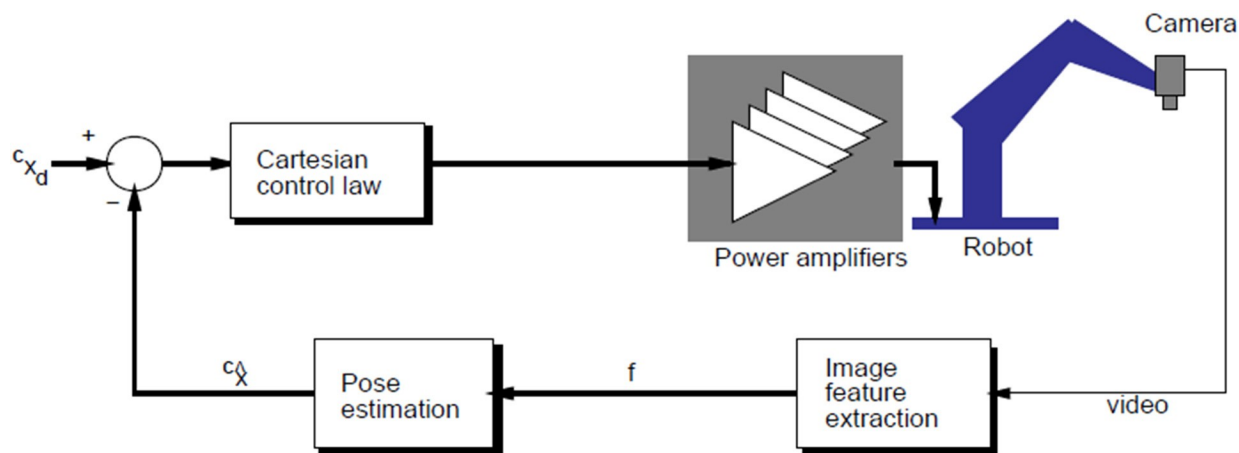


Figure 5.4: Position-based visual servo (PBVS) structure as per Weiss.

~~EX1004, Figure 5.4.~~

~~Corke explains that a key component of visual servoing systems is the use of vision sensing and a closed “feedback” loop through which the system (for each video frame) takes an image of the target object, extracts features from the object, determines the “relative pose between the camera and the target” using that single image and “knowledge of the geometric relationship between several feature points on the target,” and sends the pose estimation to the robot, causing the robot to adjust the position of the robot’s end effector relative to the object. EX1004, pp.3, 152-55.~~

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91. ~~It~~ is my opinion that Claims 1–10 and 12–28 of the '237 Patent are rendered obvious by Corke in view of the knowledge of a POSITA or obvious based on Corke in view of Wei-I in view of the knowledge of a POSITA. The claims merely recite an obvious variant of the systems and techniques taught by these

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references, and I believe that a POSITA, having knowledge of both Corke and Wei-I, would have been motivated to combine their disclosures to create the claimed elements. The reasons for my opinions are provided in the following section.

VIII. CLAIMS 1–10 and 12–28 ARE INVALID

a. GROUND 1: CLAIMS 1-4, 6-10, 17-20, AND 24-28 ARE UNPATENTABLE AS OBVIOUS OVER CORKE IN VIEW OF THE KNOWLEDGE OF A POSITA

92. It is my opinion 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.

1. Claim 1

[1.0] A useful in three-dimensional pose estimation for use with a single camera mounted to a movable portion of a robot, the method comprising:

93. To the extent the Board construes the preamble as limiting, Corke discloses the preamble. EX1003, ¶¶93-96. A preamble is limiting if it gives “life, meaning, and vitality” to a claim. *Bristol Myers Squibb Co. v. Ben Venue Labs, Inc.*, 246 F.3d 1368, 1373 (Fed. Cir. 2001). Here, the recitation in the preamble of “a single camera mounted to a moveable portion of a robot” is limiting in view of Patentee’s reliance upon this limitation for allowance. As detailed above, Patentee distinguished the claims over the prior art as “directed to methods and apparatus that employ *single-camera* three-dimensional (3-D) vision for robotic guidance.” EX1002, p.129. I understand that Element [1.0] is referred to as the “preamble” of the claim. I also understand that certain rules apply for determining whether a preamble is limiting or not. For Claim 1, I have not been instructed to apply those rules and instead have been asked to assume that these aspects of Claim

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I are requirements of the claim for the purposes of my obviousness analysis.

94. It is my opinion that Corke in view of the knowledge of a POSITA renders obvious Element [1.0].

~~25.95. As to the method recited in the preamble of Claim 1,~~ Corke discloses methods for 3D pose estimation for which “[t]he camera may be fixed, or *mounted on the robot’s end-effector* in which case there exists a constant relationship, ${}^{t_6}x_c$, between the pose of the camera and the pose of the end-effector.” EX1004, pp.152-207 (disclosing a “single camera” mounted on robot wrist). It is therefore my opinion that Corke’s techniques designed to estimate the “3D position and orientation”—i.e., “pose”—of an object are useful in

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~~in~~ three-dimensional pose estimation.⁴ EX1004, p.3 n.2; ~~EX1003, ¶95.~~ Placing the camera on the

robot's arm—corresponding to the claimed moveable portion of a robot—provides certain advantages, including “the ability to avoid occlusion, resolve ambiguity and increase accuracy, by directing its attention.” EX1004, pp.3, 166. In my opinion, Figures 4.11, 5.1, 6.10 and 6.11 of Corke all illustrate “a single camera mounted to a moveable part of the robot”:

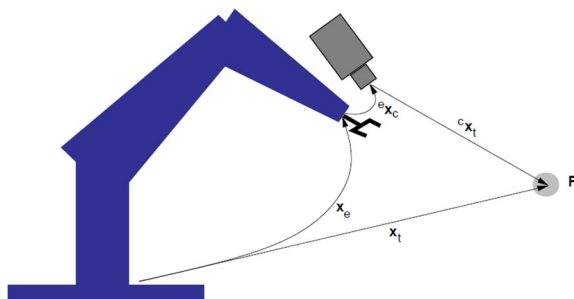


Figure 5.1: Relevant coordinate frames; world, end-effector, camera and target.

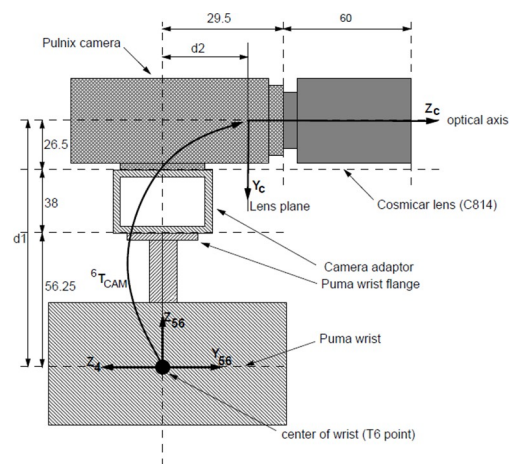


Figure 4.11: Details of camera mounting (not to scale, dimensions in mm). Robot wrist is in the zero angle pose.

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⁴~~Underlined text denotes language from the claims, unless otherwise noted.~~

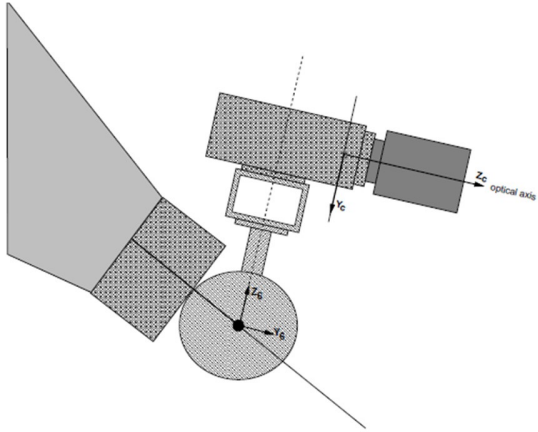


Figure 6.10: Camera mount used in this work. In this pose $\theta_6 \approx -\pi/2$.

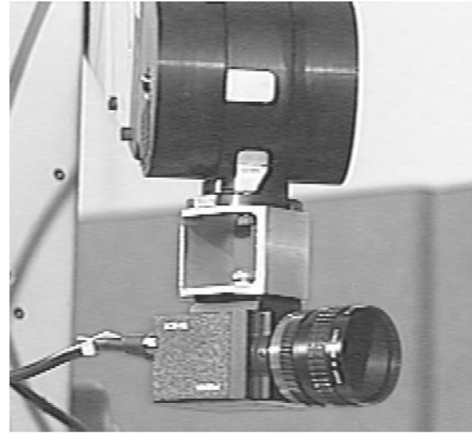


Figure 6.11: Photograph of camera mounting arrangement.

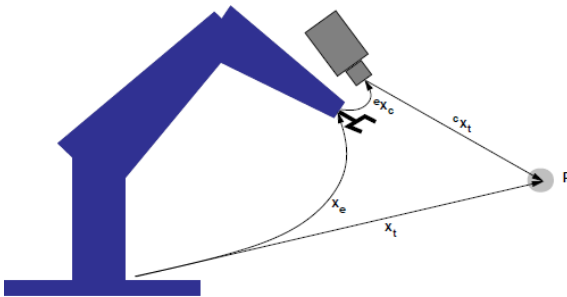


Figure 5.1: Relevant coordinate frames; world, end-effector, camera and target.

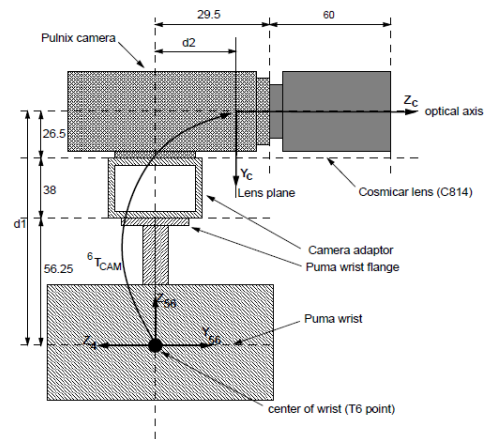


Figure 4.11: Details of camera mounting (not to scale, dimensions in mm). Robot wrist is in the zero angle pose.

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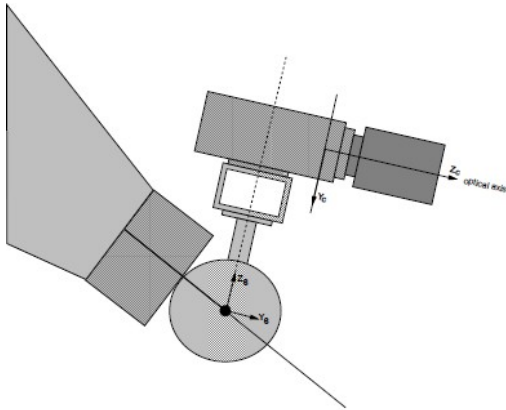


Figure 6.10: Camera mount used in this work. In this pose $\theta_c \approx -\pi/2$.

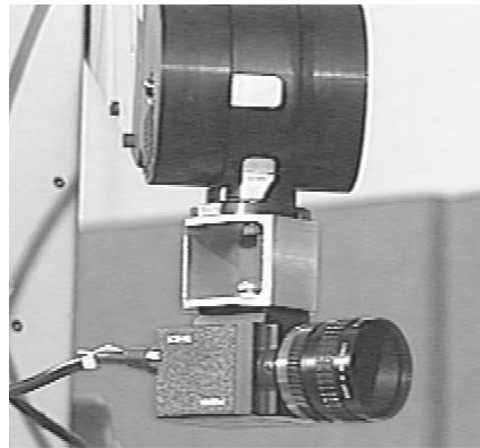


Figure 6.11: Photograph of camera mounting arrangement.

EX1004, pp.148, 152, 186-87; EX1003, ¶¶95, 187.

26-96. It is my opinion that Corke in view of the knowledge of a POSITA discloses or renders obvious Preamble Element [1.0]. EX1003, ¶¶93-96.

[1.1] capturing a two-dimensional image of a volume containing a target object;

97. In my opinion, Corke in view of the knowledge of a POSITA renders obvious Element [1.1].

27-98. It is my opinion that Corke teaches a method that “captur[es] a two-dimensional image of a volume containing a target object. EX1003, ¶¶97-101.” Corke discloses that

“[t]he camera contains a lens which *forms a 2D projection of the scene on the image plane* where the sensor is located.” EX1004, pp. 152, 159 (“A broad definition of position-based servoing...includes methods based on *analysis of 2D features*”), 159 (disclosing a method to “determine the 3D relative pose of an object...from 2D image plane coordinates”); EX1003, ¶98.”).

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As shown in Figure 5.4, Corke discloses a system that uses a video camera to capture and process multiple ~~two-dimensional~~^{2D} images of a target object, one image at a time at the “camera frame rate,” which is “effectively the sample rate in a visual

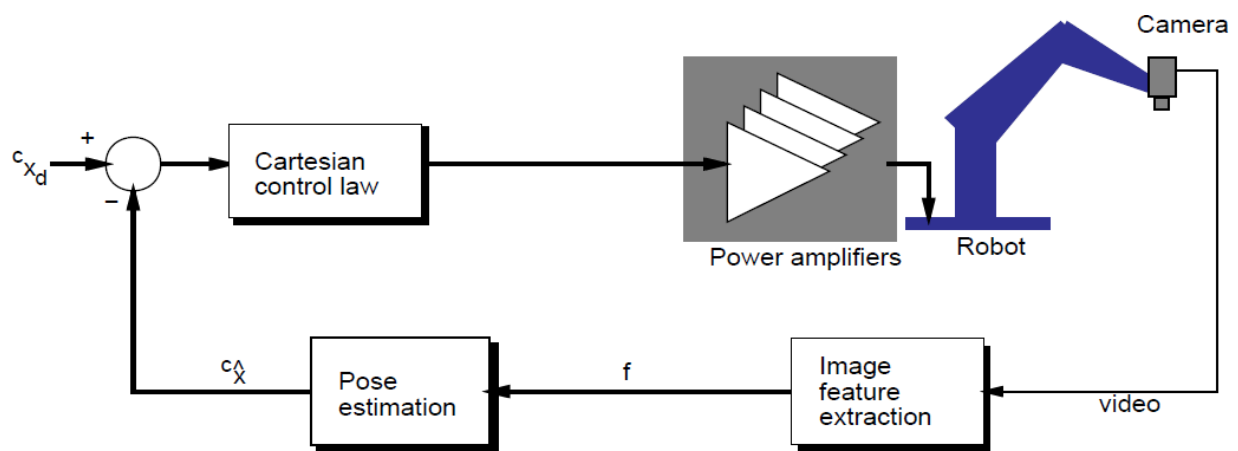


Figure 5.4: Position-based visual servo (PBVS) structure as per Weiss.

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28-99. servoing system.” EX1004, ~~pp.~~ 103, 73 (“the camera’s shutter acts as the sampler in a visual control loop”~~); §~~).¹

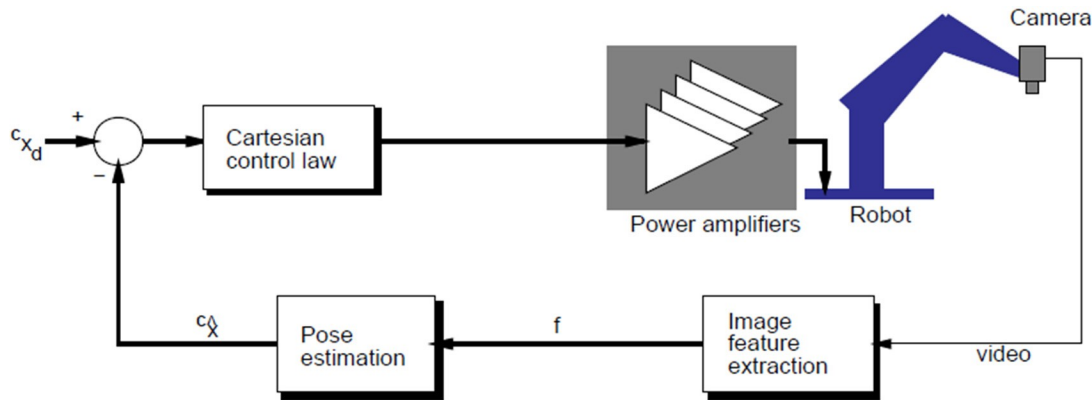


Figure 5.4: Position-based visual servo (PBVS) structure as per Weiss.

EX1004, p.155; ~~EX1003, ¶~~99.

29-100. The claim requires that the target object reside in a volume, which

Corke teaches is the space from which the image of the target object is captured.

EX1004, pp.152-153 (referring to “an image of the target” as “the object of interest, that is, the object that will be tracked,” so that “features” can be “extracted from the ~~image~~”); ~~EX1003, ¶100. In *KSR Int’l Co. v. Teleflex, Inc.*, the Supreme Court held the obviousness analysis should consider the “background knowledge possessed by a person having ordinary skill in the art.” 550 U.S. 398 (2007).⁶ A POSITA would~~

§

¹ The portions of Corke cited herein are from a single embodiment ~~referenced in both Chapter 3 (“as the “Fundamentals of image capture”)~~ discussed in Chapter 3

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and ~~Chapter 4 (“the “Machine vision” concepts), and~~ in Chapter 4 are used as a baseline for the position-based visual servoing methods discussed in Chapter 5. EX1004.

~~⁶In *Koninklijke Philips N.V. v. Google LLC*, the Federal Circuit determined that “under 35 U.S.C. § 103, the obviousness inquiry turns not only on the prior art, but~~

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image”). In my opinion, a POSITA would have understood that all 3D objects

occupy a volume. ~~EX1003, ¶100.~~ Corke discloses that “[t]he camera contains a lens which forms a

2D projection of the scene on the image plane,” and “each point on the image plane corresponds to a ray *in 3D space*.” EX1004, ~~ppp.~~152. Accordingly, it is my

opinion that Corke’s teaching ~~of that~~ capturing a ~~two-dimensional~~2D image of a target object by a single camera would have included capturing a two-dimensional image of a volume containing a target object. ~~EX1003,~~

~~¶100.~~target object.

~~30.~~101. Accordingly, in my opinion, Corke in view of the knowledge of a POSITA renders obvious Element [1.1]. ~~EX1003, ¶¶97-101.~~

[1.2] locating a number of features in the captured image of the target object;

102. In my opinion, Corke in view of the knowledge of a POSITA renders obvious Element [1.2].

~~31.~~103. It is my opinion that Corke discloses locating a number of features in

the captured image of the target object. EX1004, pp.136, 168; ~~EX1003, ¶¶102-107.~~ For example, Corke

discloses a method of “*locating features*” in each captured image where “[d]etermining the initial *location of features* requires *the entire image* to be searched.” EX1004, ~~ppp.~~136, 168; ~~EX1003, ¶103.~~ Corke further discloses that “[a] good *feature* is one that can be *located* unambiguously” such as “a hole in a gasket

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[] or a contrived pattern.” EX1004, ~~ppp~~.153; ~~EX1003~~, ¶103.

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~~whether the differences between the claimed invention and the prior art are such that the claimed invention as a whole would have been obvious . . . to a person having ordinary skill in the art to which the claimed invention pertains.” 948 F.3d 1330, 1337 (Fed. Cir. 2020) (affirming PTAB’s determination of unpatentability based upon cited prior reference in view of knowledge of POSITA).~~

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32.104. Corke also discloses that in “*position-based control, features are extracted from the image*” of a target object to “determine the pose of the target with respect to the camera.” EX1004, ~~ppp~~.152-53 (“The task in visual servoing is to control the pose of the robot’s end-effector, ${}^xT_6$, using visual information, features, extracted from the image”). EX1003, ¶104. ~~Figure 5.4 shows the.~~). This “Image feature extraction” step disclosed in Corke is shown in Figure 5.4:

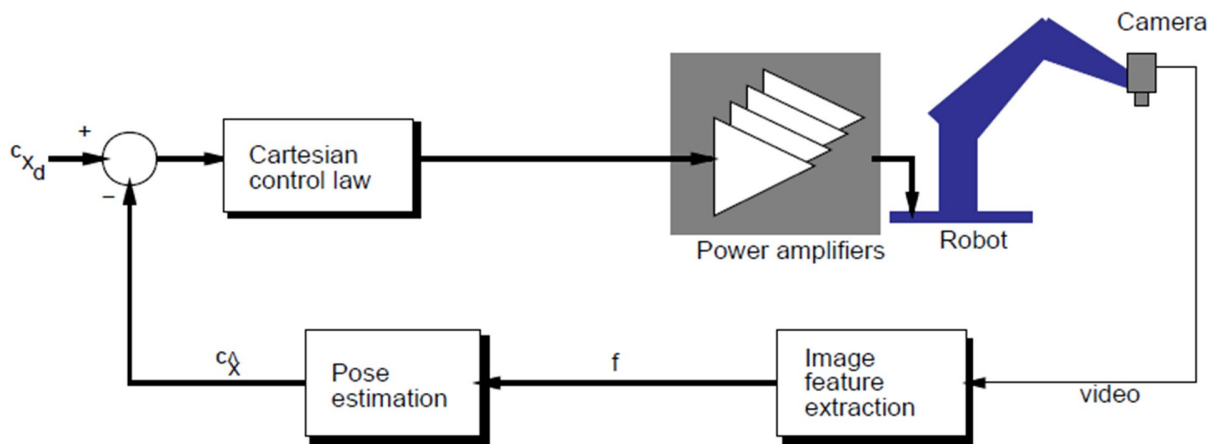


Figure 5.4: Position-based visual servo (PBVS) structure as per Weiss.
Figure 5.4: Position-based visual servo (PBVS) structure as per Weiss.

EX1004, p.155. ~~A~~

33.105. In my opinion, a POSITA would have understood that Corke teaches that features are located and processed one image at a time in view of Corke’s express disclosure that “features are extracted from *the image*.” EX1004, ~~ppp~~.153; 152 (“*features*” are “extracted from *the image*”); ~~Figure~~Fig. 5.4 (showing “*Image* feature extraction”). EX1003, ¶105. As an example of this single-image processing, Corke teaches the use of the Datacube DIGIMAX for acquiring an

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individual image from the camera and

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processing this individual image to locate features, stating “[t]he incoming analog video signal is digitized to form a **512x512 pixel digital image**,” after which various features are detected, such as “moments up to second order, perimeter and bounding box.” EX1004, p.180; ~~EX1003, ¶105.~~

34.106. Corke also ~~discloses~~explains that when machine vision is used for “part inspection and quality control,” the process involves the “extraction” of “features from the image[.]” EX1004, p.123. ~~By disclosing~~When Corke says that “features are extracted,” it is my opinion that Corke ~~teaches~~is conveying to the POSITA that a number of features are located in the captured image of the target object. ~~object. EX1003, ¶106.~~

35.107. Accordingly, in my opinion, Corke in view of the knowledge of a POSITA renders obvious Element [1.2].

~~EX1003, ¶¶102-107.~~

[1.3] determining by a processor an object space-to-camera space transformation for the target object based at least in part on a position of at least some of the located features using only the single captured image and an algorithm that employs a known or determinable physical relationship between at least some of the located features.

108. In my opinion, Corke in view of the knowledge of a POSITA renders obvious Element [1.3].

36.109. It is my opinion that Corke discloses determining by a processor

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an object space-to-camera space transformation for the target object by utilizing ~~the~~
~~position of the~~ features from a single image. ~~EX1003, ¶¶108-116.~~ The '237 Patent provides
that “object space” is ~~a~~the 3D coordinate frame that is “defined with respect to a
point on, and therefore rigid to,

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the object,” “camera space” is a coordinate frame rigid to the camera, and a “transformation” is the “three-dimensional rotation & translation between two spaces” or coordinate frames. EX1001, 3:1-34.

37.110. Corke discloses that in “*position-based* control, features are extracted from *the image*” of the target object “and used in conjunction with a geometric model of the target to determine the pose of the target with respect to the camera.” EX1004 p.153. In my opinion, a POSITA would have understood that determining the target’s pose with respect to the camera is ~~equivalent to the claimed step of the same thing as~~ determining the object

object space-to-camera space transformation. ~~EX1003, ¶110.~~ This object space-to-camera space

transformation is depicted in Figure 5.1 of Corke, where P designates the target object and ${}^c x_t$ denotes “the relative pose between the camera and the target,” *i.e.*, the transformation between the camera and the target object—the “object of interest”:

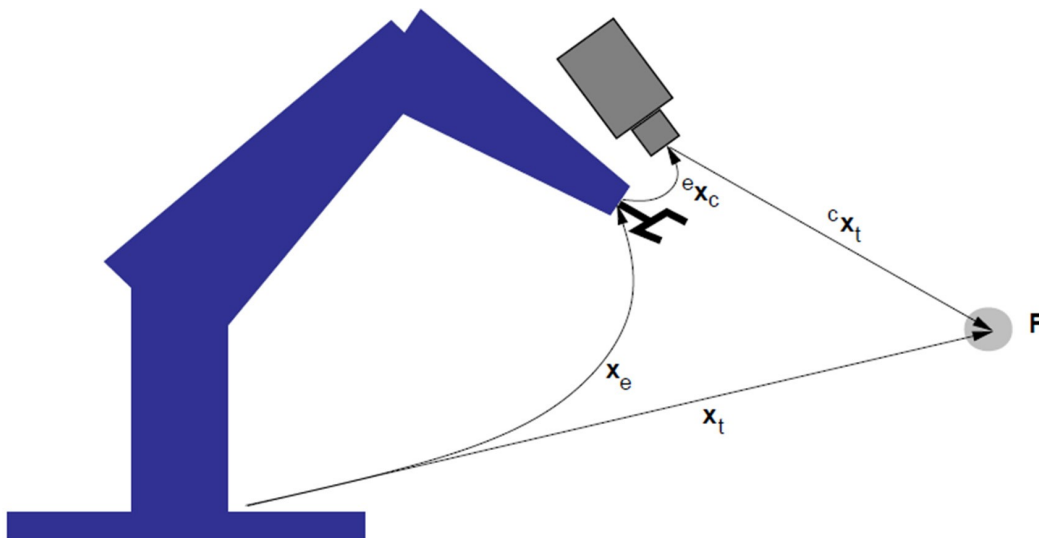


Figure 5.1: Relevant coordinate frames; world, end-effector, camera and target.

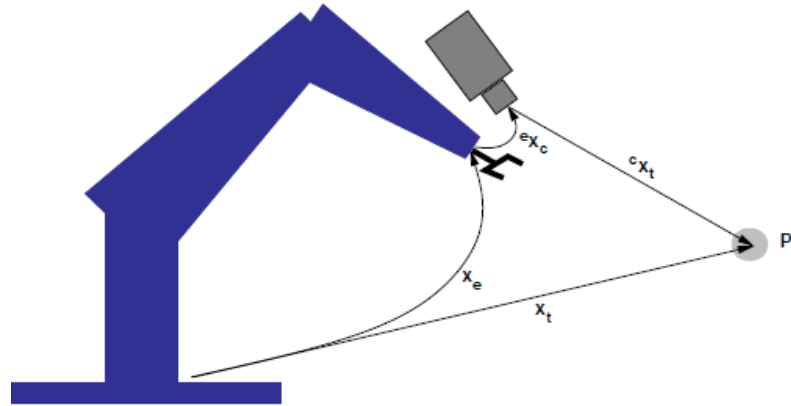


Figure 5.1: Relevant coordinate frames; world, end-effector, camera and target.

EX1004 pp.152, 138; ~~EX1003, ¶110.~~

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~~38.111.~~ In my opinion, a POSITA would have understood that Corke's references to "the image" teaches that only features from a single captured image are used to determine the object space-to-camera space transformation. EX1004, pp.152 ("The task in visual servoing is to control the pose of the robot's end-effector, ${}^*T_6^x t_6$, using visual information, features, extracted from the image."); 153 ("The image plane coordinates of three or more visual features can be used to determine the pose...of the target relative to the camera, given knowledge of the geometric relationship between the feature points."); ~~EX1003, ¶111.~~). As an example of this single-image processing, Corke teaches the use of the Datacube DIGIMAX for acquiring an individual image from the camera and processing this individual image to locate features, stating "[t]he incoming analog video signal is digitized to form a *512x512 pixel digital image*," after which various features are detected, such as "moments up to second order, perimeter and bounding box," EX1004, p.180. ~~EX1003, ¶111.~~

~~39.112.~~ It is my opinion that Corke teaches an algorithm that uses the position of the features from a single image in order to determine the object space-to-camera space transformation for the target object based at least in part on a position of at
least some of the located features.

~~EX1004, p.138; EX1003, ¶112.~~ Corke teaches in equation 4.60 (EX1004, p.138) that camera calibration matrix, C, "represents the relationship between 3-D world

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coordinates and their corresponding 2-D image coordinates as seen by the

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computer,” with i_x , i_y

$$\begin{bmatrix} i_x \\ i_y \\ i_z \end{bmatrix} = \mathbf{C} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \quad (4.60)$$

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and i_z encoding the position of a feature in the image plane, and x , y , and z encoding the position of the same feature in 3D “world coordinates”:

$$\begin{bmatrix} i_x \\ i_y \\ i_z \end{bmatrix} = \mathbf{C} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \quad (4.60)$$

and with the matrix $\mathbf{C}$ defined in equation 4.61:

$$\mathbf{C} = \begin{bmatrix} \frac{\alpha_x n_x f - X_0 n_z}{f - c_z} & \frac{\alpha_x o_x f - X_0 o_z}{f - c_z} & \frac{\alpha_x a_x f - X_0 a_z}{f - c_z} & \frac{\alpha_x c_x f - X_0 c_z + X_0 f}{f - c_z} \\ \frac{\alpha_y n_y f - Y_0 n_z}{f - c_z} & \frac{\alpha_y o_y f - Y_0 o_z}{f - c_z} & \frac{\alpha_y a_y f - Y_0 a_z}{f - c_z} & \frac{\alpha_y c_y f - Y_0 c_z + Y_0 f}{f - c_z} \\ -\frac{n_z}{f - c_z} & -\frac{o_z}{f - c_z} & -\frac{a_z}{f - c_z} & 1 \end{bmatrix} \quad (4.61)$$

EX1004, p.138. Corke teaches methods for determining the matrix $\mathbf{C}$ using the position of multiple features in a single image. EX1004, pp.139-142; ~~EX1003, ¶112.~~ Corke teaches that “[t]he calibration matrix, $\mathbf{C}$, encodes the 6 extrinsic parameters,” noting in a footnote that these extrinsic parameters are the “3D position vector and 3 angles for camera pose.” EX1004, p.144. Corke teaches an algorithm to recover these parameters from the matrix $\mathbf{C}$ by decomposing the camera calibration matrix. EX1004, pp.143-144; ~~EX1003, ¶112. A. In my opinion, a~~ POSITA would have ~~understood~~known that if the ~~3D~~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. ~~EX1003, ¶112.~~

113. Using Corke’s equation 4.60, it is my opinion that a POSITA would

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have understood that by multiplying the camera calibration $\mathbf{C}$ by the 3D position of

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any feature in 3D space, the corresponding position for that feature in the 2D image frame (i_x , i_y , i_z) is obtained, and those coordinates can be converted to ~~two-dimensional~~2D camera frame pixel coordinates— i_X , i_Y —by Corke’s equations

$$i_X = \frac{i_x}{i_z} \quad (4.56)$$

$$i_Y = \frac{i_y}{i_z} \quad (4.57)$$

4.56 and 4.57:

$$i_X = \frac{i_x}{i_z} \quad (4.56)$$

$$i_Y = \frac{i_y}{i_z} \quad (4.57)$$

EX1004, pp.138, xi; ~~EX1003, ¶113.~~ Furthermore, Corke discloses that this algorithm ~~work~~will work with features extracted ~~from a~~using only the single captured image. EX1004, p.138; ~~EX1003, ¶113.~~

~~40.114.~~ The ~~In my opinion, the~~ algorithm disclosed in Corke also employs a known

physical relationship between some ~~of the~~ located features using stored knowledge of

model feature points in 3D space. EX1004, p.159; ~~EX1003, ¶114.~~ For instance,

Corke explains that to “determine the 3D relative pose of an object ...from 2D image coordinates,” some “additional information is needed.” EX1004, p.159.

This additional information includes “*knowledge of the relationship between the observed feature points* (perhaps from a CAD model) and also the camera’s intrinsic parameters.” EX1004, ~~ppp~~.159; 153 (“three or more visual features can be

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used to determine the pose...*given knowledge of the geometric relationship between the feature points*"). Corke also explains that the object space-to-camera space transformation is determined by an algorithm using "features extracted from the image" "*in conjunction with a geometric model of the target,*" and that "each feature point yields two equations and six equations are needed to solve the six elements of the pose vector." EX1004,

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pp.153, 159-60; ~~EX1003, ¶114.~~ A. Accordingly, in my opinion, a POSITA would have understood that Corke teaches an algorithm using the position of “features extracted from the image” (claimed only the single captured image) and “a geometric model of the target” ~~(~~

(claimed known physical relationship) ~~processed by a “computer” (processor)~~ to determine the “3D relative pose of an

object” ~~((claimed object space-to-camera space transformation for the target object).~~

~~EX1004, pp.~~ EX1004, pp. 153, 159-~~160~~ 60; see also EX1004, p.153 (“features are extracted from the image and used in conjunction with a geometric model of the target to determine the pose of the target with respect to the camera”); ~~EX1003, ¶114.’).~~

41.115. Corke also discloses that the object space-to-camera space algorithm can be performed “by a computer,” which a POSITA would have understood ~~includes~~ to include the claimed processor. EX1004, p.138; ~~EX1003, ¶115.~~
~~Corke in view of the knowledge.~~

42.116. Accordingly, in my opinion, Corke in view of the knowledge of a POSITA renders obvious Element [1.3]. ~~EX1003, ¶¶108-116.~~

2. **Claim 2**

[2.0] The method of claim 1, further comprising: [2.1] capturing a number of images of a calibration object by the camera;

43.117. In my opinion, Corke in view of the knowledge of a POSITA

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renders obvious Elements [2.0] and [2.1].

Corke discloses a camera capturing a number of images of a calibration object.

44.118. ~~EX1003, ¶¶117-119.~~ In Corke's own experiments, "[f]our images of the SHAPE calibration target,

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shown in Figure 4.8 ~~below~~, were taken from different viewpoints.” EX1004, p.145.
Figure; ~~EX1003, ¶118.~~

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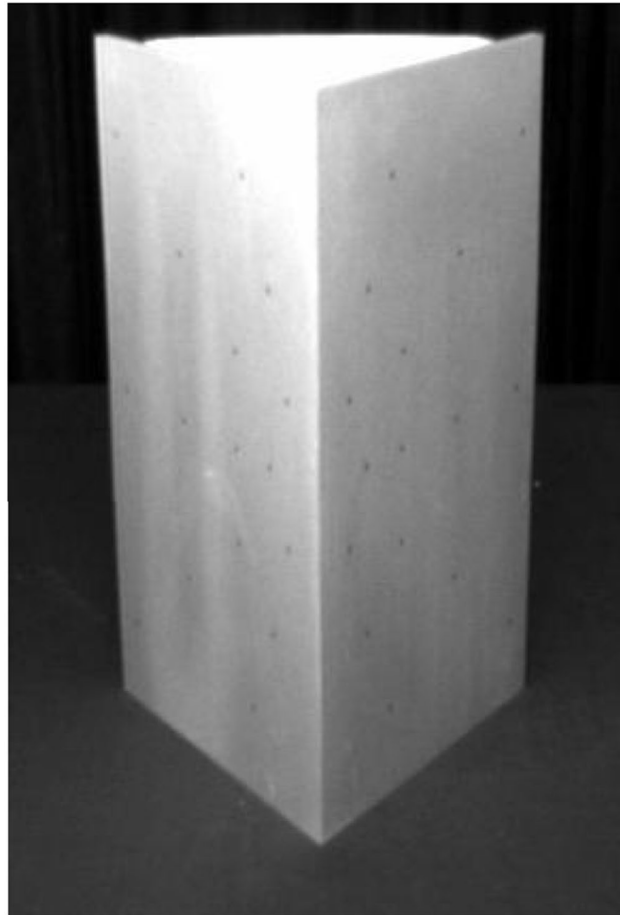


Figure 4.8: The SHAPE calibration target used for intrinsic parameter determination. The surface is brushed aluminium with black marker dots at accurately known locations on the two surfaces.

4.8 of Corke is reproduced below:

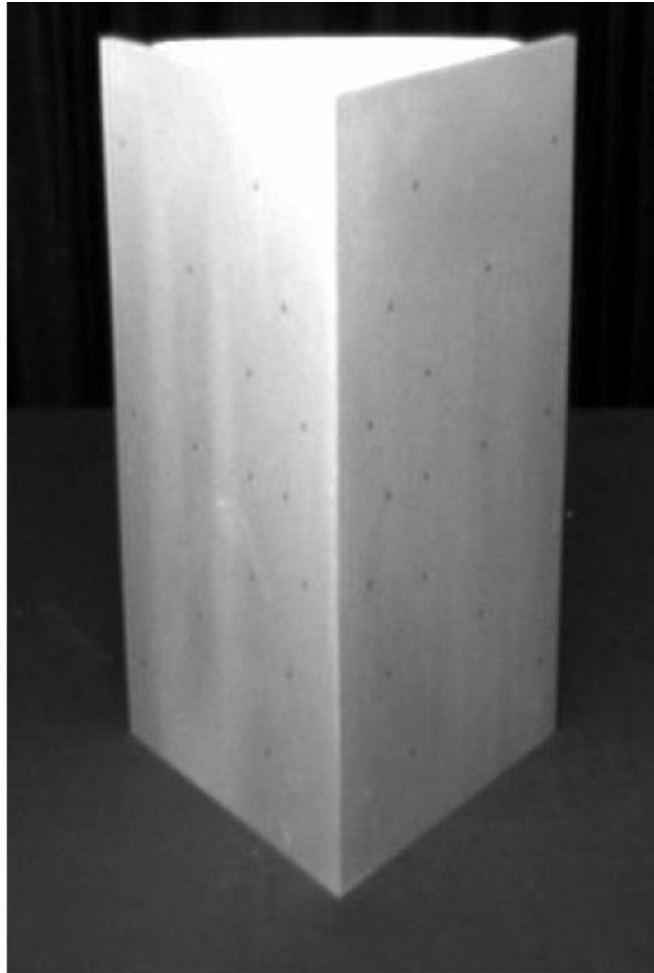


Figure 4.8: The SHAPE calibration target used for intrinsic parameter determination. The surface is brushed aluminium with black marker dots at accurately known locations on the two surfaces.

EX1004, p.140.

45:119. Accordingly, in my opinion, Corke in view of the knowledge of a POSITA renders obvious Elements [2.0] and [2.1]. ~~EX1003, ¶¶117-119.~~

[2.2] determining a set of intrinsic parameters of the camera from at least one of the number of images of the calibration object captured by the camera; and

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120. In my opinion, Corke in view of the knowledge of a POSITA renders obvious Element [2.2].

Corke discloses determining a set of intrinsic parameters of the camera from images of the calibration object by the camera. EX1004, ~~ppp.143-44; EX1003,~~

~~¶¶120-123.~~ Corke discloses that four images taken by the camera of the SHAPE

Trial	Residual (pixel)	δ (deg)	X_0 (pixel)	Y_0 (pixel)	$\alpha_x f$ (pixel)	$\alpha_y f$ (pixel)	α_y / α_x
1	0.552	-0.0277	270.1	213.7	625.7	948.9	1.52
2	0.898	0.0672	271.4	223.1	614.0	933.0	1.52
3	0.605	0.0685	278.0	205.6	617.3	938.2	1.52
4	0.639	-0.1198	275.8	196.8	616.8	939.2	1.52
mean			273.8	209.8	615.5	939.8	
σ			3.2	9.7	5.0	6.6	

Table 4.2: Summary of calibration experiment results.

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46.121. calibration target were used to compute the “calibration matrix”—~~a mathematical object~~an algorithm that determines the “intrinsic parameters of the camera.” EX1004, p.143-144 (the “calibration matrix” encodes the “5 intrinsic parameters: f , α_x , α_y , X_0 and Y_0 ”). ~~EX1003, ¶121.~~As shown in Table 4.2 ~~of reproduced below,~~ Corke discloses using the features extracted from those four

Trial	Residual (pixel)	δ (deg)	X_0 (pixel)	Y_0 (pixel)	$\alpha_x f$ (pixel)	$\alpha_y f$ (pixel)	α_y/α_x
1	0.552	-0.0277	270.1	213.7	625.7	948.9	1.52
2	0.898	0.0672	271.4	223.1	614.0	933.0	1.52
3	0.605	0.0685	278.0	205.6	617.3	938.2	1.52
4	0.639	-0.1198	275.8	196.8	616.8	939.2	1.52
mean			273.8	209.8	615.5	939.8	
σ			3.2	9.7	5.0	6.6	

Table 4.2: Summary of calibration experiment results.

images to calculate the calibration matrix, including 5 intrinsic parameters:

EX1004, pp.146, 138-139.

47.122. Corke also defines camera calibration generally as “the process of determining the internal camera geometric and optical characteristics (intrinsic parameters).” ~~EX1004, p.139; EX1003, ¶122. Corke in view of the knowledge of a POSITA renders obvious Element [2.2]. EX1003, ¶¶120-123~~EX1004, p.139.

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123. Accordingly, in my opinion, Corke in view of the knowledge of a

POSITA renders obvious Element [2.2].

[2.3] determining a set of extrinsic parameters of the camera from at least one of the number of images of the calibration object captured by the camera, the set of extrinsic parameters comprising a camera space-to-training space transformation defining a transformation between a camera space reference frame and a training space reference frame.

124. In my opinion, Corke in view of the knowledge of a POSITA renders obvious Element [2.3].

48-125. For example, in my opinion, Corke discloses determining a set of

extrinsic parameters of the camera from at least one of the images of the calibration

object captured by the camera. EX1004, p.146; ~~EX1003, ¶¶124-127.~~ Corke explains that four images of

the SHAPE calibration target were used to compute the “calibration matrix”—a mathematical object that “contains information about the position of the camera with respect to the world coordinate frame”—i.e., the extrinsic parameters. EX1004, ~~ppp.143-144~~44 (the “calibration matrix” “encodes the 6 extrinsic parameters”—i.e., the “3D position vector and 3 angles for camera pose”). Corke also defines camera calibration generally as “the process of determining the...orientation of the camera frame relative to the world coordinate system (extrinsic parameters).” EX1004,

p.139 (“the camera calibration matrix...relates a world coordinate system to the image plane coordinates for a given camera position and orientation”); ~~EX1003,~~

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¶125.”).

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49.126. In my opinion, Corke further teaches that the extrinsic parameters include a transformation between a camera space reference frame and a training space reference frame.

~~EX1003, ¶126.~~ Specifically, Corke teaches that “*extrinsic* parameters” relate to “the position and orientation of the camera.” EX1004, p.138. One of those “extrinsic” parameters is ${}^C T_P$ —“*i.e.*, “the position of the [calibration] object with respect to the camera.” EX1004, p.127. ~~A~~In my opinion, a POSITA would have understood this was the “transformation”— T —between the coordinate frame defined by the camera— C —and the coordinate frame defined by the calibration object— P . EX1004, p.xi; ~~EX1003, ¶126.~~ Because a “training space” is a “reference frame defined with respect to a point on the calibration” object, it is my opinion that a POSITA would further have understood that Corke discloses determining a set of extrinsic

parameters of the camera from at least one of the number of images of the calibration object captured by the camera, the set of extrinsic parameters comprising a camera space-to-training space transformation. EX1001, 3:22-24; ~~EX1003, ¶126;~~ ~~—see also~~ EX1004, p.3 (the

~~{~~various transformations described in Corke provide “positioning information” “directly in Cartesian or task space”—*i.e.*, training space).

50.127. Accordingly, in my opinion, Corke in view of the knowledge of a POSITA renders obvious Element [2.3].

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~~EX1003, ¶¶ 124-127.~~

3. Claims 3 and 4

[3] The method of claim 2, further comprising: positioning the camera with respect to the calibration object.

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[4] The method of claim 3 wherein positioning the camera with respect to the calibration object comprises positioning the camera orthogonally with respect to a ruled template with a number of features, where a known or determinable physical relationship exists between at least some of the features.

128. It is my opinion that Claims 3 and 4 are disclosed by Corke.

In my opinion, Corke discloses positioning the camera with respect to the calibration object.

51.129. EX1003, ¶¶128-133. In Corke's experiments of Corke, a camera mounted to a moveable part of the robot took “[f]our images of the SHAPE

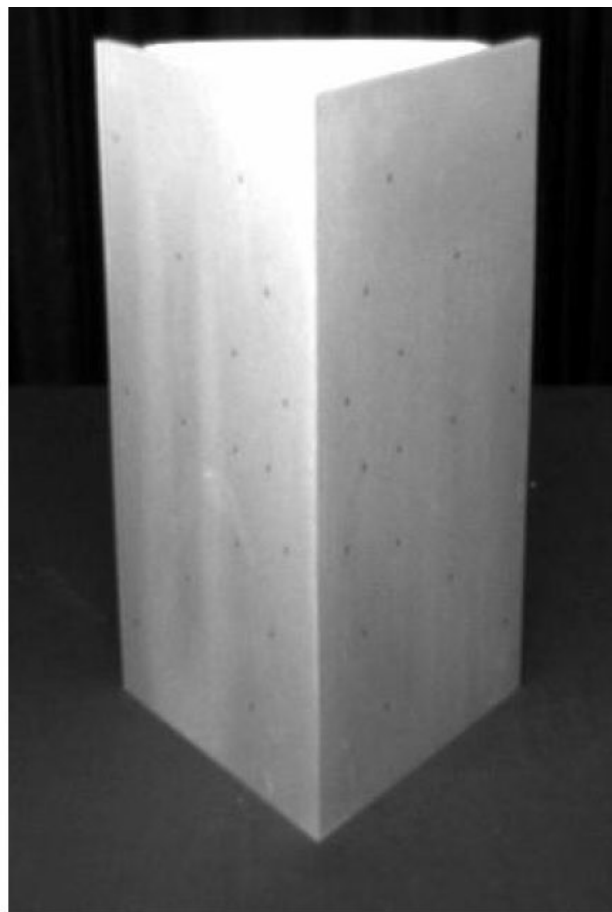


Figure 4.8: The SHAPE calibration target used for intrinsic parameter determination. The surface is brushed aluminium with black marker dots at accurately known locations on the two surfaces.

calibration target, shown in Figure 4.8...from different viewpoints.” EX1004, ¶ at 145; see also Figure 4.8:

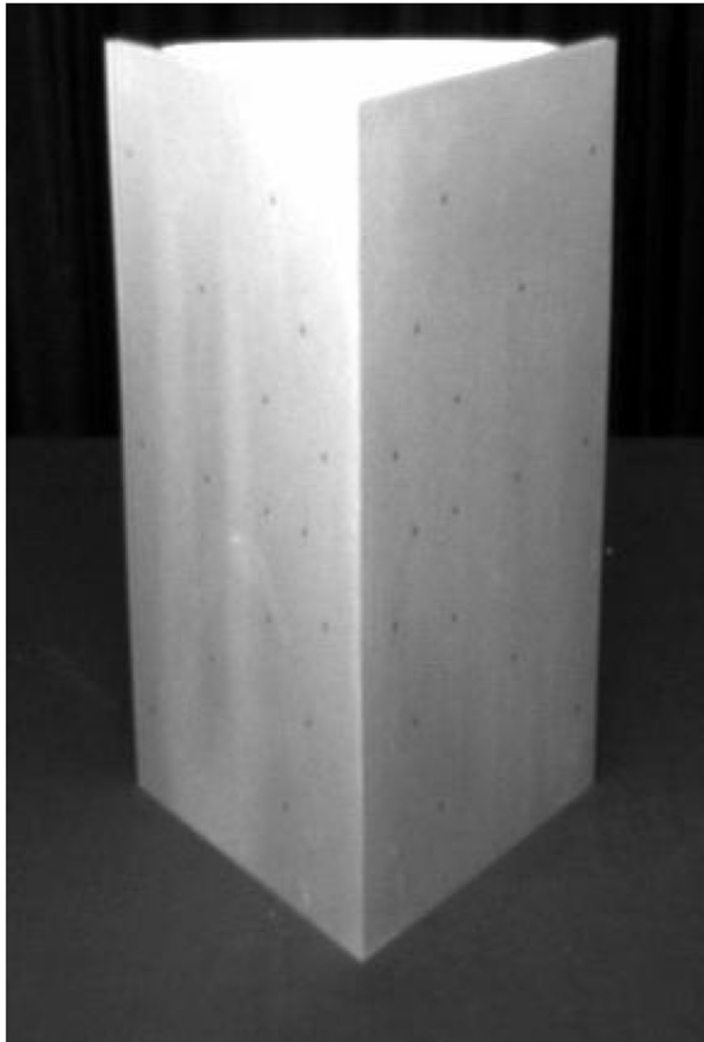


Figure 4.8: The SHAPE calibration target used for intrinsic parameter determination. The surface is brushed aluminium with black marker dots at accurately known locations on the two surfaces.

EX1004, p.140.

52-130. It is my opinion that Corke further discloses positioning the camera

orthogonal to a ruled template with a known physical relationship between the

features. ~~EX1003, ¶130.~~ For example, Corke discloses acceptable camera calibration techniques, ~~including~~

one of which is the two-plane camera model. EX1004, pp.141-43. This method, illustrated in Figure 4.9 of Corke below, shows the camera's "image plane" is parallel to the two "calibration planes,"

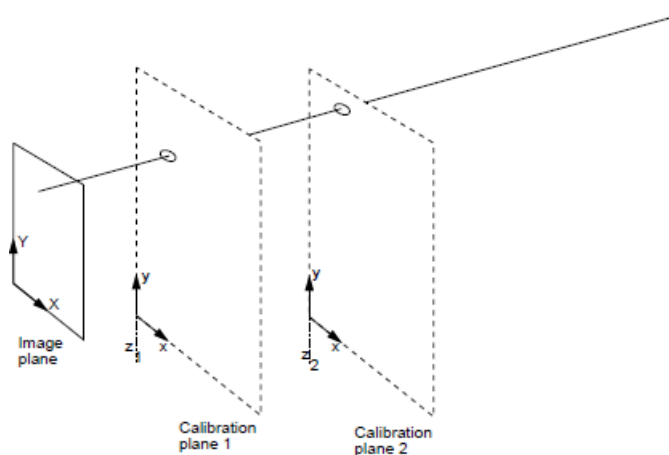


Figure 4.9: The two-plane camera model.

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meaning which in my opinion means that images were captured by a camera placed orthogonal to the calibration templates:

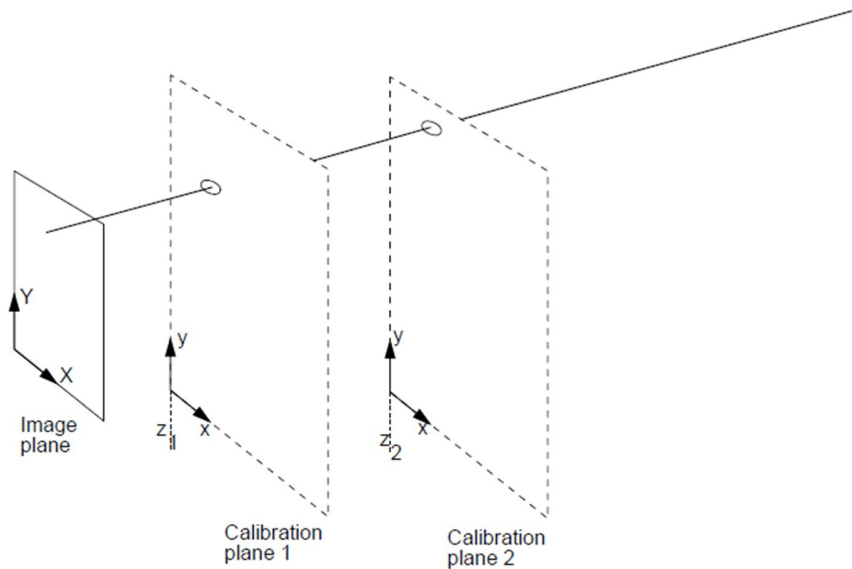


Figure 4.9: The two-plane camera model.

EX1004, p.142; ~~EX1003, ¶130.~~

53.131. The calibration templates used in Corke's two-plane calibration method have a ~~ruled template or~~ "test pattern containing an array of dots at known distances from the camera." EX1004, p.143; ~~EX1003, ¶131.~~

132. Corke also discloses that visual servoing can generally be performed to position a camera at an arbitrary orientation with respect to a target. ~~EX1004, pp.161-162; EX1003, ¶132.~~ In my opinion,

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a POSITA would have understood that visual servoing could therefore be used to position the camera to be orthogonal to the calibration target, this simply being a special case of visual servoing. ~~EX1003, ¶132. Figure 5.6 shows~~As an illustration of positioning a camera ~~orthogonal~~orthogonally to the object, ~~and~~Figure 5.6 of Corke illustrates moving a camera from the initial position (illustrated by the image in the left) to a final position that is orthogonal to the object in question

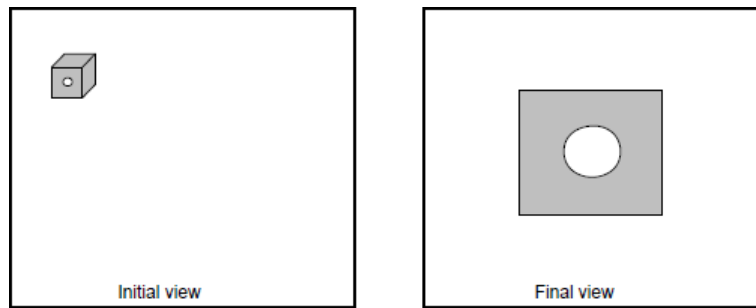


Figure 5.6: Example of initial and desired view of a cube

(right)::

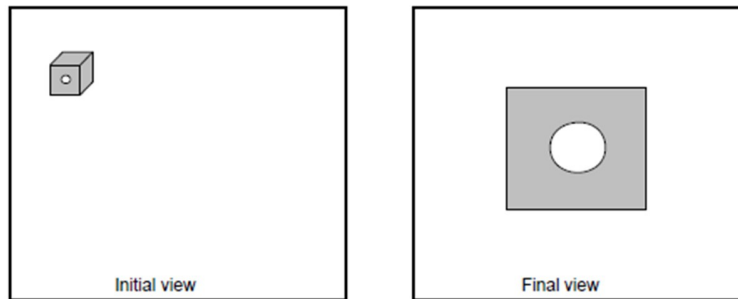


Figure 5.6: Example of initial and desired view of a cube

EX1004, p.162; ~~EX1003, ¶132.~~ Corke describes ~~that~~this scenario as “[t]he feature vector may comprise coordinates of vertices, or areas of the faces. Implicit in ~~this~~desired ~~is~~ that the robot is *normal* to, and centered over the face of the cube, at the desired distance” (EX1004 p.161), where a POSITA would have understood “normal to” as

being equivalent to placing

the camera “orthogonal to” the target. ~~EX1003, ¶132.~~ Section 5.4 of Corke says that the ROBOT is “normal” to the object. EX1004, p.161; ~~EX1003, ¶132.~~ From. A POSITA would have understood, looking at this paragraph and Figure 5.6, ~~a POSITA would have understood~~ that the robot *and* the end-effector mounted camera would be normal to the object. EX1004, p.161; ~~EX1003, ¶132.~~ Thus, Corke in view of the knowledge of a POSITA teaches positioning the camera orthogonally with respect to a ruled template with a number

of

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to a ruled template with a number of features, where a known or determinable physical relationship exists between at least some of the features.

54.133. Accordingly, in my opinion, Corke in view of the knowledge of a POSITA renders obvious Claims 3 and 4. ~~EX1003, ¶¶128-133.~~

4. Claim 6

~~Corke teaches~~ The method of claim 3 wherein capturing a number of images of a calibration object ~~at different~~

[6] by the camera comprises capturing at least one image at each of a plurality of positions. ~~EX1003, ¶¶134-136.~~ spaced perpendicularly from the calibration object.

134. ~~In Figure 4.9,~~ my opinion, Corke in view of the knowledge of a POSITA renders obvious Claim 6.

55.135. It is my opinion that Corke discloses a “two-plane calibration” method, illustrated in Figure 4.9 below, where at least two different images are taken of the calibration object. EX1004, p.142; ~~EX1003, ¶135.~~ Because the camera’s “image plane” is parallel to the two “calibration planes,” ~~Corke teaches~~ it is my opinion that a POSITA would have understood that the images were captured by a camera placed orthogonal to the calibration templates:

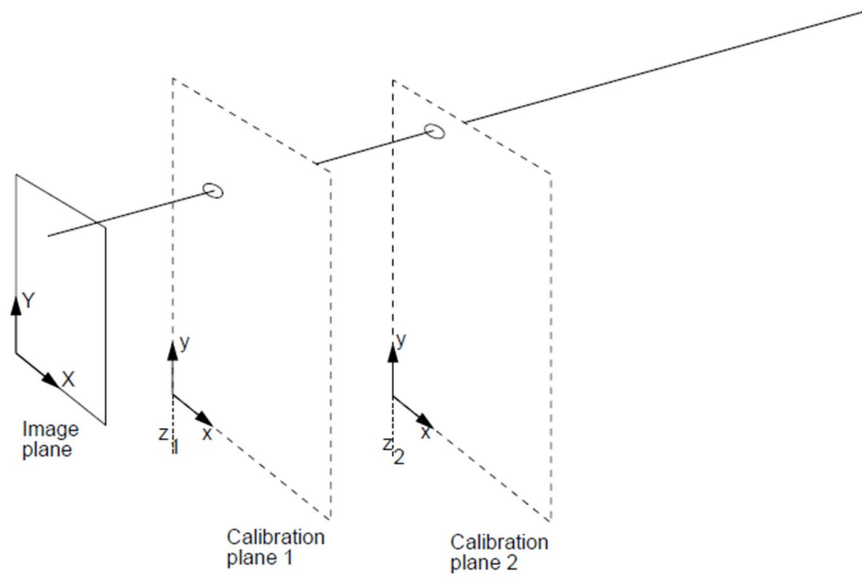


Figure 4.9: The two-plane camera model.

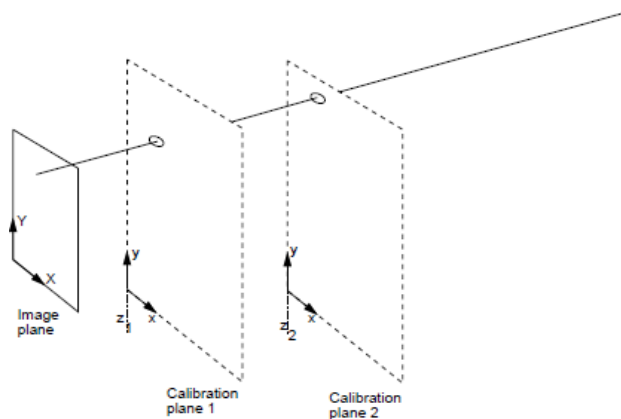


Figure 4.9: The two-plane camera model.

EX1004, p.142.

Specifically To be more precise, in my opinion, a POSITA would have understood that “spaced perpendicularly from the target” ~~to teach~~ implies that the camera locations are spaced along a line that is perpendicular to the target. ~~EX1003, ¶135.~~ For example, Corke discloses in Figure 4.9 that the image plane (which is perpendicular to the camera’s optical axis) is parallel to the two calibration planes. ~~EX1003, ¶135.~~ Thus, a POSITA would have understood that motion of the camera along the optical axis (a line perpendicular to the two calibration planes) would enable capturing a number of images of a calibration object by the camera, including capturing at least one image at each of a plurality of positions spaced perpendicularly from the calibration object.

136. Accordingly, in my opinion, Corke in view of the knowledge of a POSITA renders obvious Claim 6.

5. Claim 7

The method of claim 3 wherein capturing a number of images of a calibration object

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by the camera, ~~including comprises~~ capturing at least one image at each of a plurality of

~~f6]/[7] positions spaced perpendicularly from different orientations with respect to the calibration object. EX1003, ¶135. Corke~~

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In my opinion, Corke in view of the knowledge of a POSITA renders obvious –
~~Claim 6. EX1003,~~

~~¶¶134-136.~~

~~56.137.~~ Claim 7.

~~57.138.~~ For example, it is my opinion that Corke discloses capturing
~~several~~ a number of images of a calibration object at different orientations with
respect to the

orientations with respect to the calibration object. ~~EX1003, ¶¶137-139.~~ Corke
discloses experiments in which “four images of the SHAPE

calibration target...were taken from different viewpoints.” EX1004, p.145.

~~58.139.~~ Accordingly, in my opinion, Corke in view of the knowledge of a
POSITA renders obvious Claim 7.

~~EX1003, ¶¶137-139.~~

6. Claim 8

~~[7][8]~~ Corke teaches The method of claim 2 wherein *determining a set of
intrinsic parameters of the camera from the at least one of the number of images
of the calibration object captured by the camera, comprises determining at least
one of a focal length, a first order radial lens distortion coefficient, a set of
coordinates of a center of a radial distortion, or a scale factor indicative of a
framegrabber scanline resampling uncertainty.*

~~140. including at least one of a~~ In my opinion, Corke in view of the knowledge
of a POSITA renders obvious Claim 8.

~~59.141.~~ Corke teaches determining a set of intrinsic parameters of the

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camera from the at least one of the number of images of the calibration object

captured by the camera, including at least one of a [1] focal length, [2] a first order

radial lens distortion coefficient, and [3] coordinates of a center of a radial distortion

(called the principal point). ~~EX1003, ¶¶140-147.~~ Corke explains that “[i]ntrinsic

parameters are innate characteristics of the camera,” and “include the [1] *focal*

length, [2] *lens distortion*,

and the [3] coordinates of the *principal point*”—i.e., “the intersection of the optical axis and the [] sensor plane.” EX1004, pp.138-39. In my opinion, a POSITA would have understood that determining the “coordinates of the principal point” is the same as [3] determining a set of coordinates of a center of a radial distortion.~~EX1003, ¶141.~~

142. As for [1], it is my opinion that Corke discloses calibration of the focal length, given that the ~~known~~ pixel size in the sensing array.~~EX1003, ¶142. is known.~~ In Corke, pixel size is encoded in the parameters α_{xx} and α_{yy} . EX1004, p.137. Corke notes that “it is not possible to uniquely determine all intrinsic parameters, only the products of ffa_{xx} and ffa_{yy} ,” where f ffa_{yy} ,” in which ff denotes focal length. In my opinion, a POSITA would have

understood that camera manufacturers typically supply the specification of pixel size α_{xx}

and α_{yy} , such that Corke discloses calibration of the focal length f .~~EX1003,~~

~~¶142. For f .~~ As an example, Table 3.9 of Corke discloses α_{xx} and α_{yy} for the

Pulnix TM-6 camera and DIGIMIAX digitizer, which are computed using the manufacturer’s specifications ~~from~~ that are shown in Table 3.8:

Parameter	Value
Sensor width	6.5 mm
Sensor height	4.8 mm
Horizontal active pixels	752 pixels
Vertical active lines	582 pixels
Pixel width (p_x)	8.6 μm
Pixel height (p_y)	8.3 μm

Table 3.8: Manufacturer’s specifications for the Pulnix TM-6 camera.

Parameter	Value
Sensor width	6.5 mm
Sensor height	4.8 mm
Horizontal active pixels	752 pixels
Vertical active lines	582 pixels
Pixel width (p_x)	8.6 μm
Pixel height (p_y)	8.3 μm

Table 3.8: Manufacturer's specifications for the Pulnix TM-6 camera.

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Parameter	Value
α_x	79.2 pixel/mm
α_y	120.5 pixel/mm (frame mode)
α_y	60.2 pixel/mm (field mode)

Table 3.9: Derived pixel scale factors for the Pulnix TM-6 camera and DIGIMAX digitizer.

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Parameter	Value
α_x	79.2 pixel/mm
α_y	120.5 pixel/mm (frame mode)
α_y	60.2 pixel/mm (field mode)

Table 3.9: Derived pixel scale factors for the Pulnix TM-6 camera and DIGIMAX digitizer.

EX1004, p.111; ~~EX1003, ¶142.~~

~~60.143.~~ As for [2], it is my opinion that Corke explains that radial distortion “causes image points to be translated along radial lines from the principal point.” EX1004, p.86. According to Corke, *radial distortion* may be approximated by a polynomial, where r is the distance between the image point and the principal point, k_i are the radial *coefficients*, and k_1 is the first order radial

$$\Delta r = k_1 r^3 + k_2 r^5 + k_3 r^7 + \dots \quad (3.26)$$

distortion coefficient:

$$\Delta r = k_1 r^3 + k_2 r^5 + k_3 r^7 + \dots \quad (3.26)$$

EX1004, p.86.

~~61.144.~~ Corke adds that the *radial distortion coefficients* in the above equation “would be determined by a calibration procedure.” EX1004, p.86. In my opinion, a POSITA would have understood that the intrinsic calibration method discussed in Corke would determine a focal length, a first order radial lens distortion coefficient,

and a set of coordinates of a center of radial distortion (i.e., “the principal point”).

~~EX1003, ¶¶143-144.~~ As for [3], in my opinion, a POSITA would have understood

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that the “principal point” is the center of radial distortion because Corke discloses that “[r]adial distortion causes image points to be translated along radial lines from the principal

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principal point,” noting, in a footnote that the principal point is “[t]he point where the camera’s optical axis intersects the image plane.” EX1004, p.86; ~~EX1003, ¶144.~~

62.145. Corke discloses the experimental results of its calibration, which solves for scaling factor, focal length, and the coordinates for the principal point:

α_x X-axis scaling factor in pixels/mm (intrinsic)

α_y Y-axis scaling factor in pixels/mm (intrinsic)

X_0 image plane offset in pixels (intrinsic)

Y_0 image plane offset in pixels (intrinsic)

f focal length (intrinsic)

EX1004, p.137.

63.146. These results are shown in Table 4.2:

Trial	Residual (pixel)	δ (deg)	X_0 (pixel)	Y_0 (pixel)	$\alpha_x f$ (pixel)	$\alpha_y f$ (pixel)	α_y / α_x
1	0.552	-0.0277	270.1	213.7	625.7	948.9	1.52
2	0.898	0.0672	271.4	223.1	614.0	933.0	1.52
3	0.605	0.0685	278.0	205.6	617.3	938.2	1.52
4	0.639	-0.1198	275.8	196.8	616.8	939.2	1.52
mean			273.8	209.8	615.5	939.8	
σ			3.2	9.7	5.0	6.6	

Table 4.2: Summary of calibration experiment results.

Trial	Residual (pixel)	δ (deg)	X_0 (pixel)	Y_0 (pixel)	$\alpha_x f$ (pixel)	$\alpha_y f$ (pixel)	α_y / α_x
1	0.552	-0.0277	270.1	213.7	625.7	948.9	1.52
2	0.898	0.0672	271.4	223.1	614.0	933.0	1.52
3	0.605	0.0685	278.0	205.6	617.3	938.2	1.52
4	0.639	-0.1198	275.8	196.8	616.8	939.2	1.52
mean			273.8	209.8	615.5	939.8	
σ			3.2	9.7	5.0	6.6	

Table 4.2: Summary of calibration experiment results.

EX1004, p.146; ~~EX1003, ¶¶145-146.~~

64.147. Accordingly, in my opinion, Corke in view of the knowledge of a

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POSITA renders obvious Claim 8.

~~EX1003, ¶¶140-147.~~

7. Claim 9

~~[8]/[9]~~ ~~As discussed above for Claim~~ The method of claim 2, Corke discloses
wherein determining a set of extrinsic parameters of the camera from at least
one of the number of images of the calibration object captured by the camera,
the set of extrinsic parameters comprising a camera space-to-training space
transformation defining a transformation between a camera space reference
frame and a training space reference frame. ~~EX1003, ¶¶148-153.~~ comprises
Corke also discloses an extrinsic calibration that determines

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determining a respective translation component along three orthogonal axes, and a respective rotation component about the three orthogonal axes. ~~EX1003, ¶150.~~
~~Corke explains that~~

148. In my opinion, Corke in view of the knowledge of a POSITA renders obvious Claim 9.

149. As discussed above for Claim 2, it is my opinion that Corke discloses determining a set of extrinsic parameters of the camera from at least one of the number of images of the calibration object captured by the camera, the set of extrinsic parameters comprising a camera space-to-training space transformation defining a transformation between a camera space reference frame and a training space reference frame.

65-150. Similarly, it is my opinion that Corke also discloses an extrinsic calibration that determines a respective translation component along three orthogonal axes, and a respective rotation component about the three orthogonal axes. Corke explains that “[r]obots typically have 6 degrees of freedom (DOF), allowing the end-effector to achieve, within limits, any pose in 3D space.” EX1004, p.153. The 6 degrees include “**3 in translation and 3 in rotation.**” EX1004, ~~pp~~p.10. Corke further discloses a “calibration matrix” that determines “6 extrinsic parameters”—including the “3D vector” (x, y, z coordinates) and “3 angles for the camera pose.” EX1004, p.144.

66-151. Corke defines “3-D pose” as “comprising translation along, and rotation about the X, Y, and Z axes.” EX1004, p.xi. Figure 4.7 of Corke shows ~~the~~

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X, Y, and Z axes ~~that make up the three translational and three rotational components of the 3D~~
pose

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the X, Y, and Z axes that make up the three translational and three rotational components of the 3D pose estimation are orthogonal to each other:

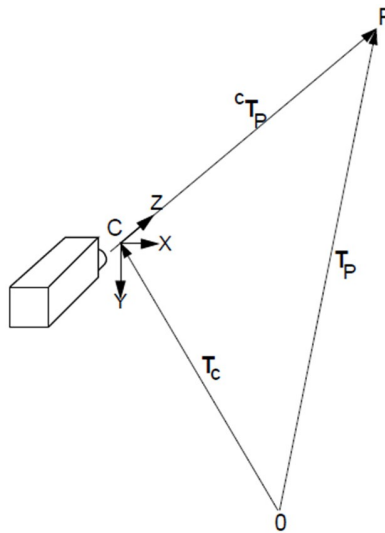


Figure 4.7: Relevant coordinate frames.

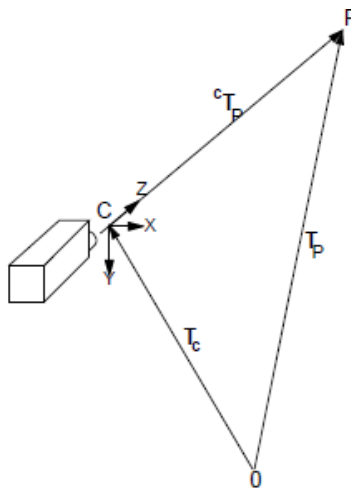


Figure 4.7: Relevant coordinate frames.

EX1004, p.139; ~~EX1003, ¶151. A.~~

67.152. Furthermore, in my opinion, a POSITA would have understood that a 3D orientation can be decomposed into three rotations about orthogonal axes, such as is obtained using an Euler angle representation or a roll-pitch-yaw angle representation. ~~EX1003, ¶152.~~ That a translation in 3D can be decomposed into

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translation along three orthogonal axes is well-known Euclidean geometry, which

in my opinion would have been understood by a POSITA. ~~EX1003, ¶152.~~

~~68.153.~~ Accordingly, in my opinion, Corke in view of the knowledge of a

POSITA renders obvious Claim 9.

~~EX1003, ¶¶148-153.~~

8. Claim 10

~~9/10~~ Corke discloses The method of claim 2, further comprising: determining a camera space-to- tool space transformation based at least in part on at least two of the number of images ~~of the calibration object~~ captured by the camera of the calibration object.

154. In my opinion, Corke in view of the knowledge of a POSITA renders obvious Claim 10.

155. In my opinion, a POSITA would have understood that Corke discloses determining a camera-space-to-tool-space transformation based on at least two images of the calibration object. ~~EX1003, ¶¶154-156.~~ captured by the camera of the calibration object.

Corke discloses that “[o]nce the target pose relative to the camera is determined, it is then necessary to determine the target pose relative to the robot’s end-effector. This requires robot eye-hand calibration.” EX1004, p.160. Corke explains that “[r]obot eye to hand calibration is the process of determining the fixed transformation between the gripper and the camera coordinate system”—i.e., the camera-space-to-tool-space transformation—and involves “the robot making a number of moves and measuring the change in image plane coordinates of a fixed target.” EX1004, p.147. ~~This~~ In my opinion, a POSITA would have understood that this requires that at least two images be captured of the “calibration target.” EX1004, p.147.

~~69.156.~~ captured of the “calibration target.” EX1004, p.147; EX1003, ¶155. Accordingly, in my opinion, Corke in view of the knowledge of a POSITA

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renders obvious Claim 10. ~~EX1003, ¶¶ 154-156.~~

9. **Claims 17, 24, and 28**

~~Corke discloses, or at least renders obvious,~~^[17] The method of claim 1, further comprising: adjusting ~~the~~a position of the movable portion of the robot

and capturing additional if the number of features located in the captured image of the target object is determined to be an insufficient number of features; and capturing another two-dimensional image of the volume containing the target object before determining the object space-to-camera space transformation for the target object.

[24] The apparatus of claim 20 wherein the pose estimating means estimates the pose of the target object further by: adjusting a position of the movable portion of the robot if the number of features located in the captured image of the target object is determined to be an insufficient number of features.

[28] The apparatus of claim 25 wherein the pose estimating means estimates the pose of the target object further by: adjusting a position of the movable portion of the robot if the number of features located in the captured image of the target object is determined to be an insufficient number of features.

157. In my opinion, Corke in view of the knowledge of a POSITA renders obvious Claims 17, 24, and 28.

~~70.~~^{158.} It is my opinion that Corke discloses, or at the very least, renders obvious, adjusting the position of the robot and capturing additional 2D image of the volume containing the target object if the number of features located in the original captured image of the target object is determined to be insufficient. ~~EX1003, ¶¶157-161.~~ For example, Corke explains that image features are chosen and extracted “on the basis of a confidence measure computed from the feature window.” EX1004, p.168. Corke also states that selecting the appropriate threshold is crucial, and discloses algorithms that select which “measurable features give [the] best control.” EX1004, pp.125,~~165.~~ ~~It would have been obvious to a POSITA based on Corke that~~

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~~certain features should be ignored or given less weight than others during pose estimation, and that when~~
~~the number~~

165. In view of Corke's teachings, it is my opinion that it would have been obvious

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to a POSITA that certain features should be ignored or given less weight than other features during pose estimation, and that when the number of viable features drops below the required minimum, it ~~is~~would be necessary to obtain additional feature points. ~~EX1003, ¶158.~~

159. Corke further discloses that while “at least three feature points” are needed to solve for pose, “[s]ix or more points always yield unique solutions, as well as the intrinsic calibration parameters.” EX1004, pp.159-60. Thus, it is my opinion that Corke teaches a minimum number of features that should be used for successful pose estimation. ~~EX1003, ¶159.~~

160. While Corke does not expressly disclose adjusting the position of the camera to take additional images if an insufficient number of features are found and capturing an additional two-dimensional image of the volume containing a target object, ~~but~~in my opinion and as described above, Corke acknowledges that a certain minimum number of features are required to estimate pose and that certain features should be ignored or given less weight in the analysis. EX1004, pp.159-~~160-~~60, 125, 165. Given the disclosures in Corke, it is my opinion that it would have been obvious to a POSITA to move the camera to a different position if the number of features ~~is~~was inadequate ~~capture another image and~~ to determine pose. ~~EX1003, ¶160.~~

161. Accordingly, in my opinion, Corke in view of the knowledge of a POSITA renders obvious ~~claims~~Claims 17, 24, 28. ~~EX1003, ¶¶157-161.~~

10. Claim 18

~~[18] As discussed above, Corke discloses~~The method of claim 1, further comprising: determining an object at least one movement of the robot that orients the camera orthogonally with respect to the target object based at least on part on the object space-to-camera space transformation.

162. In my opinion, Corke in view of the knowledge of a ~~target object. EX1003,~~
~~¶¶162-165.~~POSITA renders obvious Claim 18. Section 5.4 of Corke says that the
 ROBOT is “normal” to the object. EX1004, p.161. AIn my opinion, a POSITA
 would have understood, ~~from~~looking at this paragraph and Figure 5.6, that the robot
 AND the end-effector mounted camera would be normal to the object:

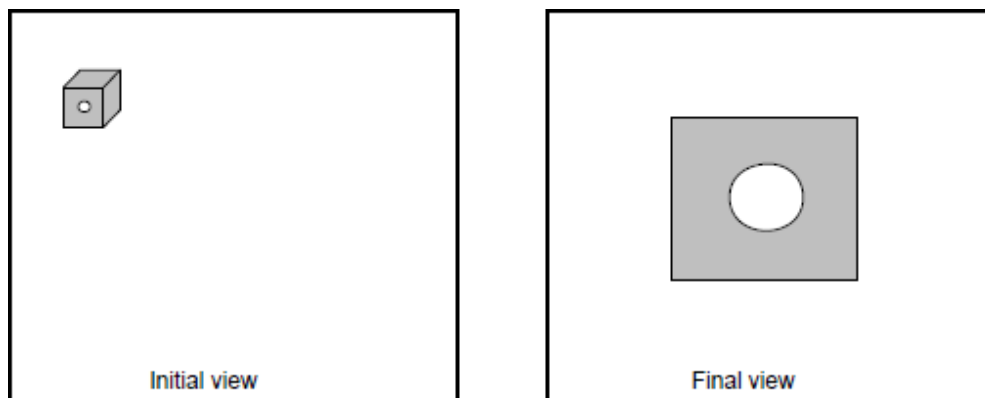


Figure 5.6: Example of initial and desired view of a cube

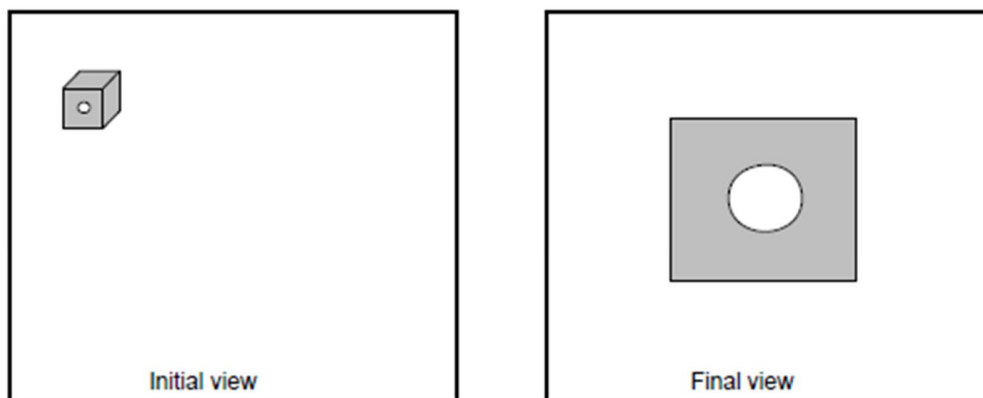


Figure 5.6: Example of initial and desired view of a cube

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EX1004, p.161; ~~EX1003, ¶162.~~

163. As discussed above, it is my opinion that Corke discloses determining an object space-to-camera space transformation of a target object. Corke describes methods

method to determine “the relative pose between the camera and the target, ~~$e_{x_t}^C$~~ x_t .”

EX1004, p.152; ~~EX1003, ¶163.~~ The object space-to-camera space transformation is depicted in

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Figure 5.1 of Corke, where $\mathbf{P}$ designates the target object and ${}^c\mathbf{x}_t$ is the transformation between the camera and the target object—i.e., the “object of interest”:

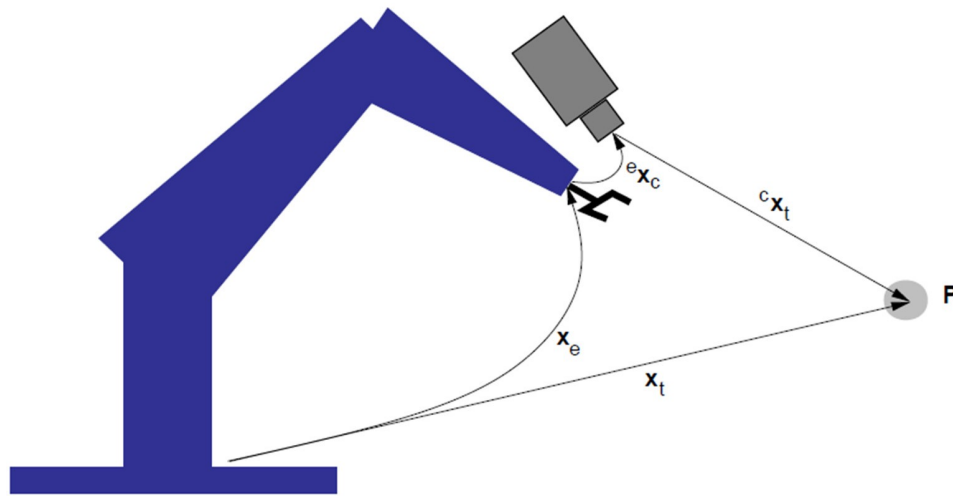


Figure 5.1: Relevant coordinate frames; world, end-effector, camera and target.

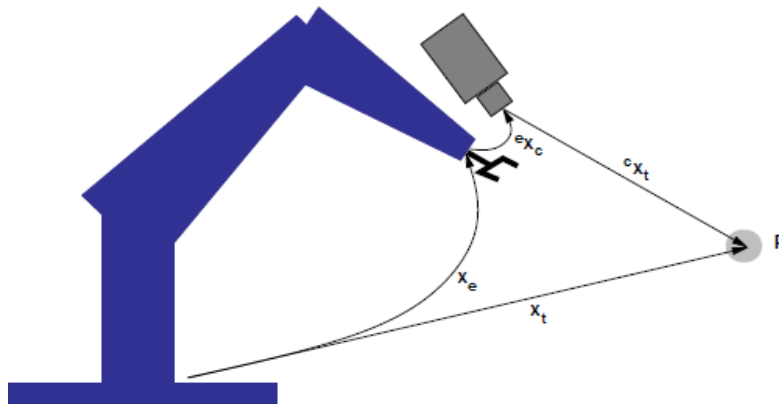


Figure 5.1: Relevant coordinate frames; world, end-effector, camera and target.

EX1004, pp.152, 138.

163;164. In my opinion, Corke also discloses determining at least one movement of the robot based on the object space-to-camera space transformation that orients the camera orthogonally with respect to the target object. ~~EX1003, ¶164.~~ According to Corke, “sensory data”—including a transformation determined by the ~~disclosed~~ algorithms disclosed in Corke—can modify a robot’s movements. ~~EX1004, p.179. Corke discloses “[m]oving [the robot] to a position defined in terms of [a] transformation” such~~

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~~that the robot's motion is "controlled by the vision system." EX1004, p.179. From Corke, EX1004~~

p.179. Corke discloses "[m]oving [the robot] to a position defined in terms of [a] *transformation*" such that the robot's motion is "controlled by the vision system."

EX1004, p.179. Based on the disclosures in Corke, it is my opinion that a POSITA

would have understood that a camera could be moved orthogonally to the target

object based on the object pose determined from the object space-to-camera space

transformation. As further

~~space transformation. EX1003, ¶164.~~ As described above, this could be accomplished, for example, using visual servo control as illustrated in the example of Figure 5.6. EX1004, p.161; ~~EX1003, ¶164.~~

~~164.165.~~ Accordingly, in my opinion, Corke in view of the knowledge of a POSITA renders obvious Claim 18.

~~EX1003, ¶¶162-165.~~

11. Claim 19

~~*[19] Corke discloses The method of claim 18, further comprising: determining a position of the object frame in the tool space reference frame. EX1003, ¶¶166-171.; and providing an object frame to the robot.*~~

166. In my opinion, Corke in view of the knowledge of a POSITA renders obvious Claim 19.

~~165.167.~~ In my opinion, Corke discloses determining a position of the object frame in the tool space reference frame. For instance, for ~~Corke's~~the visual servoing methods described in Corke it is “necessary to determine the target pose relative to the robot’s end-effector”—*i.e.*, the position of the object frame in the tool space reference frame. EX1004, p.160; ~~EX1003, ¶167.~~ Figure 5.1 of Corke depicts the location and orientation of an object

(**P**) in relation to a tool space reference frame (**e**):

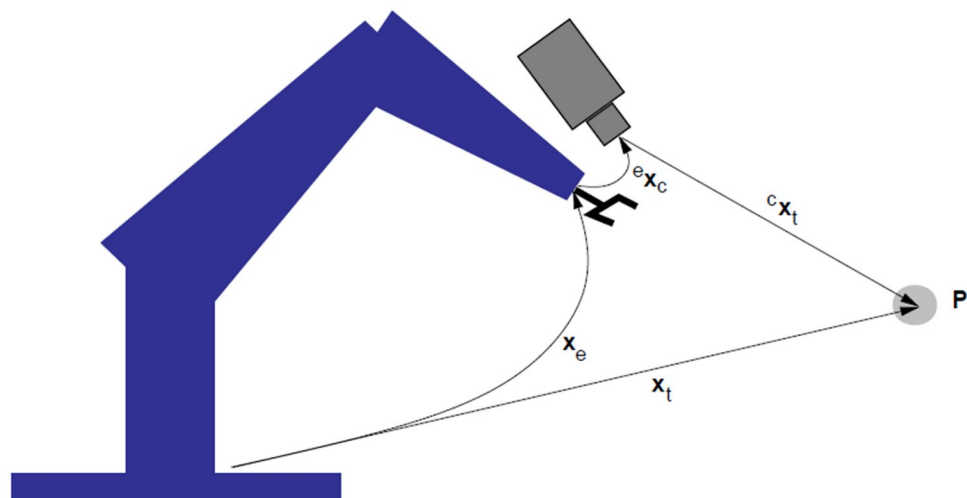


Figure 5.1: Relevant coordinate frames; world, end-effector, camera and target.

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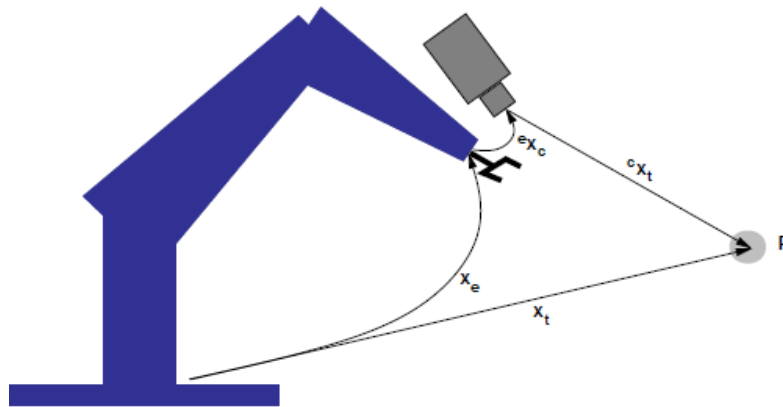


Figure 5.1: Relevant coordinate frames; world, end-effector, camera and target.

EX1004, p.152; ~~EX1003, ¶167. A.~~

~~166.168.~~ In my opinion, a POSITA would also have understood that once the object space-to-camera space and the camera space-to-tool space transformations are determined, the position of the object frame in the tool space reference frame is necessarily determined. ~~EX1003, ¶168.~~

~~167.169.~~ Corke also discloses providing the object frame to the robot.
EX1004,

p.179. According to Corke, “sensory data”—including an object frame determined by the disclosed transformations—can modify a robot’s movements. EX1004, p.179. Corke discloses “[m]oving [the robot] to a position defined in terms of [a] transformation” such that the robot’s motion is “controlled by the vision system.” EX1004, p.179.

~~According to Corke, “sensory data”—including an object frame determined by the disclosed transformations—can modify a robot’s movements. EX1004, p.179;~~

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~~EX1003, ¶169. Corke discloses “[m]oving [the robot] to a position defined in terms of [a] transformation” such that the robot’s motion is “controlled by the vision system.” EX1004, p.179.~~

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~~168-170.~~ In addition, Figure 5.4 shows that in Corke's position-based visual servoing method, the target object's "pose estimation"—*i.e.*, the object frame—is sent to the robot:

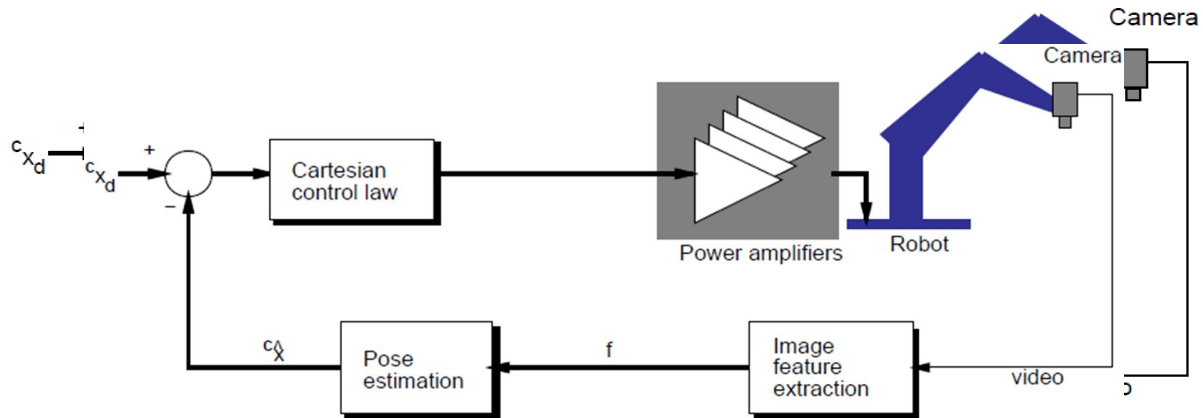


Figure 5.4: Position-based visual servo (PBVS) structure as per Weiss.
Figure 5.4: Position-based visual servo (PBVS) structure as per Weiss.

EX1004, p.155; ~~EX1003, ¶170.~~

~~169-171.~~ Accordingly, in my opinion, Corke in view of the knowledge of a POSITA renders obvious Claim 19.

~~EX1003, ¶¶166-171.~~

12. Claims 20 and 25

[20.0] An apparatus useful in robotics, the apparatus comprising:

[20.1] a single camera operable to capture a number of images of a calibration object;

[25.0] ~~similar~~ An apparatus useful in robotics, the apparatus comprising:

[25.1] a single camera operable to capture a number of images of a calibration object;

~~170-172.~~ I understand that Elements ~~[20.0]~~, [20.1], [25.0], and [25.1] are

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referred to as the “preamble” of the claims. I also understand that certain rules

apply for

~~*{25.1} {similar to 20.1}*~~

~~Regardless of~~

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determining whether ~~the~~ preamble is limiting or not. I have been instructed to apply those rules for Claims 20 and 25. In my opinion, Corke in view of the knowledge of a POSITA renders obvious Elements [20.0], [20.1], [25.0], and [25.1].

For example, in my opinion, Corke discloses an apparatus useful in robotics.-
~~EX1003, ¶¶172-176.~~ Corke describes a “computer vision system”

~~171.173.~~ using that uses “one or more cameras” to “control the position of the robot’s end-effector relative to the workplace as required by the task,” “allow[ing]” robots to perform “tasks that were not strictly repetitive.” EX1004, pp.1-2; ~~EX1003, ¶173.~~

~~172.174.~~ It is also my opinion that Corke~~-also~~ discloses a single camera operable to capture a number of images of a calibration object. ~~EX1003, ¶174.~~ The single camera used in Corke’s experiments is shown in Figures 4.11, 6.10, and 6.11:

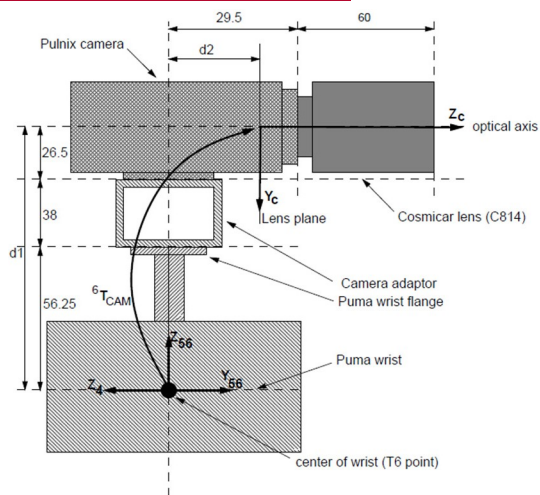


Figure 4.11: Details of camera mounting (not to scale, dimensions in mm). Robot wrist is in the zero angle pose.

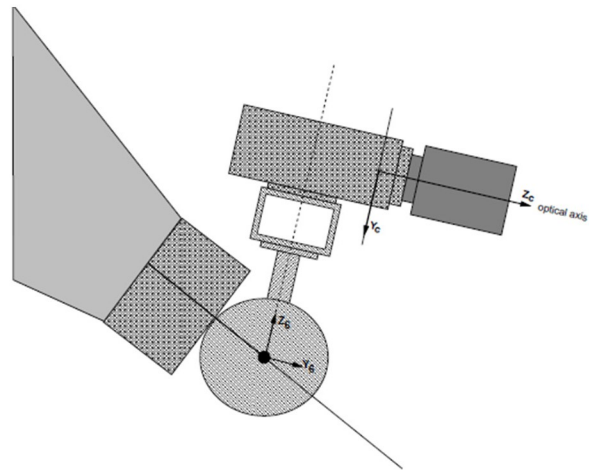


Figure 6.10: Camera mount used in this work. In this pose $\theta_6 \approx -\pi/2$.

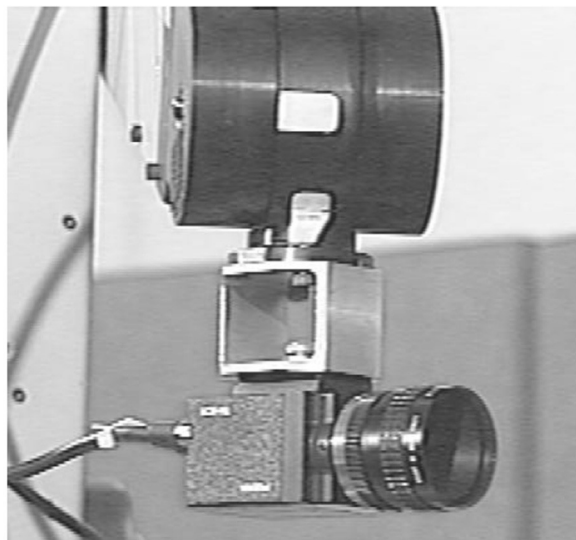


Figure 6.11: Photograph of camera mounting arrangement.

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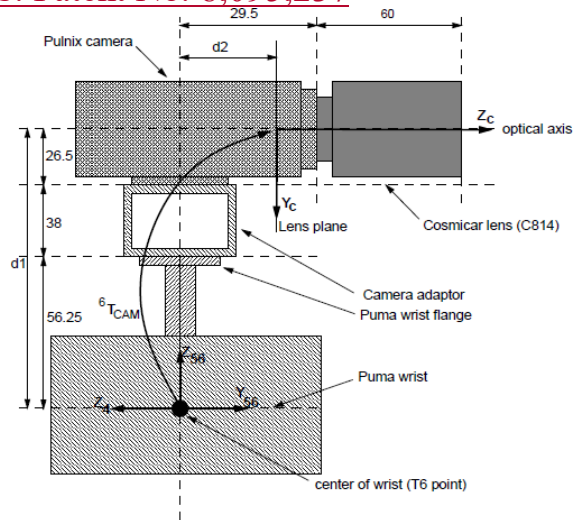


Figure 4.11: Details of camera mounting (not to scale, dimensions in mm). Robot wrist is in the zero angle pose.

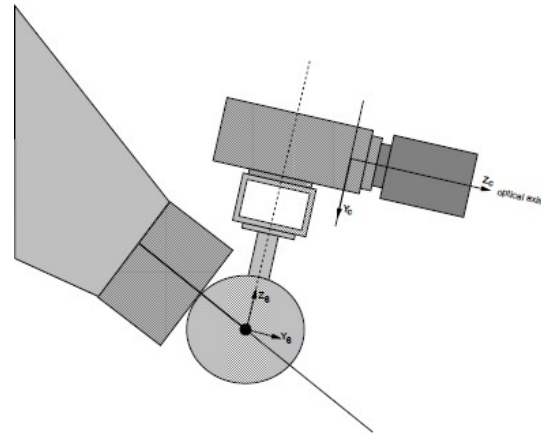


Figure 6.10: Camera mount used in this work. In this pose $\theta_6 \approx -\pi/2$.

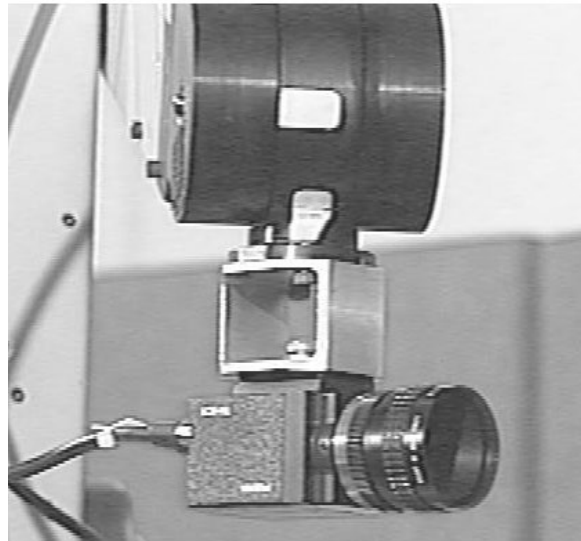


Figure 6.11: Photograph of camera mounting arrangement.

EX1004, ~~ppp~~.148, 186-87.

~~173-175.~~ Using this single camera, Corke states that “[f]our images of the SHAPE calibration target~~---~~, shown in Figure 4.8, were taken from different viewpoints.” ~~EX1004,~~EX1004, p.145. Figure 4.8 shows one image of the calibration object:

~~p.145.~~ Figure 4.8 shows one such image:

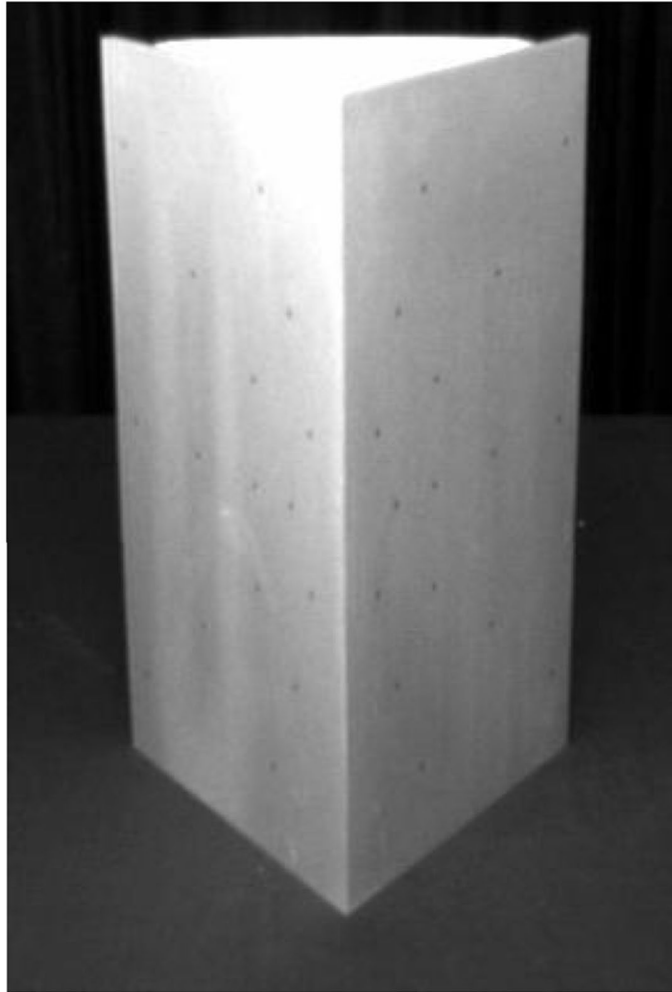


Figure 4.8: The SHAPE calibration target used for intrinsic parameter determination. The surface is brushed aluminium with black marker dots at accurately known locations on the two surfaces.

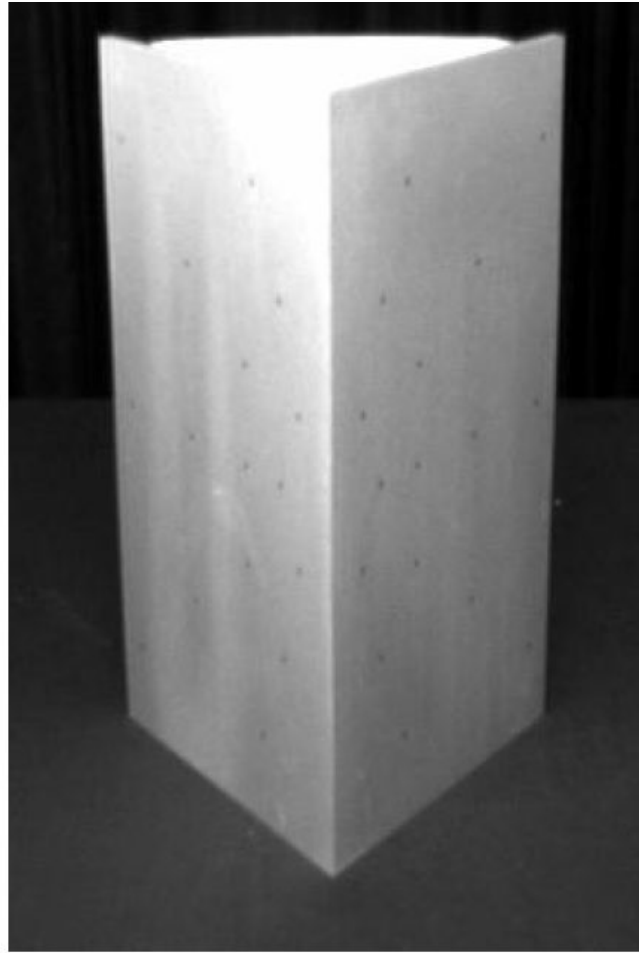


Figure 4.8: The SHAPe calibration target used for intrinsic parameter determination. The surface is brushed aluminium with black marker dots at accurately known locations on the two surfaces.

EX1004, p.147.

~~174-176.~~ Accordingly, in my opinion, Corke in view of the knowledge of a POSITA renders obvious Elements [20.0], [20.1], [25.0], and [25.1].~~EX1003, ¶¶172-176.~~

[20.2] means for calibrating the camera, by: determining a set of intrinsic parameters of the camera from at least one of the number of images of the calibration object captured by the camera; and determining a set of extrinsic parameters of the camera from at least one of the number of images of the calibration object captured by the camera,

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~~[25.2] [similar to 20.2]~~

[25.2] means for calibrating the camera, by: determining a set of intrinsic parameters of the camera from at least one of the number of images of the

calibration object captured by the camera; and determining a set of extrinsic parameters of the camera from at least one of the number of images of the calibration object captured by the camera,

177. In my opinion, Corke in view of the knowledge of a POSITA renders obvious Elements [20.2] and [25.2].

178. It is my opinion that Corke discloses determining a set of intrinsic parameters and extrinsic parameters from at least one of the number of images of the calibration target captured by the camera. ~~EX1003, ¶¶177-180.~~ In For instance, in Corke's experiments, "[f]our images of the SHAPE calibration target, shown in Figure 4.8, were taken from different viewpoints." EX1004, p.145. Corke explains that the four images were used to compute the "calibration matrix"—a mathematical object that "contains information about the position of the camera with respect to the world coordinate frame"—i.e., the extrinsic parameters—"as well as intrinsic parameters of the camera." EX1004, pp.143-~~144~~44 (the "calibration matrix" "encodes the 6 extrinsic parameters"—"i.e., the "3D position vector and 3 angles for camera pose"—"and "5 intrinsic parameters: f , α_x , α_y , X_0 and Y_0 "). By comparing the location of the calibration object's features in the images to their "known 3D marker location," Corke determines the extrinsic and intrinsic parameters. EX1004, pp.139-142; ~~EX1003, ¶178. Additionally,~~

175.179. Corke defines camera calibration generally as "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 the

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~~world coordinate system (extrinsic parameters).” EX1004, p.139 (“the camera calibration matrix which relates a world coordinate system to the image plane coordinates for a given camera position and orientation.”). EX1003, ¶179.~~

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world coordinate system (extrinsic parameters).” EX1004, p.139 (“the camera calibration matrix which relates a world coordinate system to the image plane coordinates for a given camera position and orientation.”).

180. Accordingly, in my opinion, Corke in view of the knowledge of a POSITA renders obvious Elements [20.2] and [25.2].

[20.3] the set of extrinsic parameters comprising a camera space-to-training space transformation defining a transformation between a camera space reference frame and a training space reference frame; and

[25.3] ~~similar to 20.3~~

~~Corke discloses that~~the set of extrinsic parameters include~~comprising a transformation between a~~

~~camera space reference frame and a~~to-training space transformation defining a transformation between a camera space reference frame. EX1003; and

181. In my opinion, Corke in view of the knowledge of a POSITA renders obvious Elements [20.3] and [25.3].

It is my opinion that Corke discloses that the extrinsic parameters include a transformation between a camera space reference frame and a training space reference frame. Specifically, Corke teaches that “extrinsic parameters” relate to “the position and orientation of the camera.” EX1004, p.138.

~~176.182. ¶¶181-183. Specifically, Corke teaches that “extrinsic parameters” relate to “the position and orientation of the camera.” EX1004, p.138. One “extrinsic”~~

~~parameter is ^cT_p—“One of those “extrinsic” parameters is ^cT_p —i.e., “the position of the [calibration] object with respect to the camera.” EX1004, p.127. In my opinion,~~

~~a the position of the [calibration] object with respect to the camera.” EX1004,~~

~~p.127. A POSITA would have understood this was the “transformation”—T—~~

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between the coordinate frame defined by the camera—C—and the coordinate frame defined by the calibration object—P. EX1004, p.xi; ~~EX1003, ¶182.~~ Because a “training space” is a “reference frame defined with respect to a point on the calibration” object, it is my opinion that a POSITA

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would further have understood that Corke discloses extrinsic parameters, including a camera space-to-training space transformation. EX1001, 3:22-24; ~~EX1003, ¶182~~; see also EX1004, p.3 (the various transformations described in Corke provide “positioning information” “directly in Cartesian or task space”—*i.e.*, training space).

~~177.183.~~ Accordingly, in my opinion, Corke in view of the knowledge of a POSITA renders obvious Elements [20.3] and [25.3]. ~~EX1003, ¶¶181-183.~~

[20.4] means for estimating a pose of a target object, by: capturing a two-dimensional image of a volume containing a target object;

~~[25.4] [similar to 20.4]~~

[25.4] means for estimating a pose of a target object, by: capturing a two-dimensional image of a volume containing a target object;

184. In my opinion, Corke in view of the knowledge of a POSITA renders obvious Elements [20.4] and [25.4].

In my opinion, Corke discloses means for estimating a pose of a target object. ~~EX1003,~~

~~178.185.~~ ~~¶¶184-191.~~ For example, Corke discloses that in “position based control, features are extracted from the image” of a target object to “determine the pose of the target with respect to the camera.” EX1004, pp.152-~~53~~; ~~EX1003, ¶185~~153.

186. As shown in Figure 5.4, Corke discloses ~~using a system that uses~~ a video camera to capture and process multiple ~~two-dimensional~~ 2D images of a target object one image at a time at the “camera frame rate,” which is “effectively the

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sample rate in a visual

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servoing system.” EX1004, ~~ppp~~.103, 73 (“the camera’s shutter acts as the sampler in a visual control loop”⁷).²

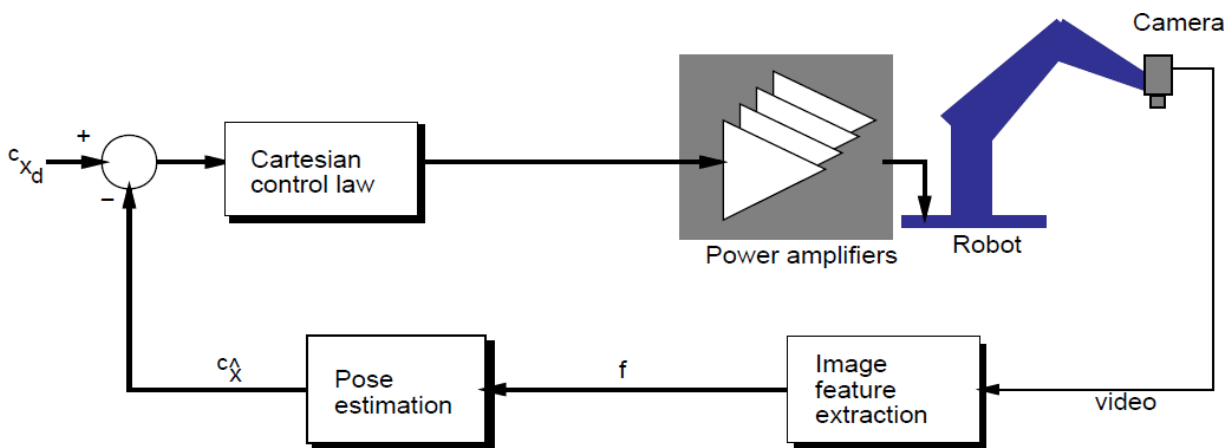


Figure 5.4: Position-based visual servo (PBVS) structure as per Weiss.

⁷The portions of Corke cited herein are from a single embodiment as Chapter 3’s “Fundamentals of image capture” and Chapter 4’s “Machine vision” concepts are used as a baseline for Chapter 5’s position-based visual servoing methods. EX1004.

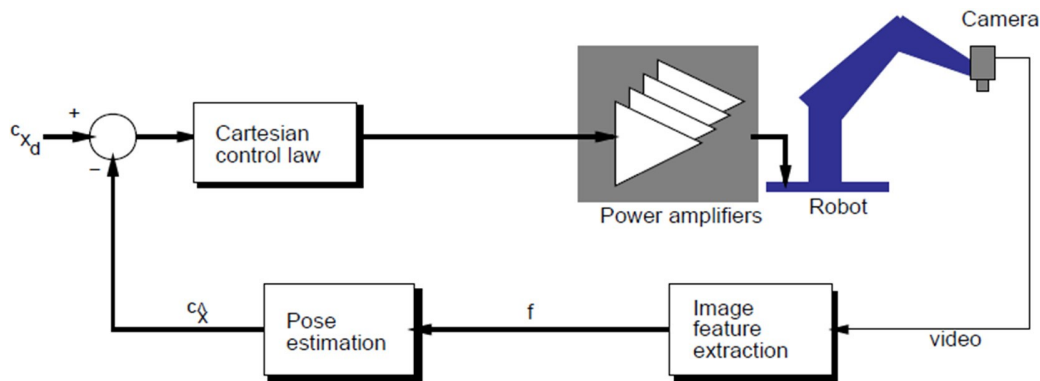


Figure 5.4: Position-based visual servo (PBVS) structure as per Weiss.

EX1004, p.155; EX1003, ¶186.

~~179-187.~~ The claim requires that the target object reside in a volume, which ~~Corke~~

Corke teaches is the space from which the image of the target object is captured.

EX1004, pp.152-153 (referring to “an image of the target” as “the object of interest, that is, the object that will be tracked,” so that “features” can be “extracted from the image”); EX1003, ¶187. A”). In my opinion, a POSITA would have understood that any 3D object occupies a volume. EX1003, ¶187. Corke discloses that “[t]he camera contains a lens which forms

a 2D projection of the scene on the image plane.” EX1004, ~~ppp~~.152. Accordingly, in

² The portions of Corke cited herein are from a single embodiment as the “Fundamentals of image capture” discussed in Chapter 3 and the “Machine vision” concepts in Chapter 4 are used as a baseline for the position-based visual servoing methods discussed in Chapter 5. EX1004.

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my opinion, Corke’s teaching that capturing a 2D image of a target object by a single camera would have included capturing a two-dimensional image of a volume-
containing a
containing a target object. ~~EX1003, ¶187.~~

~~180-188.~~ Accordingly, in my opinion, Corke in view of the knowledge of a POSITA renders obvious Elements [20.4] and [25.4]. ~~EX1003, ¶¶184-191.~~

*[20.5] locating at least six features in the captured image of the target object;
[25.5] ~~similar to~~ locating at least five features in the captured image of the
target object;*

~~181-189.~~ In my opinion, Corke in view of the knowledge of a POSITA renders obvious Elements [20.5] and [25.5].

For example, it is my opinion that Corke discloses locating at least 5 or 6 features on the target object. ~~EX1003,~~

~~182-190.~~ ~~¶¶189-191.~~ Indeed, Corke states that locating at least 6 features is preferred since that will yield “unique solutions” to pose estimation:

It can be shown that at least three feature points are needed to solve for pose. Intuitively, the coordinate of each feature point yields two equations and six equations are needed to solve for the six elements of the pose vector. In fact three feature points will yield multiple solutions, but four coplanar points yield a unique solution...***Six or more points always yield unique solutions***, as well as intrinsic camera calibration parameters.

EX1004, pp.159-~~60-160.~~

~~183-191.~~ Accordingly, in my opinion, Corke in view of the knowledge of a POSITA renders obvious Elements [20.5] and [25.5]. ~~EX1003, ¶¶189-191.~~

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[20.6] and determining an object space-to-camera space transformation based at least in part on a position of at least some of the located features in solely the captured image using an algorithm that employs a known or determinable physical relationship between at least some of the located features.

[25.6] ~~/similar to 20.6/~~

~~Corke discloses~~ and determining an object space-to-camera space transformation based at least in part on a position of at least some of the located features using the captured image without any additional captured images and an algorithm that employs a known or determinable physical relationship between at least some of the located features.

192. In my opinion, Corke in view of the knowledge of a POSITA renders obvious Elements [20.6] and [25.6].

184.193. For instance, in my opinion, Corke discloses determining an object space-to-camera space transformation for the target object utilizing features from a single image. ~~EX1003, ¶¶192-200.~~ Corke discloses that in “position-based control, features are extracted from the image” of the target object “and used in conjunction with a geometric model of the target to determine the pose of the target with respect to the camera.” EX1004

p.153. A POSITA, in my opinion, would have understood that determining the target’s pose (~~i.e., position and orientation~~) with respect to the camera is the same as determining the object space-to-camera space transformation. ~~EX1003, ¶193.~~ This object space-to-camera space transformation is depicted in Figure 5.1 of Corke, where **P** designates the target object and ${}^c\mathbf{x}_t$ is the transformation between the camera and the target object—the “object of interest”:

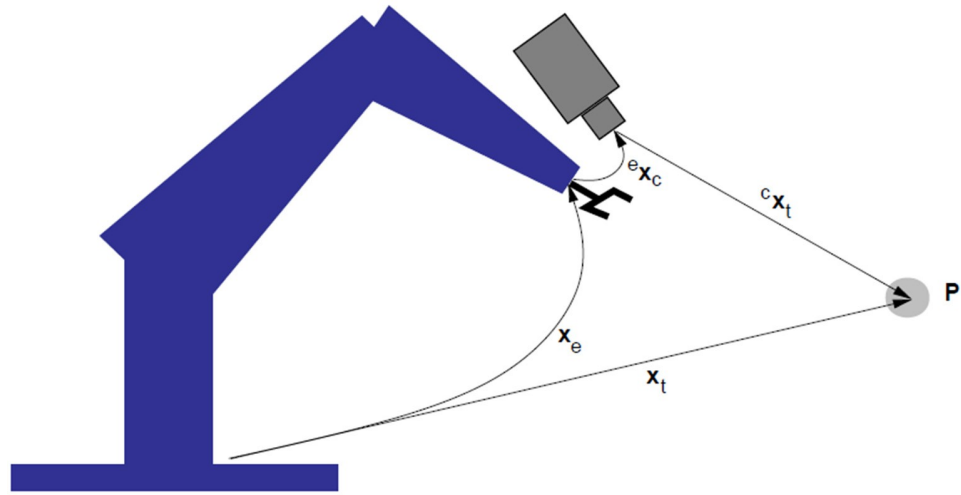


Figure 5.1: Relevant coordinate frames; world, end-effector, camera and target.

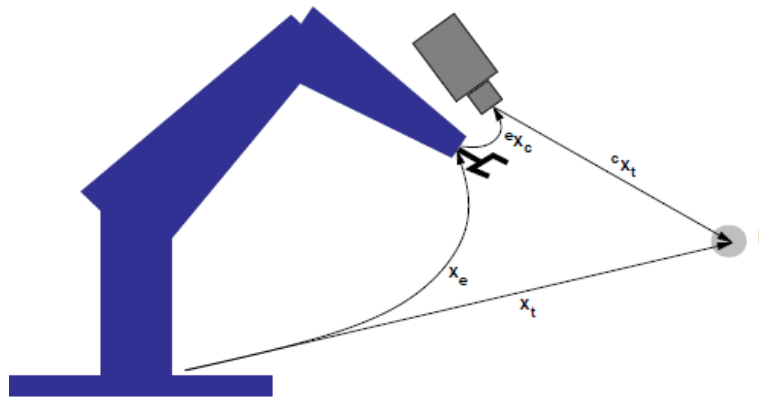


Figure 5.1: Relevant coordinate frames; world, end-effector, camera and target.

EX1004 pp.152, 138; ~~EX1003, ¶193.~~

~~185.194.~~ 185.194. ~~In my opinion, a~~ POSITA would also ~~have understood~~ understand that Corke's references to "**the** image" teaches that only features from a single captured image are used to determine the object space-to-camera space transformation. EX1004, pp.152 ("The task in visual servoing is to control the pose of the robot's end-effector, ${}^*T_6^x t_6$, using visual information, features, extracted from the image."); 153 ("The image plane coordinates of three or more visual features can be used to determine the pose...of the target relative to the camera, given knowledge of the geometric relationship between the feature points."); ~~EX1003, ¶194.~~ ¶194.). As an example of this single-image processing, Corke teaches the use of the Datacube DIGIMAX for acquiring individual images from the camera and processing these individual images to locate features, stating "[t]he incoming analog video signal is digitized to form *a 512x512 pixel digital image*," after which various features are detected, such as "moments up to second order, perimeter and

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bounding box,” EX1004, p.180. ~~EX1003, ¶194.~~

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~~186.195.~~ It is also my opinion that Corke teaches an algorithm that uses ~~the~~
~~position of features~~ feature coordinates from a single image in order to determine the
object space-to-camera

space transformation ~~for the target object based at least in part on a position of at~~
least some of the located features. EX1004, p.138; ~~EX1003, ¶195.~~ Corke teaches
in equation 4.60

(EX1004, p.138) that camera calibration matrix, C , “represents the relationship
between 3-D world coordinates and their corresponding 2-D image coordinates as
seen by the computer,” with i_x , i_y and i_z encoding the position of a feature in the
image plane, and x , y , and z encoding the position of the same feature in 3D
“world coordinates”:

$$\begin{bmatrix} i_x \\ i_y \\ i_z \end{bmatrix} = C \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \quad (4.60)$$

$$\begin{bmatrix} i_x \\ i_y \\ i_z \end{bmatrix} = C \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \quad (4.60)$$

and with the matrix C defined in equation 4.61:

$$C = \begin{bmatrix} \frac{\alpha_x n_x f - X_0 n_z}{f - c_z} & \frac{\alpha_x o_x f - X_0 o_z}{f - c_z} & \frac{\alpha_x a_x f - X_0 a_z}{f - c_z} & \frac{\alpha_x c_x f - X_0 c_z + X_0 f}{f - c_z} \\ \frac{\alpha_y n_y f - Y_0 n_z}{f - c_z} & \frac{\alpha_y o_y f - Y_0 o_z}{f - c_z} & \frac{\alpha_y a_y f - Y_0 a_z}{f - c_z} & \frac{\alpha_y c_y f - Y_0 c_z + Y_0 f}{f - c_z} \\ -\frac{n_z}{f - c_z} & -\frac{o_z}{f - c_z} & -\frac{a_z}{f - c_z} & 1 \end{bmatrix} \quad (4.61)$$

$$C = \begin{bmatrix} \frac{\alpha_x n_x f - X_0 n_z}{f - c_z} & \frac{\alpha_x o_x f - X_0 o_z}{f - c_z} & \frac{\alpha_x a_x f - X_0 a_z}{f - c_z} & \frac{\alpha_x c_x f - X_0 c_z + X_0 f}{f - c_z} \\ \frac{\alpha_y n_y f - Y_0 n_z}{f - c_z} & \frac{\alpha_y o_y f - Y_0 o_z}{f - c_z} & \frac{\alpha_y a_y f - Y_0 a_z}{f - c_z} & \frac{\alpha_y c_y f - Y_0 c_z + Y_0 f}{f - c_z} \\ -\frac{n_z}{f - c_z} & -\frac{o_z}{f - c_z} & -\frac{a_z}{f - c_z} & 1 \end{bmatrix} \quad (4.61)$$

EX1004, pp.138.

~~187.196.~~ 196. In my opinion, Corke teaches methods for determining the matrix C using the position of multiple features in a single image. EX1004, pp.139-142; ~~EX1003, ¶196.~~ Corke teaches that “[t]he calibration matrix, C, encodes the 6 extrinsic parameters,” noting in a footnote that these extrinsic parameters are the “3D position vector and 3 angles

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for camera pose.” EX1004, p.144. Corke teaches an algorithm to recover these parameters from the matrix C by decomposing the camera calibration matrix.

EX1004, pp.143-144; EX1003, ¶196. A. It is my opinion that a POSITA would have understood that if the 3D 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. EX1003, ¶196.

188.197. Using In my opinion, using Corke’s equation 4.60, a POSITA would have understood that by multiplying the camera calibration C by the 3D coordinatesposition of any feature in 3D space, the corresponding position for that feature in the 2D image frame—(i_x , i_y , i_z —are) is obtained, and those coordinates can be converted to two- dimensional camera frame pixel coordinates— i_X , i_Y —usingby Corke’s equations 4.56 and 4.57:

$$i_X = \frac{i_x}{i_z} \quad (4.56)$$

$$i_Y = \frac{i_y}{i_z} \quad (4.57)$$

$$i_X = \frac{i_x}{i_z} \quad (4.56)$$

$$i_Y = \frac{i_y}{i_z} \quad (4.57)$$

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EX1004, p.138; ~~EX1003, ¶197.~~ Furthermore, Corke discloses that this algorithm

~~works, will work~~ with features extracted using only the single captured image ~~and~~
~~without~~

~~additional captured images.~~ EX1004, p.138; ~~EX1003, ¶197.~~

198. The~~The~~In my opinion, the algorithm disclosed in Corke also employs a known physical relationship between some located features using stored knowledge of model feature points in 3D space. EX1004, p.159; ~~EX1003, ¶198.~~ For instance, Corke explains that to “determine the 3D relative pose of an object...from 2D image coordinates,” some

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“additional information is needed.” EX1004, p.159. This additional information

includes “*knowledge of the relationship between the observed feature points*

(perhaps from a CAD model) and also the camera’s intrinsic parameters.” EX1004,

pp.159; 153 (“three or more visual features can be used to determine the

pose...*given knowledge of the geometric relationship between the feature*

points”). Corke also explains that the object space-to-camera space transformation

is determined by an algorithm using ~~the position of~~ “features extracted from the

image” “*in conjunction with a geometric model of the target*,” and that “each

feature point yields two equations and six equations are needed to solve the six

elements of the pose vector.” EX1004, pp.153, 159-60; ~~EX1003, ¶198. A.~~

Accordingly, in my opinion, a POSITA would have understood that Corke teaches

an algorithm ~~that employs~~ using the position of “features extracted from the image”

~~((claimed only the single captured image) and —“a~~ “a geometric model of the

target”

~~geometric model of the target” ((claimed known physical relationship) proceed~~

by a computer (processor) to

determine the “3D relative pose of an object” (claimed object space-to-camera space

transformation for the target object). EX1004, pp. 153, 159-60 (“features are

extracted from the image and used in conjunction with a geometric model of the

target to determine the pose of the target with respect to the camera”); ~~EX1003,~~

~~¶198.-”).~~

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~~189; 199.~~ Corke also discloses that the object space-to-camera space
~~Corke in view of the knowledge of a POSITA renders obvious Elements~~
algorithm can be performed “by a computer,” which, in my opinion, a POSITA
~~[29.2] and [29.2]. EX1003, ¶¶ 177-188.~~
would have understood ~~includes~~ to include the claimed processor. EX1004, p.138;
~~EX1003, ¶199.~~

~~199-200. According to my opinion, Corke in view of the knowledge of a POSITA renders obvious Elements [20.6] and [25.6]. EX1003, ¶¶192-200.~~

13. Claims 26 and 27

~~[26] Corke discloses using The apparatus of claim 25 wherein the means for calibrating and the means for estimating a pose comprises at least one programmed computer and/or.~~

~~[27] The apparatus of claim 25 wherein the means for calibrating and the means for estimating a pose comprises at least one computer-readable medium storing instructions operating at least one computer.~~

201. In my opinion, Corke in view of the knowledge of a POSITA renders obvious Claims 26 and 27.

It is my opinion that Corke discloses using at least one programmed computer and/or computer-readable medium for calibration and pose estimation. EX1003,

~~191-202. ¶¶201-205.~~ For example, Corke discloses that visual servoing is a method used for “computer vision”—i.e., the “application of a computer system for receiving and processing information,” including image interpretation. EX1004, p.123. Corke also discloses a calibration matrix run on a computer. ~~EX1003, ¶202.~~ This matrix is a “3x4 homogenous transform which performs scaling, translation, and perspective” and “represents the relationship between 3-D world coordinates and their corresponding 2-D image coordinates as seen by the computer.” EX1004, pp.138, 167 ~~“(stating that “image processing” is handled “by a conventional computer”).~~

~~192.159. One of the computer systems used by Corke is shown in Figure 6.2:~~

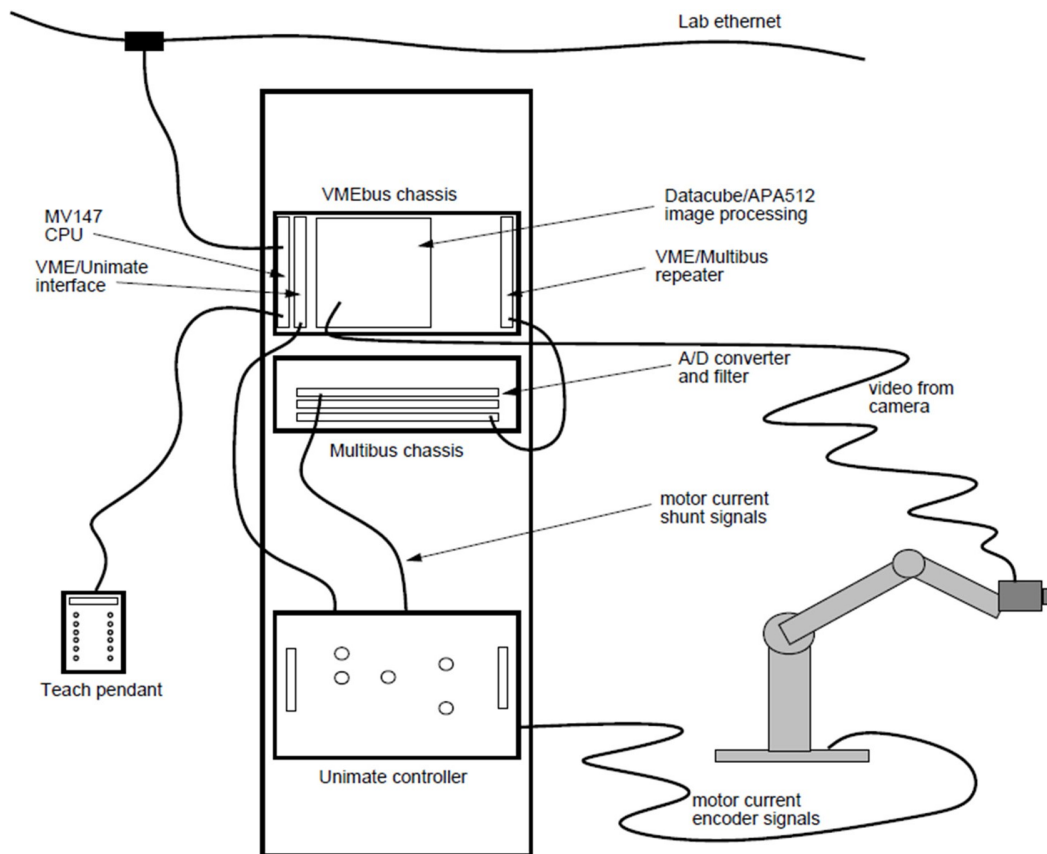


Figure 6.2: Overall view of the system used for visual servo experiments.

203. One of the computer systems used by Corke is shown in Figure 6.2:

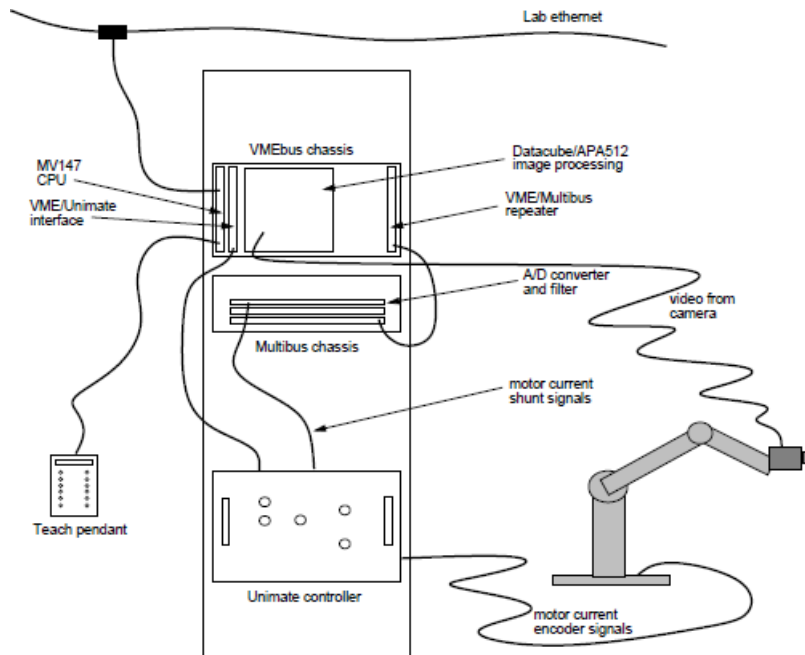


Figure 6.2: Overall view of the system used for visual servo experiments.

EX1004, p.176. ~~The~~

~~193.204.~~ In my opinion, a POSITA would have understood that the computer of Figure 6.2 processes ~~and uses~~ information received from the robot ~~and uses it~~ to calculate calibration parameters and determine pose. ~~EX1003,~~

~~194.205.~~ ~~¶203.~~ Accordingly, in my opinion, Corke in view of the knowledge of a POSITA renders obvious Claims 26 and 27. ~~EX1003, ¶¶201-205.~~

b. GROUND 2: CLAIMS 5, 12-16, AND 21-24 ARE UNPATENTABLE AS OBVIOUS OVER CORKE IN VIEW OF WEI-I

b.a. Wei-I

~~Wei-I discloses “a method for self-calibration of robotic hand cameras by means of active motion.” EX1005, p.1; EX1003, ¶¶82-83. The method involves~~

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~~“tracking a set of world points” on an object “during robot motion” to determine
“the camera internal and external parameters” and “hand-eye calibration.” EX1005,
pp.1-2.~~

206. In my opinion, Claims 5, 12–16, and 21–24 would have been obvious
to a POSITA in view of Corke and Wei-I. This is because I believe that a POSITA,

having knowledge of these two sources, would have been motivated to combine the disclosures of Corke and Wei-I to create the claimed elements.

~~Figure 4.7 shows the object used to perform self-calibration in Wei-I, the “Orbital Replacement Unit (ORU),” which was an “octagonal shape[d]” object used in a “1993 German Spacelab mission D2” during which it was “grasped in a predefined position by a space robot using telesensor programming.” EX1005, p.279:~~

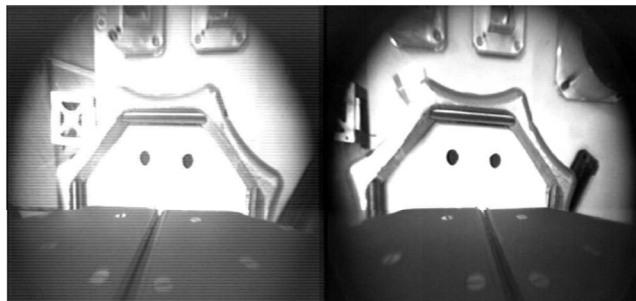


Figure 7: The images of the ORU from the hand cameras. The two black blobs are used as calibration points.

~~EX1005, p.15.~~

1. Motivation to Combine Corke and Wei-I

207. As noted above, Corke’s pose estimation methods require intrinsic, extrinsic, and hand-eye calibration. EX1004, pp.136-147. ~~Similarly, 47.~~ Corke discloses that “the task in visual servoing is to use visual information to control the pose of the robot’s end-effector relative to a target object or a set of target features,” where the “pose” is the “3D position and orientation.” EX1004, p.3. However, certain claims of the ’237 Patent require a “teaching object,” which is

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not explicitly disclosed in Corke. EX1001, Claims 5, 12–16, 21–24.

~~195-208.~~ Wei-I states that “[i]n order to use cameras for estimating robot motion for object manipulation, it is usually necessary to do the following three calibrations: camera calibration, hand-eye calibration, and robot calibration.”

EX1005, p.2. Wei-I explains that “camera calibration” “determines the camera internal and external parameters.” EX1005, p.2.

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~~“camera calibration” “determines the camera internal and external parameters.”~~

~~EX1005, p.2; EX1003, ¶¶207-208.~~

~~196.209.~~ Wei-I “propose[s] a complete autonomous approach for self-calibration of hand cameras and hand-eye relationships” that has several advantages over other calibration methods, including (1) no control points (*e.g.*, calibration plates), (2) the initial values of all unknowns are found automatically, (3) it accounts for lens distortion, and (4) it does not rely on any prior calibration.

~~EX1005, p.3; EX1003,~~

~~¶¶209-210.~~

~~A~~

210. Wei-I therefore discloses a method “for self-calibration of robotic hand cameras” using a teaching object where a determinable—rather than a known—relationship exists between at least some of the features, thus eliminating the need for a calibration plate. EX1005, p.1.

197:211. In my opinion, a POSITA would have been motivated to combine the teachings of Corke (which disclosed methods and systems that require calibration) with those of Wei-I (which provides an advantageous self-calibration method). ~~EX1003, ¶¶207-213.~~ This is because Wei-I discloses a way for a system to self-calibrate (using a teaching object) for each of the intrinsic, extrinsic, and hand-eye calibration requirements of Corke. EX1004, pp.136-147; EX1005, pp.1-3; ~~EX1003, ¶211.~~ The combination of Corke and Wei-I thus would have used Wei-I’s known calibration techniques to improve Corke’s similar device and methods in the same way as it improved Wei-I’s system. ~~EX1003, ¶211.~~

198:212. A-In my opinion, a POSITA would have ~~understood~~seen that Wei-I discloses a streamlined way to perform the calibration required by Corke. ~~EX1003, ¶212.~~ Whereas Corke requires use of a “target object” for calibration, Wei-I performs self-calibration using a teaching object of the type a robot will manipulate during calibration. EX1005, p.1. However, it is my opinion that a POSITA would ~~have understood~~understand that a “teaching object” is just a subset of a “target object” that is used specifically for self-calibration. ~~EX1003, ¶212.~~ A “target object” is simply the object that is being used to calibrate the robot. ~~EX1003,~~In a method of “self”

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calibration, like in Wei-I, that “target” object is known as a “teaching” object

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~~¶212. In a method of “self” calibration, like in Wei I, that “target” object is known as a “teaching” object because the features of the object are “determinable”—i.e., they are not already known, but can be “taught.” EX1003, ¶212. The~~

~~199:213. It is my opinion that a POSITA would have also used the “teaching object” of Wei-I in place of the “target object” of Corke. This is because this combination of Corke with Wei-I would eliminate the need for a calibration plate and would streamline, but not otherwise change, Corke’s calibration process. EX1003, ¶213.~~

2. Claims 5 and 12

[5] The method of claim 3 wherein positioning the camera with respect to ~~the calibration object comprises positioning the camera with respect to~~ a sample of a type of object the robot will manipulate, the sample having a number of features, where a known or determinable physical relationship exists between at least some of the features.

[12.1] The method of claim 1, further comprising: capturing an image of a teaching object of a type of object that will be manipulated by the robot;

[12.2] selecting a number of features from the captured image of the teaching object

[12.3] determining a set of object space coordinates for each of the selected features from the captured image of the teaching object.

~~214. As explained above, In my opinion, Corke in view of Wei-I discloses, or at least renders obvious, Claims 5 and 12.~~

~~200:215. As explained above, it is my opinion that Corke discloses all limitations of Claims 1 and found in claim 3, from on which Claims 5 and 12 depend claim 5 depends. It is also my opinion that Corke discloses all limitations of claim 1 on which claim 12 depends.~~ Corke does not specifically disclose using a teaching

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object of the type a robot will manipulate during calibration as recited in claims 5

and 12 Yet it is my opinion that Corke does

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~~as recited in Claims 5 and 12. Yet Corke does~~ disclose the use of a target object that has features where a known or determinable relationship exists between the features, and teaching objects and target object are the same—they are both objects “that will be manipulated by the robot.” EX1004, p.152; ~~EX1003, ¶215. As,~~

~~201-216. In my opinion, and as~~ described above, a POSITA would have found it obvious to improve Corke’s calibration techniques ~~(using—that use~~ a calibration object) ~~—with Wei-I’s calibration techniques (using—that use~~ a “teaching object of the type a robot will manipulate”). ~~EX1003, ¶¶214-224.”~~ This combination would eliminate the need for a calibration plate and would streamline, but not otherwise change, Corke’s calibration process discussed above. ~~EX1003, ¶216. A POSITA would have found it obvious to improve Corke’s calibration techniques with Wei-I’s teachings regarding the use of a teaching object of the type a robot will manipulate in place of a calibration object. EX1003, ¶216~~ Furthermore, Corke states that “Calibration using non-coplanar points requires a mechanically complex calibration frame,” (EX1004, p.141) which provides additional motivation for the use of a teaching object rather than a specially constructed calibration target. The combination of Corke and Wei-I thus would have used Wei-I’s known calibration techniques including a teaching object of a type of object that will be manipulated by the robot to improve Corke’s similar device and methods by eliminating the need for a specially constructed calibration target thus improving Corke in the same way that it improved Wei-I’s techniques.

~~The combination of Corke and Wei-I would have used Wei-I’s known~~

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~~calibration techniques, including a teaching object of a type of object that will be manipulated by the robot, to improve Corke's similar device and methods by eliminating the need for a specially constructed calibration target, thus improving Corke in the same way that it improved Wei-I's techniques. EX1003, ¶216.~~

~~202-217. “[¶¶]I understand that “if a technique has been used to improve one device, and a person of ordinary skill in the art would recognize~~recognized ~~that it would improve similar devices in the same way, using the technique is obvious.” KSR, 550 U.S. at 417. In other words,~~

similar devices in the same way, using the technique is obvious.” KSR Int’l Co. v.

Teleflex Inc., 550 U.S. 398, 417 (2007). In other words, it is my opinion that this

combination would have involved “the mere application of a known technique”—

Wei-I’s teachings regarding the use of a teaching object—“to a piece of prior

art”—Corke’s calibration techniques—“ready for the improvement.” ~~Id.; EX1003,~~

~~¶217. Furthermore, Corke states that “[c]alibration using non-coplanar points~~

~~requires a mechanically complex calibration frame,” which provides additional~~

~~motivation for the use of a teaching object over a specially constructed calibration~~

~~target. EX1004, p.141; EX1003, ¶216~~Id.

In my opinion, Wei-I discloses positioning the camera with respect to a sample of a type of object the robot will manipulate during the calibration step and capturing an image of a teaching object of a type of object the that will be manipulated by the robot.

~~203-218. EX1003, ¶218.~~ Wei-I discloses, in my opinion, a method “for self-calibration of robotic hand cameras” using a teaching object where a determinable—rather than a known—physical relationship exists between at least

some of the features, thus eliminating the need for a calibration plate. EX1005, p.1; ~~EX1003, ¶218.~~

As described above, it is my opinion that a POSITA would have understood that a “teaching object” is just a subset of a “target object” that is used specifically for self-calibration. ~~EX1003,~~

~~¶218.~~ In a method of “self” calibration, like in Wei-I, that “target” object is known

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as a “teaching” object because the features of the object are “determinable”—*i.e.*,

they are not already known, but can be “taught.”

~~they are not already known, but can be “taught.” EX1003, ¶218.~~

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~~204.219. Specifically,~~ Wei-I discloses using an Orbital Replacement Unit (ORU) “for camera calibration,” ~~which,”~~ EX1005, p.13. The ORU, an object used in the “1993 German Spacelab mission D2,” is an “octagonal shape” that was “to be grasped in a

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predefined position by a space robot using telesensor programming.” EX1006, ~~pp. 13,~~

~~p.279. The ORU~~ As such, it is my opinion that the ORU was a sample of the type of object the robot will manipulate. ~~EX1003, ¶219.~~

~~205.220. The~~ In my opinion, the ORU also has a number of features where a discernable physical relationship exists between some of the features. ~~EX1003, ¶220. In my opinion,~~

Wei-I discloses selecting a number of features from the captured image of the teaching object. ~~EX1003, ¶220.~~

Wei-I discloses that “two black blobs artificially marked on the object” were used as calibration points. EX1005, p.13. It is also my opinion that Wei-I also discloses capturing an image of a teaching object. ~~EX1003, ¶220.~~ As described above, ~~Wei-I’s~~ it

is my opinion that a POSITA would have understood that the “teaching object” ~~is~~ disclosed in Wei-I is simply one type of “target object” like the one disclosed in Corke. ~~EX1003, ¶220.~~ Figure 7 of Wei-I, reproduced below, shows images captured of the ORU teaching object with the two black blobs:

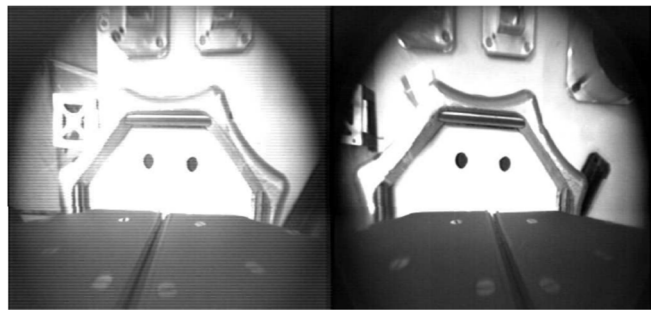


Figure 7: The images of the ORU from the hand cameras. The two black blobs are used as calibration points.

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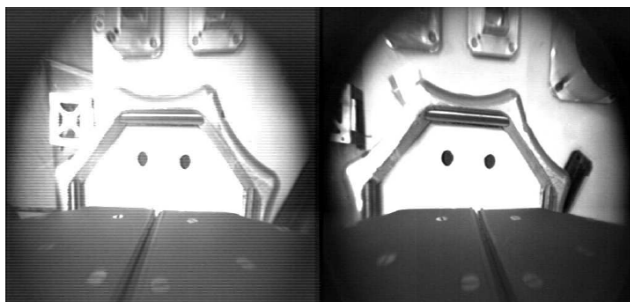


Figure 7: The images of the ORU from the hand cameras. The two black blobs are used as calibration points.

EX1005, p.15.

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~~206.221.~~ Wei-I explains that by tracking the black blobs “at various positions and orientations of the robot,” “the camera’s internal parameters (including distortion coefficients) and the mounting parameters can be calibrated.” EX1005, pp.15-16. ~~EX1003, ¶221.~~ Given the advantages ~~of~~disclosed with Wei-I’s teaching object techniques, it is my opinion that it would have been obvious to a POSITA to improve Corke with Wei-I’s disclosures regarding capturing an image of a teaching object. ~~EX1003, ¶221.~~

In my opinion, Wei-I also discloses determining a set of object space coordinates for each of the selected features from the captured image of the teaching object. ~~EX1003, ¶222.~~

For example, Wei-I explains that by tracking the black blob features on the ORU teaching object “at various positions and orientations of the robot,” the “*world points*” (“~~—i.e., “3D points”—~~”) of the black blobs were calculated. EX1005, pp.15-16. Since these 3D feature coordinates are defined with respect to the teaching object (~~, i.e., the target object~~), in my opinion a POSITA would have understood that these coordinates are in “object space.” EX1001, 3:25-26 (“object space” is “a reference frame defined with respect to a point on, and therefore rigid to, the object”); ~~EX1003, ¶222. A POSITA would have understood that use of a teaching object is preferable to the use of a special purpose calibration target, and the methods disclosed in Wei-I enable the algorithms of Corke to function without need for a calibration target. EX1003,~~

~~207.222. ¶222.”).~~ In my opinion, in view of Wei-I’s disclosure, it would

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have been obvious to a POSITA to improve Corke with Wei-I's disclosures regarding determining a set of object space coordinates for each of the selected features from the captured image of the teaching object.

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object. EX1003, ¶¶222-223. Corke in view of Wei-I discloses Claims 5 and 12.

EX1003, ¶¶214-224.

223. In sum, it is my opinion that a POSITA would have combined the teachings of Corke and Wei-I to arrive at the limitations of Claims 5 and 12 because the use of a teaching object is preferable to the use of a special purpose calibration target and the methods disclosed in Wei-I enable the algorithms of Corke to function without the need of a calibration target.

224. Accordingly, it is my opinion that Corke in view of Wei-I discloses, or at least renders obvious, Claims 5 and 12.

3. Claim 13

[13] The method of claim 12 wherein selecting a number of features from the captured image of the teaching object comprises selecting six features from the captured image of the teaching object.

208.225. In my opinion, Corke in view of Wei-I discloses, or at least renders obvious, Claim 13.

209.226. EX1003, ¶¶225-230. Corke discloses that position-based visual servoing selects features extracted from the image of a target object to determine its pose. EX1004, pp.152; 153 (“In position based control, features are extracted from the image and used in conjunction with a geometric model of the target to determine the pose of the target with respect to the camera.”); EX1003, ¶226.”).

210.227. Corke also discloses that while “at least three feature points” are needed to solve for pose, “[s]ix or more points always yield unique solutions, as

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~~well as the intrinsic calibration parameters.” EX1004, pp.159-60. Thus, according to Corke, use of six~~

~~features is preferable. EX1003, ¶227.~~

intrinsic calibration parameters.” EX1004, pp.159-160. Thus, it is my opinion that according to Corke, the use of six features is preferable.

211.228. Although Corke does not specifically disclose extracting features from an image of a *teaching* object, it discloses capturing images of a target object, extracting features, and determining the feature coordinates—and both teaching and target objects are types of objects a robot would manipulate. See, e.g., EX1004, pp.145, 152; EX1003, ¶228. For. It is my opinion, for the same reasons stated above, that it would have been obvious to a POSITA to improve Corke’s calibration procedure, which preferably selects six or more features, with Wei-I’s disclosure of a using a teaching object during calibration as described in detail above.

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features, with Wei-I's disclosure of a using a teaching object during calibration described above. EX1003, ¶¶228-229.

229. In sum, it is my opinion that a POSITA would have combined the teachings of Corke and Wei-I to arrive at the limitations of Claim 13 because Corke's teaches to use at least six feature points, and because Wei-I teaches how to obtain the 3D coordinates of these features from an object to be manipulated by the robot, rather than a specially constructed calibration target.

212,230. Accordingly, it is my opinion that Corke in view of Wei-I discloses, or at least renders obvious, Claim 13. EX1003, ¶¶225-230.

4. Claim 14

H3/[14] *The method of claim 12 further comprising: determining an object space-to-camera space transformation defining a transformation between an object space reference frame and the camera space reference frame.*

231. In my opinion, Corke in view of Wei-I discloses, or at least renders obvious, Claim 14.

213:232. Corke discloses determining an object space-to-camera space transformation of a target object, which, in my opinion, like a teaching object, is the type of object a robot would manipulate. ~~See, e.g.,~~ EX1004, p.152; ~~EX1003, ¶¶231-236.~~ The object space-to-camera space transformation is depicted in Figure 5.1 of Corke, where P is the object and ${}^c x_t$ is the transformation between the camera and the target—*i.e.*, the “object of interest”:

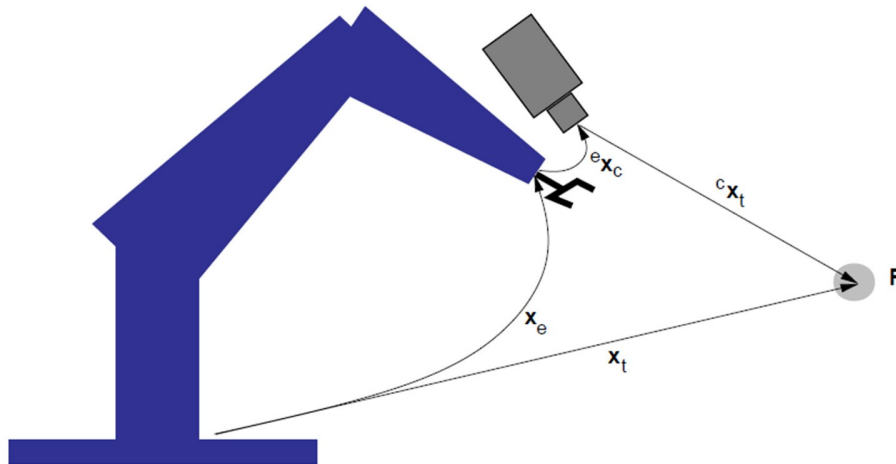


Figure 5.1: Relevant coordinate frames; world, end-effector, camera and target.

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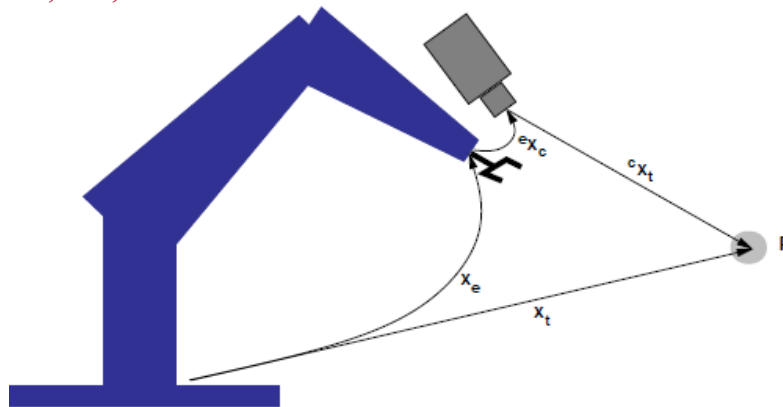


Figure 5.1: Relevant coordinate frames; world, end-effector, camera and target.

EX1004, p.152; ~~EX1003, ¶232.~~

233. Corke does not expressly disclose determining an object space-to-camera space transformation using a teaching object, but in my opinion, and as described above, ~~#Corke~~ discloses determining an object space-to-camera space transformation using a target object. EX1004, p.153; ~~EX1003, ¶233.~~ For the same reasons;

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stated above, it is my opinion that it would have been obvious to a POSITA to improve Corke with Wei-I's disclosure of using a teaching object for calibration.

~~EX1003, ¶233.~~

214.234. Wei-I discloses a self-calibration method using a teaching object—the ORU—to determine a camera's extrinsic parameters, including the “transformation from the sensor space to the world space.” EX1005, p.15~~;~~ ~~EX1006, p.279.~~ Using such a method, the “3D points” for the features on the ORU teaching object in a world space can be determined. EX1005, pp.7, 13-15. Since these 3D feature coordinates are defined with respect to the teaching object, it is my opinion that a POSITA would have understood that they are in “object space.” EX1001, 3:25-26 (“object space” is “a reference frame defined with respect to a point on, and therefore rigid to, the object”); ~~EX1003, ¶234.”).~~ Thus, in my opinion, Wei-I teaches a camera space-to-object space transformation for a teaching object. ~~EX1003, ¶234.~~ transformation for a teaching object. Given the advantages ~~of~~ disclosed with Wei-I's teaching object techniques, in my opinion it would have been obvious to a POSITA to improve Corke with Wei-I's disclosures regarding a camera space-to-object space transformation for a teaching object. ~~EX1003, ¶¶234-235.~~

235. In sum, it is my opinion that a POSITA would have combined the teachings of Corke and Wei-I to arrive at the limitations of Claim 14 because doing so would eliminate the need for a specially constructed calibration target, including

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the need for a precise geometric determination of the features on the calibration target.

~~215-236.~~ Accordingly, it is my opinion that Corke in view of Wei-I discloses, or at least renders obvious, Claim 14. ~~EX1003, ¶¶231-236.~~

5. Claim 15

~~[14]/[15]~~ *The method of claim 14 further comprising: determining a position and an orientation of an object frame in the tool frame reference frame based at least in part on the object frame-to-camera space and camera space-to-tool space transformations.*

237. In my opinion, Corke in view of Wei-I discloses, or at least renders obvious, Claim 15.

~~216-238.~~ Corke discloses determining object space-to-camera space and camera space-to-tool space transformations. ~~EX1003, ¶¶237-242.~~ For example, Corke discloses that in “position-based control, features are extracted from the image” of the target object “and used in conjunction with a geometric model of the target to determine the pose of the target with respect to the camera”—~~(“—i.e., the object space-to-camera space transformation)—~~and the “pose of the camera” with respect to “the pose of the end-effector”—~~(“—i.e., the camera space-to-tool space transformation)—~~. EX1004, p.152. Corke explains that “[o]nce the target pose relative to the camera is determined, it is then necessary to determine the target pose”—i.e., the position and orientation of the object frame—“relative to the robot’s end-effector”—i.e., the tool reference frame— based at least in part on the object space-to-camera-space and camera space-to-tool space calibrations. EX1004, p.160. “This requires robot hand-eye calibration.” EX1004, p.160; ~~EX1003, ¶238.~~

217.239. Corke does not expressly disclose determining an object space-to-camera space or camera space-to-tool space transformation using a teaching object, but in my opinion, and as described above, it discloses those transformations using a target object. EX1004, p.152; ~~EX1003, ¶239. For the same reasons stated above. In my opinion,~~ it would have been obvious to a POSITA to improve Corke with Wei-I's disclosure of using a teaching object to perform these transformations. ~~EX1003, ¶239.~~

218.240. Wei-I discloses a self-calibration method using a teaching object to determine an object space-to-camera space transformation ~~—(i.e.,~~ extrinsic calibration) and a camera ~~_~~space-to-tool ~~_~~space transformation (i.e., hand-eye calibration). EX1005, pp.1-3. Corke states that calculating the hand-eye calibration necessarily involves a determination of “the target pose relative to the robot's end-effector.” EX1004, p.160. Thus, in my opinion, Wei-I also discloses using a teaching object to determine the position ~~and orientation of the~~ of the object frame in the tool frame reference frame. Given the advantages disclosed with Wei-I's teaching object techniques, it is my opinion that it would have been obvious to a POSITA to improve Corke with Wei-I's disclosures regarding determining an object space-to-camera space transformation and a camera space-to-tool space transformation. ~~EX1003, ¶¶240-241.~~

241. In sum, it is my opinion that a POSITA would have combined the teachings of Corke and Wei-I to arrive at the limitations of Claim 15 because doing so would eliminate the need for a specially constructed calibration target, including

the need for a precise geometric determination of the features on the calibration target.

219-242. Accordingly, it is my opinion that Corke in view of Wei-I discloses ,or at least renders obvious, Claim 15. ~~EX1003, ¶¶237-242.~~

6. Claim 16

~~[15]~~[16] *The method of claim 15, further comprising: providing the position and orientation of the object frame to the robot; and training an intended operation path inside the object frame.*

243. In my opinion, Corke in view of Wei-I discloses ~~providing, or at least renders obvious,~~ Claim 16.

In my opinion, the ~~position and orientation of the object frame to the robot.~~ ~~EX1003, ¶¶243-252.~~

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220.244. The claimed “training an intended operation path” seems to be merely ~~specifies~~specifying the locations of “way points” (*i.e.*, points that should explicitly be visited by the robot) with respect to the object frame, or specifying a tool trajectory with respect to the object frame. ~~EX1003, ¶244.~~ In both cases, these points can then be converted to any of the other coordinate frames (*e.g.*, tool space, camera space, robot space, etc.) using the calibration information. ~~EX1003, ¶244.~~ Transformations of this kind are given by Corke in, for example, Equations (4.58) and (4.59):

$${}^0\mathbf{T}_P = {}^0\mathbf{T}_c {}^c\mathbf{T}_P \quad (4.58)$$

$${}^c\mathbf{T}_P = ({}^0\mathbf{T}_c)^{-1} {}^0\mathbf{T}_P \quad (4.59)$$

245. ~~EX1004, p.138; EX1003, ¶245.~~ Transformations of this kind are also given by Corke in, for example, Equations (4.58) and (4.59):

$${}^0\mathbf{T}_P = {}^0\mathbf{T}_c {}^c\mathbf{T}_P \quad (4.58)$$

$${}^c\mathbf{T}_P = ({}^0\mathbf{T}_c)^{-1} {}^0\mathbf{T}_P \quad (4.59)$$

EX1004, p.138.

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~~221-246.~~ Similarly, transformations of this kind are illustrated in Figures 4.7
and

5.1 of Corke:

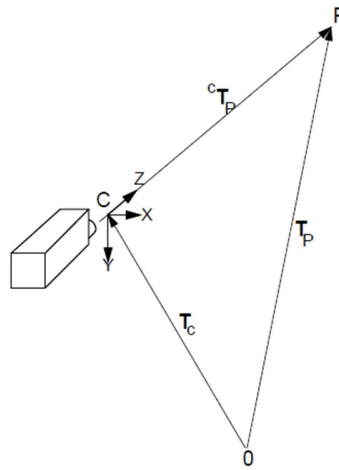


Figure 4.7: Relevant coordinate frames.

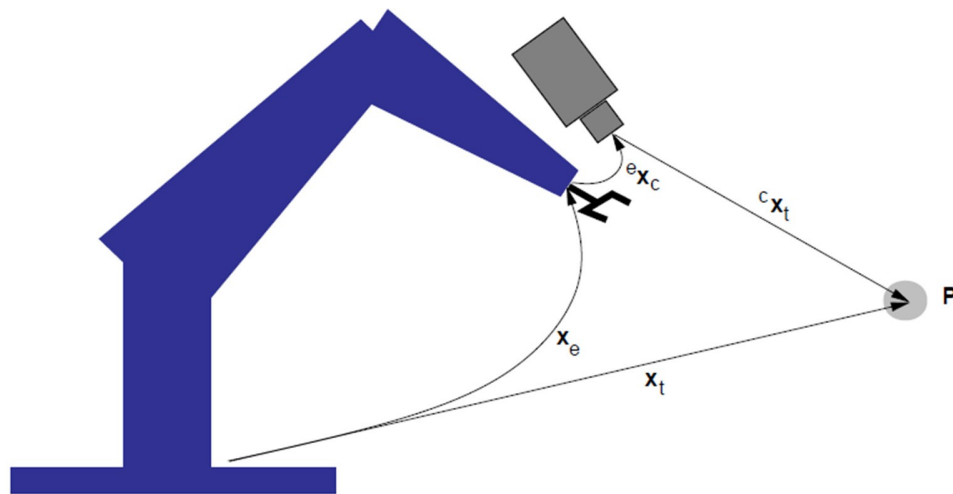


Figure 5.1: Relevant coordinate frames; world, end-effector, camera and target.

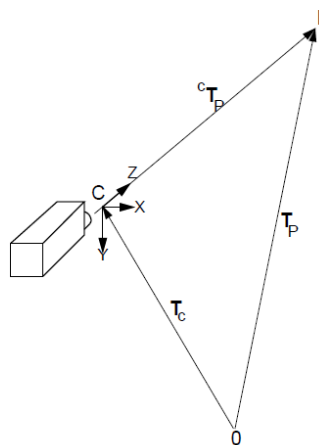


Figure 4.7: Relevant coordinate frames.

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EX1004, ~~ppp.~~ 139, -

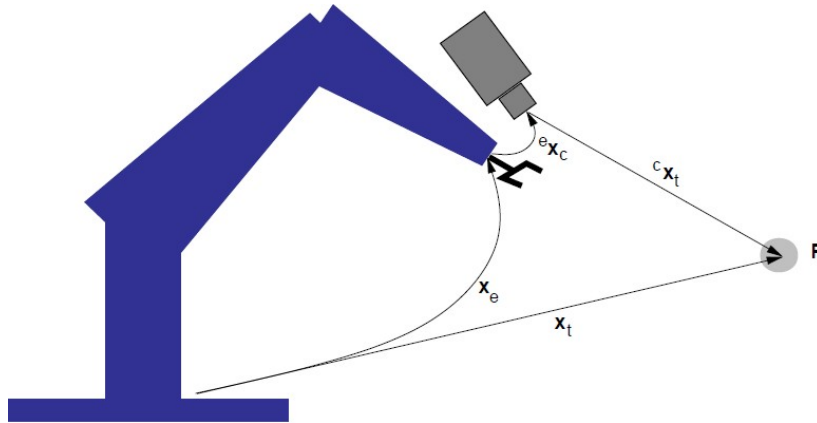


Figure 5.1: Relevant coordinate frames; world, end-effector, camera and target.

EX1004, p. 152; EX1003, ¶ 246.

247. ~~Figure 5.4 of Corke~~ Further, in my opinion, Corke discloses providing the position and orientation of the object frame to the robot. Figure 5.4 of Corke, reproduced below,

shows that the position-based visual servoing method disclosed in Corke sends the target object's "pose estimation"—*i.e.*, the object frame—to the robot:

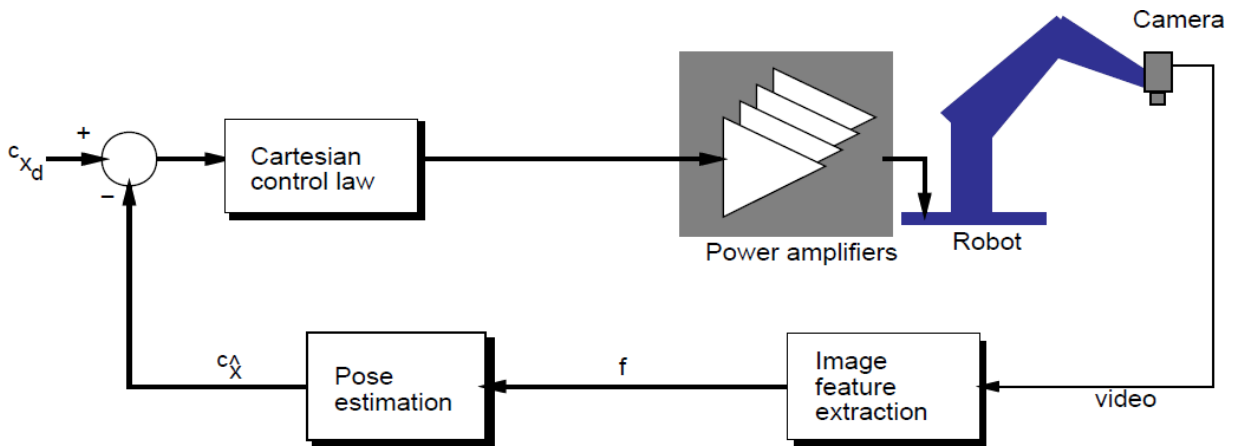


Figure 5.4: Position-based visual servo (PBVS) structure as per Weiss.

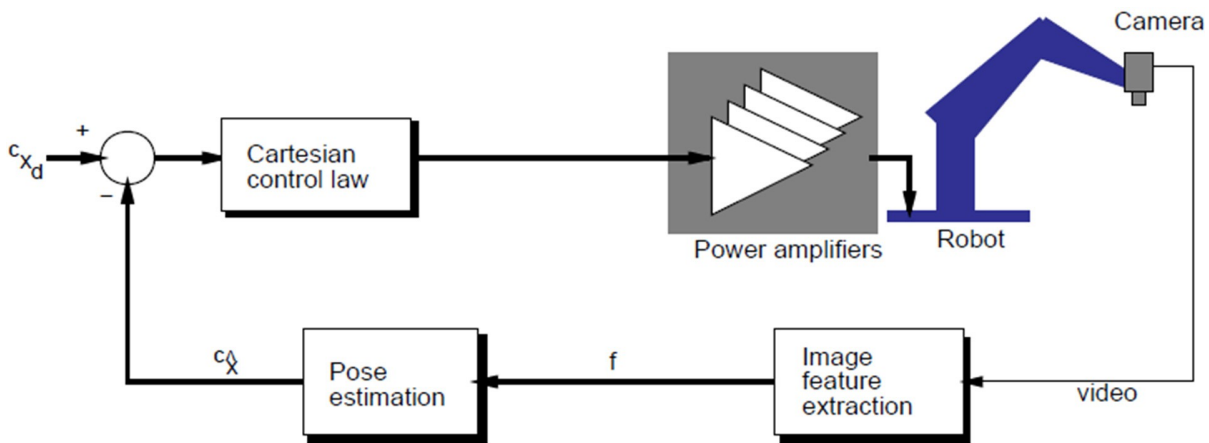


Figure 5.4: Position-based visual servo (PBVS) structure as per Weiss.

EX1004, p.155; EX1003, ¶247.

222-248. Corke also describes training an intended operation path inside the object frame. EX1003, ¶248. According to Corke, “sensory data”—including an object frame determined by Corke’s transformations—can modify a robot’s movements. EX1004, p.179. Corke discloses “[m]oving [the robot] to a position defined in terms of [a] transformation” such that the robot’s motion is “controlled by the vision system.” EX1004, p.179. Figure 6.4 of Corke illustrates a method by which the trajectory of the robot is altered based on information received about the object’s pose by a “trajectory generator”:

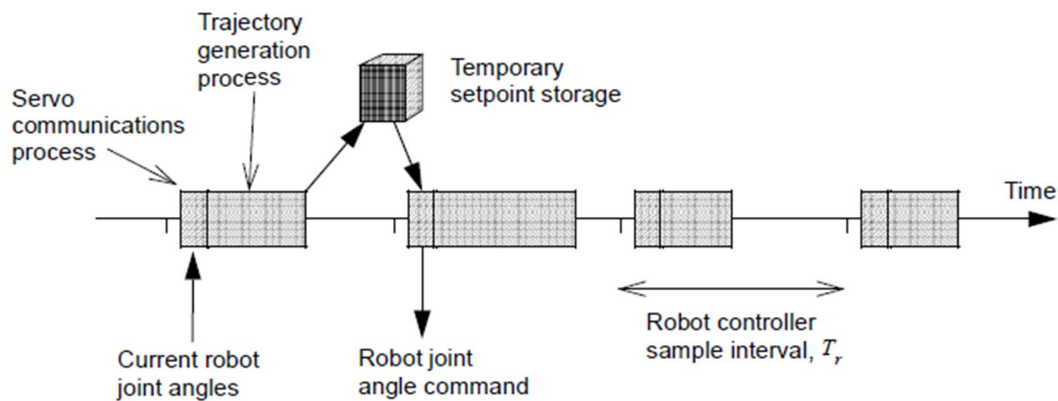


Figure 6.4: Timing of ARCL setpoint generator and servo communication processes.

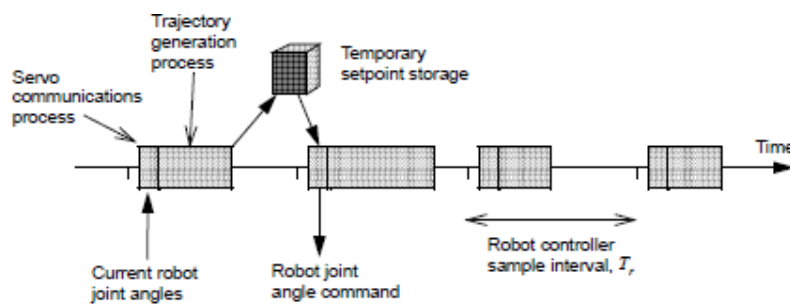


Figure 6.4: Timing of ARCL setpoint generator and servo communication processes.

EX1004, p.179.

223.249. Corke's "trajectory generator" "move[s] the robot to the general vicinity of the target." EX1004, p.265. In my opinion, a POSITA would have understood that Corke's trajectory generator can train an intended operation path inside the object

inside the object frame based on pose information (*i.e.*, an "object frame"). ~~EX1003, ¶249.~~

224.250. Corke does not expressly disclose a teaching object, but in my opinion, and as described ~~in great detail~~ above, it discloses providing the position and orientation of an object frame to the robot and training the robot's operation path.

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~~EX1003, ¶250. For the same reasons stated above,~~It is my opinion that it would have been obvious to a POSITA to improve Corke's teaching of providing the object frame to the robot with Wei-I's disclosure of using a teaching object to generate the object frame.~~EX1003, ¶¶250-251.~~

251. In sum, it is my opinion that a POSITA would have combined the teachings of Corke and Wei-I to arrive at the limitations of Claim 16 because doing so would eliminate the need for a specially constructed calibration target, including

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the need for a precise geometric determination of the features on the calibration target.

Accordingly, it is my opinion that Corke in view of Wei-I discloses ~~Claim, or~~
at least renders obvious, ¶¶ 16-243, 243-252.

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252. Claim 16.

7. Claim 21

~~[21.1]~~⁸

[21.1] The apparatus of claim 20, further comprising: means for training, comprising: capturing an image of a teaching object of a type of object that will be manipulated by the robot;

~~225-253.~~ In my opinion, Corke in view of Wei-I discloses, or at the very least, renders obvious, Element [21.1].~~EX1003,~~

~~226-254.~~ ~~¶¶253-258.~~ For example, in my opinion and as explained above, Corke discloses all limitations in ~~Claim~~claim 20 ~~from~~on which ~~Claim~~claim 21 depends. Corke does not expressly disclose training of a teaching object, but in my opinion and as described above, it discloses capturing images of a target object, extracting features, determining the feature coordinates, and determining a target object space-to-camera space transformation. ~~For the same reasons stated above,~~It is my opinion that it would have been obvious to a POSITA to improve Corke's calibration techniques with Wei-I's disclosure of using a teaching object to perform the calibration.~~EX1003, ¶254.~~

~~227-255.~~ For example, in my opinion, Wei-I discloses using a teaching object of a type that will be manipulated by the robot. ~~EX1003, ¶255.~~Specifically, Wei-I discloses a self-calibration method that does not use calibration plates, but rather any object that

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has features where a determinable relationship exists between those features.

EX1005, p.2. Wei-I discloses using an ORU “for camera calibration.” EX1005,

p.13. The ORU is an “octagonal shape” that was “to be grasped in a predefined

position by a space robot using telesensor programming.” EX1006, p.279. During

prosecution when application claim 54 (issued Claim 21) was rejected as

anticipated and obvious over Wei-II (which disclosed a method of machine vision

that “avoids” all calibration), it is my understanding that the Patent Owner did not

argue that the object used in those experiments was not “the type of object the

robot will manipulate.” EX1002, p.642. An image of the ORU is shown in Figure

7 of Wei-I; ~~EX1006, p.279. During prosecution when application claim 54~~

~~⁸The cited portions of EX1003 provide the claim language for the corresponding portions of the claim.~~

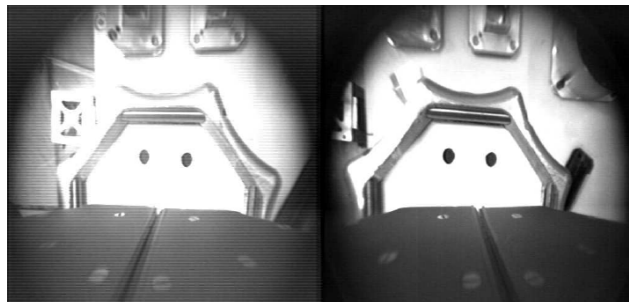


Figure 7: The images of the ORU from the hand cameras. The two black blobs are used as calibration points.

~~(issued Claim 21) was rejected over Wei-II (which disclosed a method of machine-vision that “avoids” all calibration), the Patent Owner did not argue that the object used in those experiments was not “the type of object the robot will manipulate.”~~

~~EX1002, p.642. An image of the ORU is shown in Figure 7 of Wei-I:~~

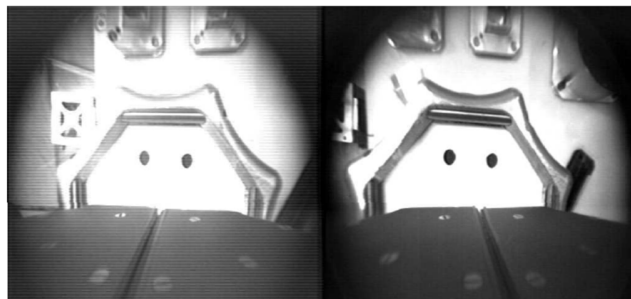


Figure 7: The images of the ORU from the hand cameras. The two black blobs are used as calibration points.

EX1005, p.15. ~~The~~

~~228:256.~~ In my opinion, the ORU used in Wei-I’s calibration method was a sample of the type of object the robot will manipulate. ~~EX1003, ¶256.~~ Given the advantages disclosed with Wei-I’s teaching object techniques, it is my opinion that it would have been obvious to a POSITA to improve Corke with Wei-I’s disclosures regarding

capturing an image of a teaching object of a type that will be manipulated by the robot. ~~EX1003,~~

~~257. ¶¶256-257.~~ In sum, it is my opinion that a POSITA would have combined the teachings of Corke and Wei-I to arrive at the limitations of Element [21.1] because doing so would eliminate the need for a specially constructed calibration target, including the need for a precise geometric determination of the features on the calibration target.

258. Accordingly, it is my opinion that Corke in view of Wei-I discloses, or at least renders obvious, Element [21.1].

[21.2] selecting a number of features from the captured image of the teaching object; determining a set of object space coordinates for each of the selected features from the captured image of the teaching object;

~~229-259.~~ In my opinion, Corke in view of Wei-I discloses, or at least renders obvious, Element [21.1]. ~~EX1003, ¶¶253-258-2.~~

~~[21.2]~~

~~230-260.~~ For example, it is my opinion that Wei-I discloses selecting a number of features from the captured image of the teaching object. ~~EX1003, ¶¶259-263.~~ Specifically, Wei-I states that “two black blobs” were “artificially marked on the object” and used as calibration features. EX1005, p.13; ~~EX1003, ¶260.~~

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~~Wei-II~~ It is also ~~my opinion that Wei-I~~ discloses determining a set of object space coordinates for each of the selected features from the captured image of the teaching object. ~~EX1003, ¶261.~~

~~231.~~261. Wei-I explains that by capturing images of the black blobs “at

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various positions and orientations of the robot,” the camera’s extrinsic parameters, including the “transformation from the sensor space to the world space,” and the “world points”—“—i.e., “3D points”—of the features, are calculated. EX1005, pp.15-16, 1. Since these ~~3Dfeature~~3D feature coordinates are defined with respect to the teaching object, ~~they are~~ it is my opinion that a POSITA would have understood these coordinates to be in “object space.” EX1004, pp.137-~~38~~138; EX1001, 3:25-26 (defining “object space” as “a reference frame defined with respect to a point on, and therefore rigid to, the object”). For the same reasons stated above, it is my opinion that it would have been obvious to a POSITA to improve Corke’s calibration techniques with Wei-I’s disclosure of using a teaching object to perform the calibration. ~~EX1003, ¶¶261-262. Corke in view of Wei-I discloses Element [21.2]. EX1003, ¶¶259-263.~~

~~{21.3}~~

262. In sum, it is my opinion that a POSITA would have combined the teachings of Corke and Wei-I to arrive at the limitations of Element [21.2] because doing so would eliminate the need for a specially constructed calibration target, including the need for a precise geometric determination of the features on the calibration target.

263. Accordingly, it is my opinion that Corke in view of Wei-I discloses, or at least renders obvious, Element [21.2].

[21.3] determining an object space-to-camera space transformation defining a transformation between an object space reference frame and the camera space reference frame.

~~264. space reference frame. EX1003, ¶¶264-268.~~ In my opinion, Corke in view of

~~Wei-I discloses, or at least renders obvious, Element [21.3].~~

~~For instance, in my opinion, Wei-I discloses determining an object space-to-camera space transformation defining a transformation between an object space reference frame and the camera space reference frame.~~ The algorithms of Wei-I

“can compute the pose of an object from an image containing several noncoplanar feature points of the object.” EX1005, p.24. Put another way, Wei-I determines the

“transformation from the sensor space”—i.e., camera space—“to the world space.”

EX1005, pp.15-16;

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232-265. EX1003, ¶265. Since these world coordinates are defined with respect to the teaching object, ~~they are~~ it is my opinion that a POSITA would have understood these coordinates to be in “object space.” EX1004, pp.137-38; EX1001, 3:25-26 (defining “object space” as “a reference frame defined with respect to a point on, and therefore rigid to, the object”).

233-266. Moreover, the '237 Patent states that “the calibration and teaching steps” “can be combined by using a self calibration method of robotic eye and hand-eye relationship with model identification as described in” Wei-I. EX1001, 8:30-39. The '237 Patent states that the self-calibration method in Wei-I can be used “for computing the 3D position of the selected features automatically, without any ~~prior knowledge of the part.~~” EX1001, 6:6-7:2. ~~For the same reasons stated above, it would have been obvious to a POSITA to improve Corke’s calibration techniques with Wei-I’s disclosure of using a teaching object to perform the calibration. EX1003, ¶266-267. Accordingly, Corke in view of Wei-I discloses Element [21.3]. EX1003, ¶¶264-268.~~

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prior knowledge of the part.” EX1001, 6:6-7:2. For the same reasons stated above, it is my opinion that it would have been obvious to a POSITA to improve Corke’s calibration techniques with Wei-I’s disclosure of using a teaching object to perform the calibration.

267. In sum, it is my opinion that a POSITA would have combined the teachings of Corke and Wei-I to arrive at the limitations of Element [21.3] because doing so would eliminate the need for a specially constructed calibration target, including the need for a precise geometric determination of the features on the calibration target.

268. Accordingly, it is my opinion that Corke in view of Wei-I discloses, or at least renders obvious, Element [21.3].

8. Claims 22 and 23

[22] Corke—discloses—using The apparatus of claim 21 wherein the means for calibrating, the means for estimating a pose, and the means for training comprises at least one programmed computer and/or.

[23] The apparatus of claim 21 wherein the means for calibrating, the means for estimating a pose, and the means for training comprises at least one computer-readable medium— for — calibration — and — pose — storing — instructions operating at least one computer.

269. In my opinion, Claims 22 and 23 are disclosed, or at least rendered obvious, by Corke in view of Wei-I.

In my opinion, Corke discloses using at least one programmed computer and/or computer-readable medium for calibration and pose estimation. EX1003,

234-270. ¶¶269-275. For example, Corke discloses that visual servoing is a

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method used for “computer

vision”—*i.e.*, the “application of a computer system for receiving and processing information,” including image interpretation. EX1004, p.123. Corke also discloses a calibration matrix run on a computer. ~~EX1003, ¶270.~~ This matrix is a “3x4 homogenous transform which performs scaling, translation, and perspective” and “represents the relationship between 3-D world coordinates and their corresponding 2-D image coordinates as seen by the computer.” EX1004, p.138; see also EX1004, p.167 (stating that “image processing” is handled “by a conventional computer”).

271. One of the computer systems used by Corke is shown in Figure 6.2:
~~One of the computer systems used by Corke is shown in Figure 6.2:~~

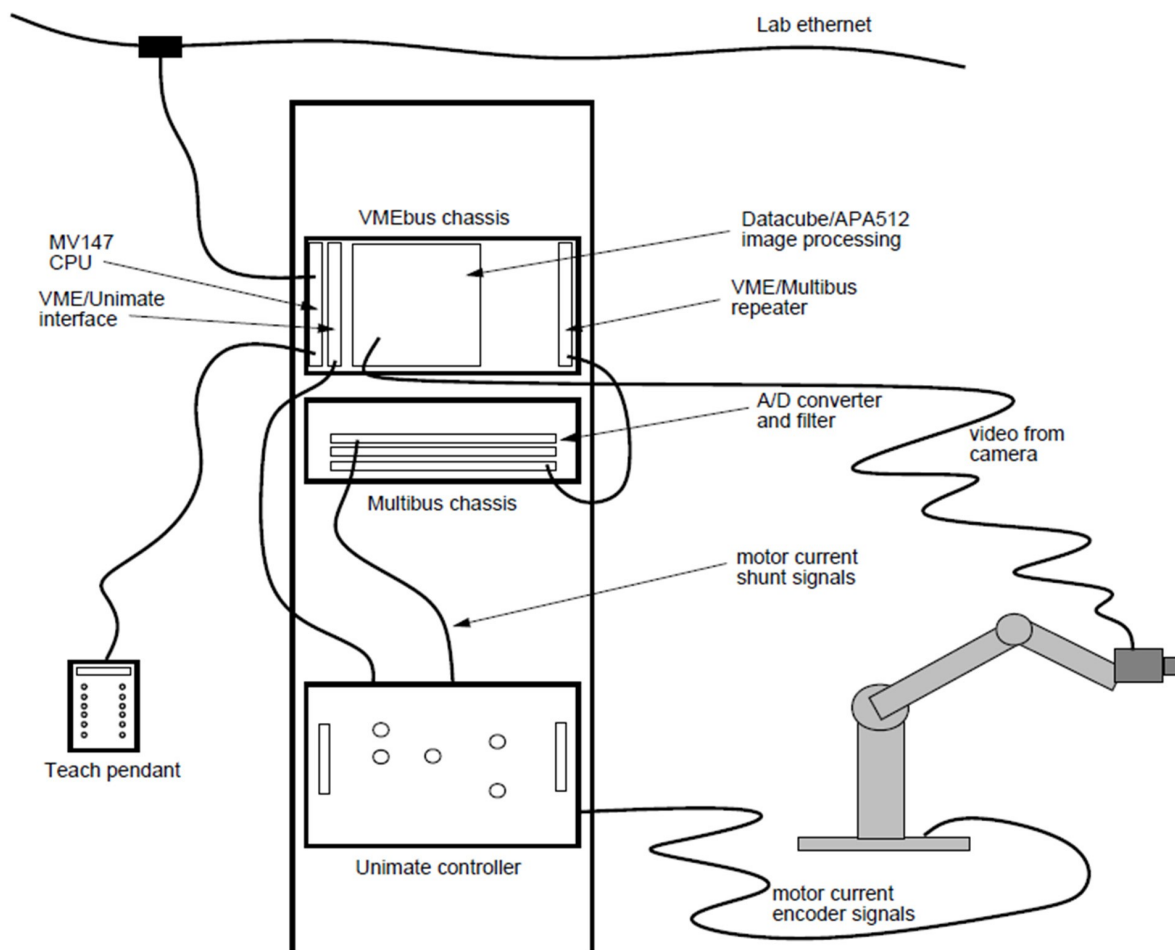


Figure 6.2: Overall view of the system used for visual servo experiments.

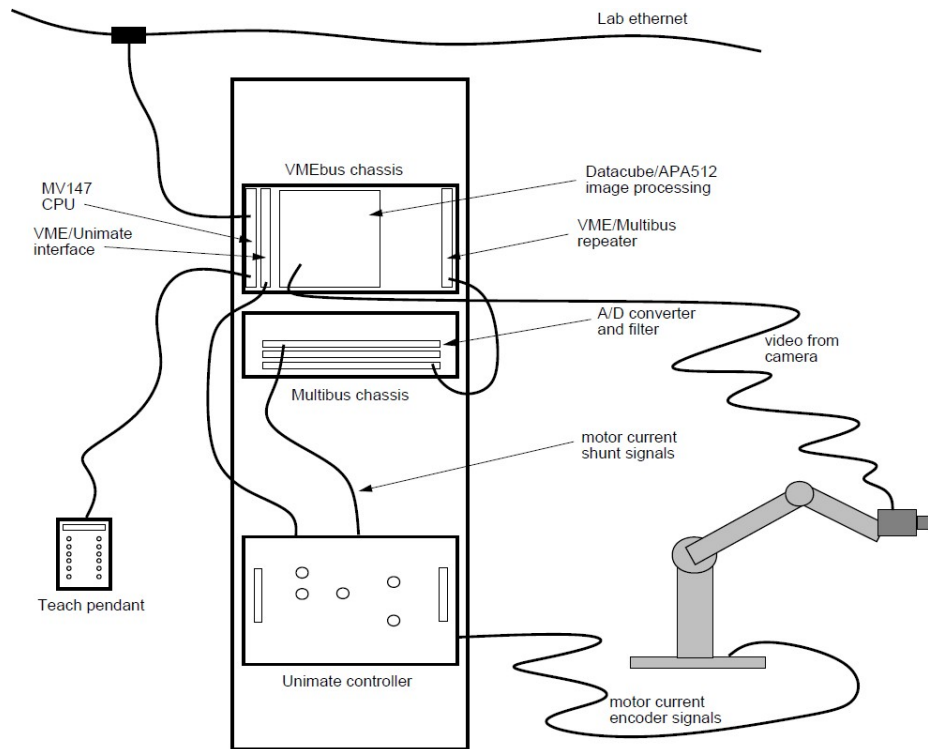


Figure 6.2: Overall view of the system used for visual servo experiments.

EX1005, p.176; ~~EX1003, ¶271. The~~

~~235-272.~~ In my opinion, a POSITA would have understood that the computer in Figure 6.2 processes information received from the robot and uses it to calculate calibration parameters and determine pose. ~~EX1003, ¶272. A~~In particular, in my opinion, a POSITA would have understood that the Datacube image processing device in Figure 6.2 is a computer that processes images obtained from the camera. EX1004, pp.175-177; ~~EX1003, ¶272.~~ Corke also describes the processor and operating system used in the system shown in Figure 6.2, “[t]he CPU is a Motorola MV147 68030 processor card,” which a POSITA would have understood to be a computer, and the operating system as VxWorks, a “real-time multi-tasking operating system is used to support software running in the target processor.” EX1004, pp.175-177; ~~EX1003, ¶272. A.~~ In my opinion, a POSITA would have ~~therefore~~ understood that this operating system requires a computer system that includes a computer-readable medium for storing instructions. ~~EX1003, ¶272.~~

~~236-273.~~ Corke does not specifically disclose use of a teaching object, but in my opinion and as described above, it discloses use of a target object, and there is no discernable difference between a teaching and target object. ~~EX1003, ¶273. For the same reasons stated above, to~~ To the extent it would not have been understood from Corke to use a “teaching object of the type a robot will manipulate,” it is my opinion that it would have been obvious to do so in view of Wei-I. ~~EX1003, ¶¶273-274.~~ because Wei-I discloses the use of a computer processor—specifically a Datacube MaxVideo 200 image processing system—to determine the calibration

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parameters. EX1005, p.13.

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~~Corke in view of Wei I discloses Claims 22 and In sum, it is my opinion~~²³~~23.~~
EX1003, ¶¶269-275.

~~XI. DISCRETIONARY DENIAL UNDER § 314 OR § 325(d) IS NOT WARRANTED~~

~~A. § 314~~

~~The Petition should not be denied under the discretionary factors set out in *Apple Inc. v. Fintiv, Inc.*, IPR2020-00019, Paper 11, at 6 (PTAB March 20, 2020) (“*Fintiv I*”). Petitioner addresses each factor below:~~

~~1. Stay. No stay has been requested in the Related Litigation. Given that , the Board should not infer the outcome of any such motion. *Apple Inc. v. Fintiv, Inc.*, IPR2020-00019, Paper 15, at 12 (PTAB May 13, 2020) (“*Fintiv IP*”). This factor is neutral on discretionary denial.~~

~~2. Trial Date. Pursuant to 35 U.S.C. §316(a)(11), a Final Written Decision will likely issue in February 2025. By contrast, jury selection in the Related Litigation is scheduled to being, at the earliest, on April 21, 2025. EX1013, p.13. Accordingly, the trial court proceedings POSITA would not be completed until several months after a Final Written Decision would be due in this IPR. *Fintiv I* states that this factor does not implicate the decision whether to institute even “if the trial date is at or around the same time as the projected statutory deadline.” IPR2020-00019, Paper 11, at 6. This factor weighs against discretionary denial.~~

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3. — Investment. The Related Litigation is in its initial stages, and the investment in it has been minimal. Indeed, fact discovery in the matter is in its early stages.

EX1011. This factor weighs against discretionary denial.

4. — Overlap. Instituting a proceeding will allow the Board to address the art and the issues will be narrowed in the Related Litigation through the estoppel provisions of 35 U.S.C. §315(e)(2). The most efficient course is for the Board to address the issues before it, and the district court to address the issues that that remain in view of the estoppel provisions of 35 U.S.C. §315(e)(2). This factor weighs against discretionary denial.

5. — Same party. Petitioner is the defendant in the Related Litigation filed by Patent Owner. EX1011. That is true of most Petitioners in IPR proceedings. This factor should not be a basis for denying institution.

6. — Other circumstances. As discussed above, the prior art strongly demonstrates that Claims 1-10 and 12-28 are unpatentable as obvious. The merits of Petitioner's arguments are strong and the evidence in support of them is substantial. Thus, this factor weighs against discretionary denial. *See Sand Revolution II, LLC v. Continental Intermodal Group—Trucking LLC*, IPR2019-01393, Paper 24 at 13 (PTAB June 16, 2020).

B. § 325(d)

~~Noninstitution under § 325(d) also is unwarranted based on the factors set forth in *Becton, Dickinson & Co. v. B. Braun Melsungen AG*, IPR2017-01586, Paper 8 at 17-18 (P.T.A.B. Dec. 15, 2017) (precedential). Neither Corke nor Wei I, the prior art references relied upon in this Petition, were relied upon during the prosecution in a rejection. Furthermore, Corke does not appear in the record for prosecution history. Wei I is expressly referenced in the specification of the '237 Patent (EX1001, 6:6-7:2), but was not relied upon by the Examiner during prosecution. The Examiner did rely upon Wei II, another reference authored by the same author as Wei I, to reject the claims, but these references disclose completely different methods. See fn. 1. In fact, Patent Owner overcame Wei II on the basis that "Wei[II] ...is directed to the use of a stereo *pair of cameras*" but the claimed invention is "directed to methods and apparatus that employ *single camera* three-dimensional (3-D) vision for robotic guidance." EX1002, p.129. Indeed, this Petition relies upon prior art to supply have combined the teachings of Corke and Wei-I to arrive at the limitations that Patent Owner argued were missing from the prior art, which the Examiner relied upon to allow the claims. Furthermore, neither Corke nor Wei I are cumulative of the art relied upon by the Examiner during prosecution, and the proposed challenges to this Petition do not overlap with the arguments made during prosecution.~~

~~Accordingly, this Petition should not be denied on discretionary factors.~~

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~~U.S. Patent No. 8,095,237~~

~~Dated: September 22, 2023~~ — ~~Respectfully submitted,~~

~~/s/Andrew R. Sommer~~

~~Andrew R. Sommer~~

~~Reg. No. 53,932~~

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CERTIFICATE OF COMPLIANCE

~~This petition complies with the word count limits set forth in 37 C.F.R. § 42.24(a)(i), effective May 2, 2016, of Claims 22 and 23 because this Petition contains 13,874 words, excluding the parts of the petition exempted by doing so would eliminate the need for a specially constructed calibration target 37 C.F.R. § 42.24(a), as determined using the word count provided by Microsoft Word, which was used to prepare this Petition.~~

~~Dated: September 22, 2023~~ ~~Respectfully submitted,~~

~~/s/Andrew R. Sommer~~

~~Andrew R. Sommer
Reg. No. 53,932~~

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U.S. Patent No. 8,095,237

CERTIFICATE OF SERVICE

237.274. Pursuant to 37 C.F.R. §§ 42.6(e) and 42.105(a), the undersigned certifies that on September 22, 2023, I caused a true and correct copy of the Petition for *Inter Partes* Review, including Exhibit List; Power of Attorney; and Exhibits 1001 through 1013, by UPS on the Patent Owner at the correspondence address of record for U.S. Patent No. 8,095,237 as follows: the need for a precise geometric determination of the features on the calibration target.

Seed Intellectual Property Law Group LLP
701 Fifth Avenue
Suite 5400
Seattle, WA 98104

I further certify that a courtesy copy of the above identified materials were served on litigation counsel by electronic means upon the foregoing individuals:

John Shaw—Nathan Hoeschen—
Anna Phillips—John Rozendaal—
Kristina Caggiano Kelly—Michael Joffre—
William Milliken—

/s/Andrew R. Sommer

275. ~~Andrew R. Sommer Reg. No. 53,932~~ Accordingly, it is my opinion that Corke in view of Wei-I discloses, or at least renders obvious, Claims 22 and 23.

IX. OBJECTIVE INDICIA OF NON-OBVIOUSNESS

276. I am not aware of any objective indicia of non-obviousness that would make Claims 1–10 and 12–28 of the '237 Patent non-obvious over the prior art considered herein. In my opinion, any possible objective indicia of nonobviousness would not overcome the prior art that clearly demonstrates that the subject matter of Claims 1–10 and 12–28 of the '237 Patent would have been obvious to a POSITA

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~~as of January 31, 2002.~~

277. I reserve the right to supplement my opinions as appropriate if RVT alleges or offers any purported evidence of any such objective indicia of nonobviousness.

278. 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 the 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 the Title 18 of the United States Code.

Executed this 22nd day of September 2023.

Respectfully submitted,

A handwritten signature in blue ink, appearing to read "Seth Hutdinson", written over a horizontal line.

Seth Hutdinson, Ph.D.