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Ruhr-Universität Bochum
Lehrstuhl für Automatisierungstechnik
und Prozessinformatik
Prof. Dr.–Ing. J. Lunze

**Review of the dissertation**

# Inertial stabilization, estimation and visual servoing for aerial surveillance

submitted by Ing. MARTIN ŘEZÁČ

## 1 Motivation and Scope

The thesis presents the results of the author's research activities within a project for the development of stabilised platforms, which has been carried out at the Czech Technical University in Prague in close cooperation with industrial partners. The research was focused on several control problems that had to be solved in this project. The dissertation describes new ideas for line-of-sight inertial stabilisation of optical systems that are carried by a moving object like an aircraft. There is an increasing interest in the automatic control of such platforms in order to create autonomous aerial surveillance and object tracking systems.

Although the problems solved are taylored to a specific application at hand, they are solved on an abstract level by applying and extending advanced control-theoretic methods and lead to systematic ways for solving control problems for aerial surveillance systems. Hence, they set up a suitable topic for research on a PhD level.

## 2 Contents

The main contributions of the thesis are presented in chapters 4 through 7 and can be summarised as follows. **Chapter 4** develops new control methods for the line-of-sight inertial stabilisation of optical systems. A single-axis dual-stage and a four-joint dual-stage stabilisation method has been developed. As the experimental evaluation of the controllers showed the influence of substantial vibrations, the controllers were extended by a feedforward part that attenuates these disturbances.

**Chapter 5** extends the results to visual tracking, which uses the line-of-sight inertial stabilisation as inner control loop and expands the system by a feedback of data received by a computer vision system to enable the overall system to track objects on ground. As the transformation between the coordinate system of the tracked object and the coordinate system of the platform introduces nonlinearities into the system, the „inverse nonlinearities" are inserted into the control loop to get linearised dynamics.

**Chapter 6** deals with the compensation of the time delay in the control loops that is brought about by the real-time video processing unit. The evaluation of the visual data leads to a delay of one sampling period, which is compensated by using additional measurement data.

**Chapter 7** develops an attitude estimation algorithm in form of an extended Kalman filter.

Chapters 1 through 3 introduce the scientific problems, give a survey of the available literature, explain the mechanical configurations and their system-theoretic models, and summarise the main ideas of cascade control used in Chapter 5.

# 3 Evaluation of the results and the presentation

From a practical viewpoint, the main objectives of the work have been fulfilled. The experiments show that the aims of stabilising optical systems and of visually tracking objects on ground by cameras have been successfully reached.

For the evaluation of these results with respect to the PhD degree, it has to be emphasised that the way of solution, which was developed by the author, is systematically structured, applies advanced control methods and leads to design methods that are general enough to be applied successfully to similar systems. Hence, the methodology has a strong scientific foundation and shows the creativity and the scientific abilities of the author, who has structured the overall system in a clever way, has made reasonable assumptions in the modelling and the design steps, and circumvented the constraints of the application by combining different advanced control methods.

The assumptions made for modelling the optical platform are summarised in Section 2.2.2. As the experiments show, these assumptions are reasonable for the systems considered. The system-theoretic platform models are not new, but they are developed in Chapter 2 in a clear and systematic way, starting with the double-gimbal platform and extending the result towards a four-gimbal dual-stage platform.

The stabilisation method developed in Chapter 4 exploits the weak couplings between the movement of the platform with respect to azimuth and elevation and presents two decoupled inertial rate controllers. For the single-axis dual-stage system, the control task is decomposed into an inertial angular velocity control problem and an angular deviation control problem. $H_\infty$ control is applied here to get a multivariable control law. The extension of this control method towards a four-joint dual-stage system applies the same decomposition.

The delay compensation described in Chapter 6 uses the well-known Smith predictor idea, but modifies this idea for the set-up of the optical platform. Measurements, which are different from the control variable, are processed to get a nearly delay-free information about the plant behaviour.

Chapter 7 is an addition to the control problems solved in Chapters 4 – 6, which does not really fit into the thesis. This criticism does not only concern the subject of this chapter, but also the presentation, which partly uses different conventions with respect to the symbols and the style of explanation. However, even without this chapter, the thesis would be complete.

The thesis is clearly structured and written in good technical English. Many illustrations accompany the analytical derivation of the results and make the main ideas clear. The combination of theoretical results with experimental results demonstrate the progress obtained by the author, who could use an experimental set-up that he had created together with other partners.

## 4 Conclusions

The thesis shows the author's deep knowledge of systems and control theory and his well-developed abilities to solve important theoretical problems and to verify the solutions experimentally.

The results have been published in several ways including three journal paper and 8 papers at international conferences. Altogether, this outcome leads to a solid dissertation.

The author of the thesis proved to have an ability to perform research and to achieve scientific results. I do recommend the thesis for presentation with the aim of receiving the Degree of Ph.D.

Bochum, 18 February 2014