



Faculty of Engineering
Mechatronics Engineering Department

Position Based Visual Servoing Control System for a Movable
Platform

A thesis submitted in partial fulfillment of the requirements for the
degree of

MASTER OF ENGINEERING SCIENCE

in

MECHANICAL ENGINEERING
(MECHATRONICS)

By

Wael Sami Abd Elhamid Taie

B.Sc. Mechatronics Engineering

October 6 University, 2009

Supervisors:

Prof. Magdy M. Abdelhameed

Dr. Mohammed A.R. Marey

Cairo, 2015

Examiners Committee

The undersigned certify that they have read and recommend to the Faculty of Engineering – Ain Shams University for acceptance a thesis entitled “Position Based Visual Servoing Control System for a Movable Platform” submitted by Wael Sami Abd Elhamid Taie, in partial fulfillment of requirement for the degree of Master of Engineering Science in Mechatronics Engineering.

Signature

Prof. Dr. Farid A. Tolbah
Professor of Automatic Control
Mechatronics Engineering Dept.
Faculty of Engineering – Ain Shams University

Prof. Dr. Magdy M. Abdelhameed
Professor of Automatic Control and
Mechatronics
Mechatronics Engineering Dept.
Faculty of Engineering – Ain Shams University

Prof. Dr. Osama Ezzat Abd Ellatif
Professor of Mechanical Engineering
Mechanical Engineering Dept.
Faculty of Engineering – Shobra – Banha
University

Researcher Profile

Name : Wael Sami Abd Elhamid Taie
Last Degree : BS.c. Mechatronics Engineering
Specialty : Mechatronics Engineering
From : October 6 University, Faculty of Engineering
Current Position: Teaching Assistant, October 6 University

Name: Wael Sami Abd Elhamid Taie

Signature:

Statement

This thesis is submitted in the partial fulfillment of master degree in Mechanical Engineering to Ain Shams University.

The author carried out the work included in this thesis, and no part of this thesis has been submitted for a degree or qualification at any other university.

Signature

Wael Sami Abd Elhamid Taie

Acknowledgement

I would like to express my warmest gratitude to Prof. Magdy Abdelhamed for his continuous encouragement to always be better and facilitating the usage of the robot platform.

I would also like to thank Dr. Mohammed Marey for providing me with valuable resources and his effective help during the measuring phase.

I would like to thank my friends and colleagues for their friendship and support.

I owe my loving thanks to my parents. Without their encouragement and understanding it would have been impossible for me to finish this work.

My special gratitude is due to all my family members for their enormous encouragement.

Summary of the M.Sc. Thesis

Visual sense is one of the most human senses that provide sufficient information and non contact measurements from unknown environment. Without visual information, many arm robot tasks can be only performed in a well known environment where every object is known and can be found in a well known pose. Any error in the pose of the object or about the robot pose will lead to task failure. Potential sources (such as gear backlashes, bending of the links, joints slippage, and poor fixture) would lead to the errors in the robot end-effector pose.

Position based visual servoing control system consists of many subsystems such as vision sub system , robotics sub system and computer sub system which are combined together in one control scheme. Position based visual servoing control system is used to solve the above problems by using the visual information in a feedback loop to control the robot end-effector pose relative to the pose of the object being manipulated. The main core of position based visual servoing (PBVS) is the estimation of the pose of the object frame with respect to the camera frame. Many algorithms have been developed to solve the problem of pose estimation.

To implement this work, the theoretical study of robot kinematics, vision systems, pose estimation methods and visual servoing control schemes is very important. So, it was the first step of this work.

The second step of the work is the simulation. It is a vital step because it can help in the prediction of the overall system behavior. And also can help in saving our platform from any dangerous motion through the experiments. CRS robot simulator and real camera simulator are developed and combined through the control scheme to test and evaluate the pose estimation methods and the PBVS system.

To develop simulator that accurately mimics the real system, the actual system parameters must be known and used through the simulation. So camera calibration is performed to measure the camera intrinsic

parameters also the camera robot calibration is performed to calculate the actual transformation of the camera frame with respect to the end effector frame.

Working on the real environment is the last step. In the real environment, the open architecture controller of the real robot has been studied and modified to be suitable for combining with the PBVS control scheme.

In the real image, certain features must be extracted and arranged in the same order of the previous image features to be fit to be used as input of pose estimation software. So, feature extraction and feature matching functions must be used to prepare the real image.

Kalman filter and classic Posit are two techniques that are used for pose estimation process. The two methods are implemented and tested through the simulation. The algorithm with the best results is used in the PBVS control scheme.

Table of Contents

Summary of the M.Sc. Thesis.....	VI
Table of contents.....	VIII
List of figures.....	XI
List of tables.....	XVI
List of symbols.....	XVII
1. Chapter 1: Introduction.....	1
1.1 Problem Definition.....	1
1.2 Visual servoing.....	3
1.2.1 Definition of visual servoing.....	3
1.2.2 Type of visual servoing.....	4
1.2.3 Advantages of PBVS	4
1.3 The objective of the research	5
1.4 Thesis architecture.....	6
2. Chapter 2: Literature review.....	7
2.1 History of visual servoing	7
2.2 Classification of visual servoing	8
2.3 Camera Configurations in visual servoing.....	10
2.4 Image feature.....	11
2.5 3D pose estimation	12
2.6 Kalman Filter.....	14
3. Chapter3: Mathematical Modeling and Methodologies ...	16
3.1 CRS Robot Kinematics	16
3.1.1 Coordinate Frames in D-H Convention	16
3.1.2 CRS Robot parameters.....	18
3.1.3 Deducing CRS Robot Forward Kinemtics.....	19
3.1.4 CRS Robot Jacobian	23

3.2	Vision system	25
3.2.1	Image Formation	26
3.3	Position Based Visual Servoing Control Scheme	30
3.3.1	Pose estimation	31
3.3.2	Position based visual servoing control law	37
4.	Chapter 4: System Setup.....	41
4.1	Real Systems Specifications.....	41
4.1.1	Arm robot platform	42
4.1.2	Camera system	51
4.1.3	Camera robot configuration	54
4.2	Calibration.....	55
4.2.1	Camera calibration	55
4.2.2	Eye hand calibration.....	58
4.3	Simulators of the position based visual servoing	63
4.3.1	Robot simulator.....	64
4.3.2	Camera simulator	66
4.4	Softwares.....	70
4.4.1	Feature Extraction from real camera images	70
4.4.2	Feature Matching	74
4.4.3	Pose Estimation.....	76
4.4.4	Position based visual servoing control law	79
4.4.5	The position based visual servoing control scheme	80
5.	Chapter 5: Experiments and Results.....	81
5.1	Robot model verification.....	81
5.2	Pose estimation using camera simulator	86
5.2.1	Pose estimation using POSIT algorithm	89
5.2.2	Pose estimation using EPnP	93
5.2.3	Pose estimation using kalman filter	97

5.3	Pose estimation using real images.....	101
5.4	Position based visual servoing	107
6.	Chapter 6: Conclusions and Suggested Future Works ...	112
6.1	Conclusions	112
6.2	Suggested Future Works	114
7.	References.....	115
	ملخص الرسالة باللغة العربية	122

List of Figures

Figure 3-1: CRS Robot	17
Figure 3-2: Representations of coordinate frames in D H convention [48]	17
3-3:CRS Robot schematic.....	18
Figure 3-4: Image formation process	26
Figure 3-5: The difference between the perspective projection and the SOP	28
Figure 3-6: The effect of radial distortion on parallel lines image	29
Figure 3-7: The position based visual servoing control scheme.....	30
Figure 3-8: The frames used in PBVS process and the relationship between each of them.....	32
Figure 3-9: The relation between all frames in current and desired pose	38
Figure 4-1: CRS arm robot	42
Figure 4-2:: Open and closed architecture control systems	44
Figure 4-3: q_crs_pos_cntrl_joint simulink file	47
Figure 4-4: The entire joint space position control process	47
Figure 4-5: q_crs_pos_cntrl_world simulink model.....	48
Figure 4-6: The world based position control process.....	49
Figure 4-7: q_crs_speed_cntrl_world simulink model	50
Figure 4-8: The world speed based control process.....	50
Figure 4-9: Camera Cad Model	52
Figure 4-10: Cad model of camera based	52
Figure 4-11: lens cad model.....	53

Figure 4-12: Camera installation on end effector	54
Figure 4-13: Camera calibration chess board	56
Figure 4-14: Camera calibration dot board.....	56
Figure 4-15: Eye in hand configuration in two different poses	59
Figure 4-16: The camera frame and the end effector frame representation in the world frame according to the hand eye calibration results	63
Figure 4-17: The inputs and the outputs of the forward kinematics function	64
Figure 4-18: The inputs and the output of the Matlab jacobian function	65
Figure 4-19: The robot simulator schematic at the home configuration..	65
Figure 4-20: The robot in another configuration	66
Figure 4-21: 3D Cube model	67
Figure 4-22: Shows the inputs and the outputs of camera simulator	68
Figure 4-23: Image point at relative pose 1	69
Figure 4-24: Image of the object at the second pose	70
Figure 4-25: The inputs and the outputs of the centroid extract function	72
Figure 4-26: RGB image of 3D object.....	73
Figure 4-27 Grey scale image of 3D object.....	73
Figure 4-28: Binary image of 3D object	74
Figure 4-29: Indicates the centroid of round shapes.....	74
Figure 4-30: The inputs and the outputs of the feature matching function	75
Figure 4-31: Feature matching.....	76
Figure 4-32 : POSIT function inputs and outputs.....	77
Figure 4-33: Kalman filter pose estimator inputs and output	78
Figure 4-34: The PBVS simulation control scheme	80
Figure 4-35: The real time PBVS control scheme	80

Figure 5-1: Initial robot configuration	81
Figure 5-2: Final robot configuration	82
Figure 5-3: Translations of end effector path	83
Figure 5-4: Rotation angels of end effector path	83
Figure 5-5: Values of joint 1 through the path.....	84
Figure 5-6: Values of joint 2 through the path.....	84
Figure 5-7: Values of joint 3 through the path.....	85
Figure 5-8: Values of joint 4 through the path.....	85
Figure 5-9: Values of joint 5 through the path.....	86
Figure 5-10: The relationship between the pose vectors	87
Figure 5-11: The estimated and the desired translation in X axis in Posit experiment.....	90
Figure 5-12: The estimated and the desired translation in Y axis in Posit experiment.....	90
Figure 5-13: The estimated and the desired translation in Z axis in Posit experiment.....	91
Figure 5-14: The estimated and the desired yaw angle in Posit experiment	91
Figure 5-15: The estimated and the desired pitch angle in Posit experiment.....	92
Figure 5-16: The estimated and the desired roll angle in Posit experiment	92
Figure 5-17: The estimated and the desired translation in x axis in EPnP experiment.....	94
Figure 5-18: The estimated and the desired translation in y axis in EPnP experiment.....	94

Figure 5-19: The estimated and the desired translation in z axis in EPnP experiment.....	95
Figure 5-20: The estimated and the desired yaw angle in EPnP experiment.....	95
Figure 5-21: The estimated and the desired pitch angle in EPnP experiment.....	96
Figure 5-22: The estimated and the desired roll angle in EPnP experiment	96
Figure 5-23: The estimated and the desired translation in x axis in kalman filter experiment.....	98
Figure 5-24: The estimated and the desired translation in y axis in kalman filter experiment.....	98
Figure 5-25: The estimated and the desired translation in z axis in kalman filter experiment.....	99
Figure 5-26: The estimated and the desired yaw angle in kalman filter experiment.....	99
Figure 5-27: The estimated and the desired pitch angle in kalman filter experiment.....	100
Figure 5-28: The estimated and the desired roll angle in kalman filter experiment.....	100
Figure 5-29: The real object with the path of each feature	103
Figure 5-30: Tx estimated by EPnP and kalman filter.....	104
Figure 5-31: Ty estimated by EPnP and kalman filter.....	104
Figure 5-32: Tz estimated by EPnP and kalman filter.....	105
Figure 5-33: yaw angle estimated by EPnP and kalman filter	105
Figure 5-34: Pitch angle estimated by EPnP and kalman filter	106
Figure 5-35: Roll angle estimated by EPnP and kalman filter.....	106

Figure 5-36: Tx translation estimated through PBVS.....109

Figure 5-37: Ty translation estimated through PBVS.....109

Figure 5-38: Tz translation estimated through PBVS.....110

Figure 5-39: Yaw angle estimated through PBVS.....110

Figure 5-40: Pitch angle estimated through PBVS111

Figure 5-41: Roll angle estimated through PBVS111