11. 12 2014

The Review of Ph.D. Thesis "Active Adaptive Control" by Ing. Jan Rathouský

Reviewer: Prof. Ing. Miroslav Šimandl, CSc.

Significance for Control Engineering and Robotics. Stochastic optimal control represents important topic of Control Engineering and Robotics. Cautious control and dual adaptive control belong to big challenges in theoretical development of automatic control and they are also promising for applied research and practical application. Therefore, the topic of the thesis is very significant.

Contents and structure of the thesis. The thesis has 113 pages and consists of seven chapters. The first chapter introduces probabilistic approach to modelling and controlling systems with uncertain parameters and sets the aims of the thesis based on a literature survey and weak points of current approaches. It also provides a motivation for using certainty equivalent control instead of cautious control. The next chapter presents an alternative derivation of the cautious LQ controller for the ARMAX model with known parameters of the MA part. New results on the convergence of the Riccati-like difference equation that needs to be solved to obtain the cautious LQ controller on an infinite time horizon are provided in Chapter 3. Chapter 4 is very brief because it only recalls a single-step active adaptive controller based on the cautious controller presented in Chapter 2. A further significant contribution is presented in Chapter 5, where a multi-step active adaptive controller based on the certainty equivalent controller is derived and some simple approximation techniques are presented. Since the design of the multi-step active adaptive controller represents a nonconvex optimization problem and a simple approximation might not be effective enough, a more elaborate approximation technique called the ellipsoid algorithm is introduced in Chapter 6. The last chapter summarizes the results of the thesis.

The goal of the thesis. The goals of the thesis are to analyze cautious control for infinite horizon and to examine dual control strategies and propose new active adaptive strategies that are based on the certainty equivalent controller.

Technical correctness and quality of presentation. The topic requires deep knowledge of modern stochastic and adaptive control. The structure of the manuscripts and achieved results confirm that the author has the necessary knowledge and is able to carry out research. The thesis is well structured and written in accepted academic style. The references cover important works on optimal control of stochastic systems. Overall, the thesis is of a high quality as far as the formal and technical aspects are concerned.

The manuscript contains the following minor technical inexactness, typographical errors and certain statements are incorrect:

Pages 18-19 – The comparison of the cautious and certainty equivalent controllers is performed for a particular time step. Is it possible to support the statement in the thesis that cautious control diverge while the certainty equivalent controller is stable by a simulation example? Is this a case of the turn- off effect?

Page 21 – It is assumed that the unknown parameters a_i and b_i are constant or slowly changing. However, the state space estimation model in Chapter 2.1 does not include the a priori information that the parameters might change over time (page 22).

Page 29 – It is argued in Note 2.7 that the covariance matrix of estimation error $\boldsymbol{P}_{k+1}$ depends on the input u_k. It is not clear how this relates to (2.20) as it contains only covariance matrices from the time step k and not $k+1$. It seems that P at time instant k is independent of u at time instant k. It is not necessary to assume independence.

Page 21 - Is it necessary for all polynomial orders to be the same in (2.1)?

Page 5 – From the description, it is not clear whether the vector of parameters theta is a random variable or not. Why the couple x_k and θ is not considered to be the state of the system?

Page 7 - It follows from (1.3) that y_k and x_{k+1} depend on θ_k, x_k and u_k. Since the past data D_0^{k-1} contain information about parameters θ_k, it does not generally holds that $p(y_k, x_{k+1}|x_k, u_k, D_0^{k-1}) = p(y_k, x_{k+1}|x_k, u_k)$.

Minor comments and typos

Page 16 – The system in (1.24) is not the closed loop system of (1.19) because the noise is missing.

Page 25 – The notation for the design matrices Q and R in (2.13) can be confusing as the same symbols are used to denote the covariance matrices on Page 23.

Page 25 – There is a redundant definition of the matrix A_{e}, because it is already defined on Page 22.

Page 29 - The key approximations that allow the approximate cautious controller to be derived are mentioned just briefly in Note 2.7. It seems inadequate.

Page 30 – The first assumption in (2.21) (Line 10) should consider the expected value as the others.

Page 39 – The phrase "divergence be studied" should be replaced by "divergence will be studied".

Pages 61-62 – Although it is assumed in (4.4) that the variance of the parameter b is within the range [1,10^5], Figure 4.1 shows range [10,10^5].

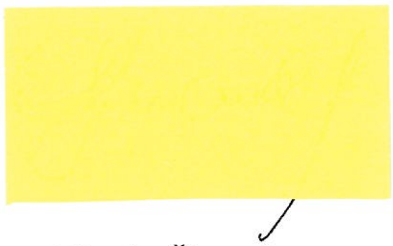
Fulfilments of aims and new results. The goal focused on analyses of cautious control for infinite horizon is fulfilled in Chapter 3. The convergence analysis of the Riccati-like difference equation on infinite horizon extends the well-known results for scalar systems and multidimensional systems with structured parametric uncertainties to more complex systems. The goal focused on active adaptive control is fulfilled in Chapters 5.2 where the new multistep active adaptive control is formulated as a nonlinear programming problem. The general solution and approximation algorithms are given in 5.3 and in Chapter 6. A new simple active adaptive algorithm is also derived in Chapter 4.

Other comments. Ing. Rathouský is a co-author of 1 journal paper and 10 papers at international conferences. Most of them are related to the topic of the Ph.D. thesis. Three of the publications have been cited. The facts confirm the quality of the thesis as well.

Question. Is it possible to compare (control quality and computational demands) the proposed multistep active adaptive controller with the Filatov algorithm, mentioned on page 2, reference 19, in a numerical example?

Conclusion. Some of the thesis results were published in an impacted journal and international conference proceedings. The presented approximate solution of active adaptive control is an original contribution in the area of dual control. It is my understanding that this high quality manuscript fulfils the conditions laid on a Ph.D thesis. Therefore, I recommend to award the degree of Doctor of Philosophy to the candidate.

In Pilsen, December 2, 2014



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