THE INSTITUTE OF INFORMATION THEORY AND AUTOMATION
OF THE CZECH ACADEMY OF SCIENCES

Evaluation of the Ph.D. dissertation Higher Order Neural Unit Adaptive Control and Stability Analysis for Industrial System Applications prepared by Ing. Peter Mark Beneš

I was kindly asked to evaluate the thesis entitled above by the Vice-Dean of the Faculty of Mechanical Engineering of the Czech Technical University in Prague, prof. Ing. Tomáš Jirout, PhD.

Let me give first very brief sketch of the overall focus of the evaluated thesis. The main goal of the dissertation is to study the so-called higher-order neural units (HONU) and their possible use in adaptive control schemes suitable for applications of various types. The key and rather straightforward idea is to provide more realistic and computationally tractable alternative for numerous recently proposed advanced methods in the field of adaptive control that may appear quite over-engineered or too complex especially where a majority of practical industrial processes are of linear or low to moderately non-linear process dynamics. Here, HONU contain basically polynomial terms of possibly general order, these terms are weighted and interconnected via coefficients collected in the so-called multidimensional array of the HONU. The simplest examples are linear neural units (LNU), quadratic neural units (QNU) and cubic neural units (CNU). Corresponding networks can be trained using various weight update laws based on iterative optimization algorithms. These concepts are then used to address various adaptive control schemes, e.g. well known model reference adaptive control (MRAC). Extensive computer simulation and computations based experimental results are included addressing various practically motivated systems and processes.

To evaluate this dissertation, let me follow the outline suggested by the evaluation request.

1. *Goals of the thesis and their fulfilment.* After giving some overview of the existing methods and problems in adaptive control, the author formulates five basic objectives and intended contributions of the dissertation:

- *Recall and extend on theories of HONU adaptive control*
- *Propose new point wise state-space representation of a HONU*
- *Propose a new point wise state-space representation of a HONU via polynomial decomposition*
- *Derive a new ISS based stability condition for BIBS stability assessment of HONU polynomial architectures*
- *Experimental analysis to validate the proposed discrete-time HONU stability condition (DHS) and discrete-time decomposed HONU stability condition (DDHS) approaches*

These goals are then addressed during the rest of the dissertation and various original results are achieved and described. These results were published in international publications co-authored by the author of the dissertation. Their extent is quite broad and obviously required significant efforts of the author. Though their theoretical impact perhaps is not so deep, they may provide some guidelines for applications in industrial control area.

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2. *State of the art exposition and survey*. First, the author gives some overview of methods and problems of control of systems and processes in the Introduction. Next, there is quite extensive chapter, called "Overview of the Methods and Problems in Adaptive Control ", whose content correspond to its title. My impression is that this survey is bit incongruous, it is not clear what is the difference between survey in Introduction and in that of the next mentioned chapter. Overall surveyed area in these two chapters seems to be very broad, so that consequently the selection of the described results seem to be bit random, as it is impossible to survey such a broad area in approximately 20 pages. It also seems to me that they are not closely related to the goals and results of the thesis. On the contrary, perhaps the initial part of Chapter 3 called "Theoretical Background of Adaptive Identification and Control with HONUs" contains actual focused state of the art of the more narrow subfield relevat to the dissertation scope. Overall, I evaluate the state of the art exposition as acceptable, with strong reservation to its organization and readability, as indicated above, and discussed later on when evaluating formal aspects and presentation quality of the thesis.

3. *Contribution to theory.* Some interesting extensions of existing theory were provided, but no fundamentally new results and concepts are visible. Interesting theoretical extensions are the so-called pointwise state-space representation of a HONU and pointwise state-space representation of a HONU via polynomial decomposition. Further, the analysis of the input to state stability and bounded input bounded state stability of the respective HONU polynomial architechtures.

4. *Contribution to practice.* It can be evaluated as very good. All methods presented in theoretical part of the dissertation work are implemented on physical industrial systems with focus to rail automation applications to validate the feasibility of their use for our modern industry. The extent of the respective parts of the thesis is large and the contribution to practical application is perhaps the most valuable. Though systems are mostly experimental laboratory ones, the presented algorithms showed potential to be used in real industrial applications.

5. *Suitability of used methods and their application.* Used methods are adequate, as explained earlier, the idea was to use method convenient for practical industrial processes having linear or low to moderately non-linear process dynamics. Here, HONU representation and related update laws, as well as introduced point wise state space representations and their ISS and BIBS analysis are clearly sufficient to solve the stated goals. The chosen methods were applied correctly.

6. Competence of the author. Ing. Peter Mark Beneš showed the necessary knowledge and expertise in the field of the defence and the respective study branch. He also showed good level of creativity and originality when applying his expertise to achieve the dissertation goals.

7. Formal quality of dissertation and its presentation assessment. Unfortunately, the dissertation presentation deserves much better. It does not read well and easy and it is not suitable organized. The goals of the thesis should be stated at the very beginning of the thesis. The same applies for the formulation of the used methods. In concluding part, I miss the clear assessment of the fulfilment of the dissertation goals. Moreover, one cannot find anywhere a clear statement in which chapter or section each of dissertation goals is solved. State of the art should be given in some separate chapter and should be better organized and readable. The first of the thesis goals contains again partly state of the art description, this clearly is not a goal to be achieved.

All these drawbacks make it really unnecessary laborious to read and understand the thesis. Furthermore, it is therefore very difficult to evaluate if the thesis contain all obligatory requisites

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required by the respective law and bylaws. Perhaps, the frequently encountered thesis structure is not obligatory, but there is a risk that evaluator may not see if the thesis contains all required requisites. So, I would conclude the formal evaluation saying that the dissertation is almost on the edge of formal acceptability.

There are also minor imprecisions, errors and lacks of clarity throughot the thesis. Let me mention some of them:

- Description of two-tank liquid level system in section 5.1 is difficult to follow. The notation in Figure 7 is inconsistent with the notation used e.g. in formula (28), (29) and the text later on (A1, B1, C1, y in Figure 7 are not used in formulas et all and used symbols are not in Figure 7, etc.). Then Qt is used for flow rate, but Figure 7 indicates just some u, only much later mentioned by chance to be pump voltage, perhaps related to Qt, but this relation is not given at all, though it is not obvious. You may have some static relation via multiplication by some constant, but also some dynamical dependence. Indeed, Figure 1 indicates that liquid is pumped all over the combined heights of tanks. Note, that Section 5.1 serves as reference for further study of this system in other parts of the thesis, so one wonders why at its first appearance system is not described more carefully.
- Page 8, line 7: the comma might be considered to be added before "their", line later perhaps before "especially". I am not expert on obligatory English hyphenation, but that sentence is very long and hard to understand, commas would help readability.
- References [3] and [14] are incomplete, the former misses list of authors, the latter pages, volume, publication year.
- Author uses both "back-stepping" and "backstepping", also both "non-linear" and "nonlinear", in some random way, yet another time suggesting the idea he did not really read thesis text too many times for corrections and style polishing.
- Page 10, line 9: the comma is redundant. If not, then comma line before is missing.
- Abbreviation MLP is neither defined in the text, nor included in the list of abbreviations at the beginning of thesis. Similar case is LMI, though the latter is generally known, it sould be given somewhere.
- It is quite common practice to include several different lists of references. A - the list of all references quoted in the text of thesis; B - extra list of author works related to the thesis (even duplicating those in A); C - list of other author works. Both B and C is usually structured into impacted journal papers, reviewed papers, conferences, etc. Authorship share of the thesis author is usually at least roughly estimated. Perhaps such a structure is not obligatory, but highly recommendable. The evaluated thesis contains just a single list of references where those of thesis author are put at the end.

To conclude my evaluation, I would like to state that based on the thorough analysis of all above listed positive features and drawbacks of the dissertation and some rather uneasy decision making, **I recommend the dissertation to be considered for the defence.**

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