TECHNISCHE UNIVERSITÄT DRESDEN

Fakultät Elektrotechnik und Informationstechnik Institut für Automatisierungstechnik

Bachelor Thesis

zum Thema

Image Based Visual Servoing for Aerial Robot

vorgelegt von Pablo Rodríguez Robles
im Studiengang Aerospace Engineering, Jg. 2014
geboren am 28.02.1996 in León, Spain

Betreuer: Dipl.-Ing. Chao Yao
Verantwortlicher Hochschullehrer: Prof. Dr. techn. Klaus Janschek
Tag der Einreichung: 27.03.2018

Aufgabenstellung

Test der PDF-Integration

Achtung

Auch wenn die Möglichkeit besteht, die eingescannte Aufgabenstellung als PDF zu integrieren, muss in **einem einzureichendem Exemplar** die Aufgabenstellung **im Original** eingebunden werden.

TECHNISCHE UNIVERSITÄT DRESDEN

LS-AT

Fakultät Elektrotechnik und Informationstechnik Institut für Automatisierungstechnik

Image Based Visual Servoing for Aerial Robot

Hier muss der Text für die deutsche Kurzfassung inklusive eines aussagekräftigen Bildes eingefügt werden.

Betreuer:	Dipl.-Ing. Chao Yao
Hochschullehrer:	Prof. Dr. techn. Klaus Janschek
Tag der Einreichung:	27.03.2018

Bearbeiter: Pablo Rodríguez Robles

TECHNISCHE
UNIVERSITÄT
DRESDEN

Fakultät Elektrotechnik und Informationstechnik Institut für Automatisierungstechnik

Image Based Visual Servoing for Aerial Robot

Here an English abstract including one significant image must be inserted.

Tutor:	Dipl.-Ing. Chao Yao
Supervisor:	Prof. Dr. techn. Klaus Janschek
Day of Submission:	27.03.2018

STUDENT RESEARCH THESIS

Author: Pablo Rodríguez Robles

Contents

List of Figures

List of Tables

List of Listings

1 Introduction

1.1 Motivation and Background

During the last decade, the use of Unmanned Aerial Vehicles (UAVs) has spread among very different applications. Flying robots can be very helpful to improve the way some tasks are already achieved by terrestrial platforms. For example, object transportation, environment mapping or surveillance. At the Institute of Automation Engineering[1] of the Technical University of Dresden, a drone is being developed in cooperation with the Institute of Solid Mechanics[2] to investigate the use of flying robots in aerial manipulation.

When dealing with manipulation of objects, it is desired that the aerial robot adopts a certain pose with respect to the target before the manipulation process really starts. The present work deals with the development of a Visual Servoing (VS) control system that helps a quadrotor robot to acquire the desired pose by means of image data.

A monocular monochrome camera as well as an Inertial Measurement Unit (IMU) are planed to be the only available on board sensors. For the controller proposed the feedback is directly computed from image features rather than estimating the robot's pose and using the pose errors as control input.

Vision results to be a passive (in contrast to GPS) and cheap sensor (in contrast to LIDAR system). Visual odometry is very helpful to navigate in GPS denied environments like indoors, but its not appropriated to regulate the relative navigation of the vehicle with respect to a target.

In order to integrate the visual servoing algorithm into the future modular robot system, the algorithm has been designed and tested on a under-actuated conventional quadrotor. The aerial robot is implemented within the ROS[3] framework, where the visual servoing controller developed for this thesis is also integrated. Instead of using real hardware the complete system is simulated

[1] Technische Universität Dresden. Institut für Automatisierungstechnik. 01062 Dresden, Germany

[2] Technische Universität Dresden. Institut für Festkörpermechanik. 01062 Dresden, Germany

[3] www.ros.org

using Gazebo[4].

1.2 Aims and Objectives

The aim of this work is to implement and test a VS control algorithm for a quadrotor, which could be later used by the Flypulator (TODO: Add reference) project. This includes the review of the state of the art with regard to Visual Servoing, the design of a solution and a prototypical implementation with in the ROS framework and simulation with Gazebo of a test case.

The present thesis documents comprehensively the theoretical background, implementation details and results of the conducted work through the following structure. In Chapter 2 the theoretical background and state of the art of Visual Servoing is presented. Chapter 3 gives a description of the system requirements as well as the system decomposition by Structure Analysis (SA) *Systementwurf mit Strukturierter Analyse* 2016. Chapter 4 describes the solution developed and the algorithms to be tested. Chapter 5 deals with the implementation, testing and validation. Finally, Chapter 6 contains the final results and conclusions and Chapter 7 suggests future improvement and research paths.

[4] www.gazebosim.org

2 Theoretical Background and State of the Art

3 Software Requirements Specification and Structured Analysis

This chapter deals with the Software Requirement Specification (SRS) (described in *IEEE 830-1998 - IEEE Recommended Practice for Software Requirements Specifications* 2017) and the Structured Analysis (see *Systementwurf mit Strukturierter Analyse* 2016) of the system developed in this work. Thanks to these two procedures, the objectives that the system must fulfil and a decomposition of it into different functions are stated. This leads to a complete definition of the system.

The purpose of this work is to design a Visual Servoing controller to provide an under-actuated aerial robot the commands necessary to reach a desired pose with respect to a target object.

The VS controller developed is to be integrated into the hector_quadrotor[1] (see Meyer et al., 2012), an under-actuated aerial robot equipped with a monocular monochrome camera pointing downwards.

3.1 Software Requirements Specification

In this section the Software Requirement Specification (described in *IEEE 830-1998 - IEEE Recommended Practice for Software Requirements Specifications* 2017) for the Visual Servoing controller developed in this thesis is presented. Using SRS helps to define the system that is being designed, tracking continuously that the product developed satisfies the needs of the user. Only when every requirement stated therein is fulfilled the implementation would be completed.

3.1.1 Product Perspective

The VS controller is to be used with an aerial robotic system based on the ROS framework. From the perspective of the robotic system, the VS controller

[1] http://wiki.ros.org/hector_quadrotor

subsystem will appear as a ROS node which publishes control commands through a ROS topic to the rest of the system.

The used aerial robotic system is the hector_quadrotor[2] model Meyer et al., 2012. (TODO: Add diagram).

The subsystem developed here is to interact with the camera hardware of the robot, a monocular monochrome camera pointing downwards (TODO: Add hardware). The output of the subsystem are the control inputs of the aerial robot system, a kinematic control is adopted, being this inputs the linear velocities of the vehicle and its yaw angular velocity. These inputs interact with the inner control loop for the attitude already implemented in the robotic system and are the main input for the outer control loop, the one in charge of the translation.

3.1.2 User Characteristics

The product developed in this thesis will be used as part of a ROS-based system, thus the expected user is a designer willing to implement a VS control strategy for his robotic system. The user should be familiarized with the ROS framework and the system will need the structure and interfaces of any standard ROS product.

3.1.3 Assumptions and Dependencies

The software has been tested on the following platforms, forward or backward support is not guaranteed on a different set-up.

- ROS version: ROS Indigo[3]
- Operating System: Ubuntu 14.04[4] Trusty Tahr, 64 bit

3.1.4 Functional Requirements

The functional requirements describe what the system must do to complete the overall task:

[2] http://wiki.ros.org/hector_quadrotor
[3] http://wiki.ros.org/indigo
[4] http://releases.ubuntu.com/14.04/

- F1: *Give visual servoing control input.* Control input based on image data so that the aerial robot comes closer to the target pose. Control as a difference on the image features, no pose estimation.

- F2: *Tell user when the target pose is achieved.* The system must be able of telling the user whether the target pose has been already achieved or not.

3.1.5 Other Requirements

- A1: All components are working reliably.

- A2: The software is sufficiently fast, modular and modifiable.

- A3: The implementation is transparent and comprehensible.

- A4: Control inputs must provide stable and smooth flight maneuvers.

- A5: Robot must be able to start from different initial positions.

- A6: Algorithm must be fast enough to allow real time control of the aerial robot.

- A7: The implementation should follow the style guide of ROS (see *ROS Style Guide* 2017)

3.1.6 General Constraints

- The environment must be sufficiently illuminated for the camera to work.

- The observed object must be planar and continuous and provided to the program as a binary image obtained by segmentation algorithms.

- The target pose must be provided by a sufficient number of features.

- The target must be always in the filed of view of the camera, so features can be extracted an control input computed.

- Testing computer is a MacBook Pro[5] (Early 2015) with 2.7 GHz Intel Core i5 processor, 8 GB 1867 MHz DDR3 memory and Intel Iris Graphics 6100 1536 MB graphics. Linux OS is run using Oracle VM VirtualBox[6] (Version 5.1.14 r112924) with 5 GB base memory and two processors.

3.2 Structured Analysis

[5] https://everymac.com/systems/apple/macbook_pro/specs/macbook-pro-core-i5-2.7-13-early-2015-retina-display-specs.html
[6] www.virtualbox.org

4 Visual Servoing Algorithm Description

5 Implementation of the Visual Servoing Controller

6 Final Results and Conclusions

7 Future Work

References

Asl, H. J. and J. Yoon (2015). “Vision-based control of a flying robot without linear velocity measurements”. In:

Bourquardez, O., R. Mahony, N. Guenard, F. Chaumette, T. Hamel, and L. Eck (2009). “Image-Based Visual Servo Control of the Translation Kinematics of a Quadrotor Aerial Vehicle”. In: *IEEE Transactions on Robotics*.

Ceren, Z. (2012). “Image Based and Hybrid Visual Servo Control of an Unmanned Aerial Vehicle”. In: *Journal of Intelligent & Robotic Systems*.

Ceren, Z. and E. Altug (2009). “Vision-based servo control of a quadrotor air vehicle”. In: *2009 IEEE International Symposium on Computational Intelligence in Robotics and Automation - (CIRA)*.

Chaumette, François and Hutchinson, Seth (2007). “Visual servo control, Part II: Advanced approaches”. In: *IEEE Robotics and Automation Magazine*.

Danko, T. W. and P. Y. Oh (2014). “Evaluation of Visual Servoing Control of Aerial Manipulators Using Test Gantry Emulation”. In:

Guenard, N., T. Hamel, and R. Mahony (2008). “A Practical Visual Servo Control for an Unmanned Aerial Vehicle”. In: *IEEE Transactions on Robotics*.

Hamel, T. and R. Mahony (2002). “Visual Servoing of an Under-actuated Synamic Rigid-body System: An Image-based Approach”. In: *IEEE Transactions on Robotics and Automation*.

IEEE 830-1998 - IEEE Recommended Practice for Software Requirements Specifications (2017). URL: https://standards.ieee.org/findstds/standard/830-1998.html (visited on 11/14/2017) (cit. on p. 4).

Jabbari, H., G. Oriolo, and H. Bolandi (2012). “Dynamic IBVS control of an underactuated UAV”. In: *2012 IEEE International Conference on Robotics and Biomimetics (ROBIO)*.

Kim, Suseong, Hoseong Seo, Seungwon Choi, and H. Jin Kim (2016). "Vision-Guided Aerial Manipulation Using a Multirotor With a Robotic Arm". In: *IEEE/ASME Transactions on Mechatronics*.

Laiacker, M., F. Huber, and K. Kondak (2016). "High Accuracy Visual Servoing for Aerial Manipulation Using a 7 Degrees of Freedom Industrial Manipulator". In:

Lippiello, V., J. Cacace, A. Santamaria-Navarro, J. Andrade-Cetto, M. Trujillo, Y. R. Esteves, and A. Viguria (2016). "Hybrid Visual Servoing With Hierarchical Task Composition for Aerial Manipulation". In: *IEEE Robotics and Automation Letters*.

Lippiello, V. and F. Ruggiero (2012). "Exploiting redundancy in Cartesian impedance control of UAVs equipped with a robotic arm". In: *2012 IEEE/RSJ International Conference on Intelligent Robots and Systems*.

Malis, E., F. Chaumette, and S. Boudet (1999). "2 frac12;D visual servoing". In: *IEEE Transactions on Robotics and Automation*.

Mebarki, Rafik, Vincenzo Lippiello, and Bruno Siciliano (2013). "Exploiting image moments for aerial manipulation control". In: *ASME Dynamic Systems and Control Conference*.

Mebarki, R. and V. Lippiello (2014). "Image-Based Control for Aerial Manipulation". In: *Asian Journal of Control*.

Mebarki, R., V. Lippiello, and B. Siciliano (2014). "Image-based control for dynamically cross-coupled aerial manipulation". In: *2014 IEEE/RSJ International Conference on Intelligent Robots and Systems*.

Mellinger, D. W. (2012). "Trajectory Generation and Control for Quadrotors". iUniversity of Pennsylvania.

Meyer, Johannes, Alexander Sendobry, Stefan Kohlbrecher, Uwe Klingauf, and Oskar von Stryk (2012). "Comprehensive Simulation of Quadrotor UAVs using ROS and Gazebo". In: to appear (cit. on pp. 4, 5).

Palunko, I., P. Cruz, and R. Fierro (2012). “Agile Load Transportation : Safe and Efficient Load Manipulation with Aerial Robots”. In: *IEEE Robotics Automation Magazine*.

Papanikolopoulos, N., P. K. Khosla, and T. Kanade (1991). “Adaptive Robotic Visual Tracking”. In: *1991 American Control Conference*.

Piepmeier, Jenelle Armstrong (1999). “A Dynamic Quasi-newton Method for Model Independent Visual Servoing”. AAI9953830. PhD thesis. Atlanta, GA, USA. ISBN: 0-599-56997-2.

ROS Style Guide (2017). URL: http://wiki.ros.org/StyleGuide (visited on 11/15/2017) (cit. on p. 6).

Santamaria-Navarro, A., P. Grosch, V. Lippiello, J. Sol, and J. Andrade-Cetto (2017). “Uncalibrated Visual Servo for Unmanned Aerial Manipulation”. In: *IEEE/ASME Transactions on Mechatronics*.

Systementwurf mit Strukturierter Analyse (2016). German. URL: https://www.et.tu-dresden.de/ifa/fileadmin/user_upload/www_files/richtlinien_sa_da/Nutzeranforderungen_nach_IEEE.pdf (visited on 11/14/2017) (cit. on pp. 2, 4).

Tahri, O. and F. Chaumette (2005). “Point-based and Region-based Image Moments for Visual Servoing of Planar Objects”. In: *IEEE Transactions on Robotics*.

Thomas, J., G. Loianno, K. Daniilidis, and V. Kumar (2016). “Visual Servoing of Quadrotors for Perching by Hanging From Cylindrical Objects”. In: *IEEE Robotics and Automation Letters*.

Thomas, J., G. Loianno, K. Sreenath, and V. Kumar (2014). “Toward Image Based Visual Servoing for Aerial Grasping and Perching”. In:

Selbstständigkeitserklärung

Hiermit versichere ich, Pablo Rodríguez Robles, geboren am 28.02.1996 in León, Spain, dass ich die vorliegende Bachelor Thesis zum Thema

Image Based Visual Servoing for Aerial Robot

ohne unzulässige Hilfe Dritter und ohne Benutzung anderer als der angegebenen Hilfsmittel angefertigt habe; die aus fremden Quellen direkt oder indirekt übernommenen Gedanken sind als solche kenntlich gemacht. Bei der Auswahl und Auswertung des Materials sowie bei der Herstellung des Manuskripts habe ich Unterstützungsleistungen von folgenden Personen erhalten:

Dipl.-Ing. Chao Yao

Weitere Personen waren an der geistigen Herstellung der vorliegenden Bachelor Thesis nicht beteiligt. Mir ist bekannt, dass die Nichteinhaltung dieser Erklärung zum nachträglichen Entzug des Diplomabschlusses (Masterabschlusses) führen kann.

Dresden, den 27.03.2018 ....

Unterschrift