9.6.

Review of the Doctoral Dissertation Thesis

Inertial stabilization, estimation and visual servoing for aerial surveillance

submitted by

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Content of the Dissertation

The thesis deals with the problem of inertial stabilization of a camera attached to a mobile carrier. The introductory chapter presents the main principles and common mechanical configurations of the stabilized camera systems. The concept of dual-stage four-gimbal platform which is being developed at the CTU in Prague is explained. The next chapters are devoted to a design of a cascade control structure which consists from the inner line-of-sight stabilization loop and outer visual-based position control loop. The last part deals with the implementation issues and the problems associated with imperfect measurements.

The main contribution of the thesis is a systematic approach to the design of a structured MIMO angular rate controller, development of a time-delay compensation scheme of the image-tracking loop and inertial estimation of the camera attitude using imperfect sensor information.

Appraisal and Discussion of the Disertation

The angle rate control design is performed using the well-established framework of H-infinity optimization. Performance improvement compared to the conventional PI control is shown both by simulation and experimental results. The particular chosen structure of the MIMO controller comes from the heuristic assignment of two controller-output pairs. It could be interesting to examine, at least in terms of numerical simulations, whether a design of a full-order MIMO compensator would bring any significant improvement in performance. The same comment holds for the four-joint configuration which is composed from two independent single-axis controllers. (**Question 1**). A partially misleading fact is that a current controller in the innermost loop is assumed in the former part of the chapter (e.g. Fig. 4.2 on page 55, Figs.4.3 & 4.4 p. 56) whereas the four gimbal dual stage controller uses directly the motor voltage as the manipulating variable. It could be mentioned why the current controllers were not used in this case and whether they could bring any significant advantage (e.g. due to the linearization of the inner dynamics of the electrical part of the motors) (**Question 2**). The presented simulation and experimental result prove the viability of the proposed control scheme for the task of angle rate stabilization.

The next part deals with the visual tracking loop which is constructed above the angle rate control level. The problem of nonlinear kinematics between the image and camera reference frames is systematically solved using a feedback linearizing point-tracking controller. Particular issue of delay compensation due to the slow image processing routines is studied.

The problem is formulated as one step prediction of a process variable in a multi-rate discrete-time system consisting of fast inner angle rate loop and slow outer visual feedback loop which uses delayed output measurement. It is shown that the proposed technique of successive integration of the angular velocity signal is a special case of the lifting technique for a particular choice of the observer error dynamics. Experimental results show significant advance in the precision of position-tracking especially for low sampling rates of the outer visual loop. It could be pointed out, whether the tuning of the observer gain in the lifting method can bring any further improvement in the practical experiments. (**Question 3**)

The last part discusses the problem of attitude estimation using combined measurement from GPS, magnetometers, gyros and accelerometers. Particular problem of sensor bias estimation is solved using two different approaches – Extended Kalman filtering and inverse Jacobian based feedback linearization. Experimental results show, that even a low-cost hardware can be used for precise measurement when complemented by smart data processing methods. Next issue is a compensation of disturbing translational acceleration of the carrier which affects the measurements obtained from the accelerometers. A correction algorithm which uses numerical derivative of the GPS signal is proposed. Practical experiments which were executed with a car-mounted sensor show an improvement in the correction of the estimated orientation. It would be interesting to evaluate the significance of the problem of translational accelerations of the carrier also in the actual target application onboard a plane or helicopter. (**Question 4**).

Evaluation of the presented results

The work is at a high level in terms of structure, language and overall layout. Although the thesis does not bring a significantly new theoretical result, it systematically deals with a challenging engineering problem which is being solved with use of the modern methods from various technical disciplines. A large amount of effort had to be expended on the thorough understanding of the problem from both theoretical and practical perspective. Number of practical experiments proves the validity of the proposed methods. The developed algorithms for the camera tracking could be useful also in other applications of visual servoing such as robotics. The same holds for the problem of inertial measurement from imperfect sensors. The promising results indicate possibilities in development of advanced motion control applications even with a low-cost instrumentation. Overall, the thesis is evaluated as outstanding.

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.

Pilsen, 5th June 2014

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