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Review of Roman Senkerik PHD Thesis
PHD thesis title: OPTIMAL CONTROL OF DETERMINISTIC CHAOS

This dissertation on "Optimal Control of deterministic Chaos" is divided on two parts; theoretical and experimental parts. The first one describes the methods used by the author to control chaos, some chaotic systems and an overview of the Evolutionary Algorithms (EA) algorithms used in simulations in the manuscript. The second part is dedicated to experimentation where seven case studies are proposed.

This dissertation shows the benefit and how to use optimizing tools like EA for the optimization of deterministic chaos control. Exhaustive comparative studies are given taking into account different i) chaotic discrete-time models (one and higher dimensional), ii) control methods based on two Pyragas methods (TDAS and ETDAS) with different EA optimisation algorithms (for example SOMA and DE) and iii) Cost Functions (CF). These studies allow to author to prove the capability of different EA algorithms to find optimal control for several examples of chaotic systems and to test various designs of CF with comparison to their performance.
The candidate has provided a very detailed analysis and critical discussion of the proposed developments. These results show potentials of EA to solve the problem of optimisation of chaos control and the importance of the CF in such design. He also proposes future research by extending these approaches to the continuous-time case. In this sense, I suggest the author completes his studies by comparing his future research with existing literature in the domain

and particularly studies using Lyapunov methods and LMI optimisation. In my view, this type of comparison lacks this manuscript.

In my opinion, the doctorial thesis of Mr. Roman Senkerik entitled "Optimal Control of deterministic Chaos" proposes a significant contribution in the field of chaos control using EA techniques. It is well structured, clearly written and provides many interesting illustrations that increase its utility.

In conclusion, I recommend the thesis and candidate for Ph.D. title.

Yours sincerely,

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Evaluation of Doctoral thesis

Optimal Control of Deterministic Chaos

by

Ing. Roman Šenkeřík

Thesis is devoted to the optimal control of deterministic chaos via computational methods based on various type of evolutionary algorithm. This topic appears to be very contemporary and the urgent one. Various type of chaotic systems are being controlled via ad hoc methods that require significant control action, perfect knowledge of the model structure and the corresponding parameters values. At the same time, controlled systems are usually of lower dimensions and are far from real chaotic phenomena appearing in natural sciences models. Therefore, time has come to try to develop some universal computer based methods not requiring complete knowledge of the models.

This thesis concentrates on possiblity of automatic tuning of controllers parameters via suitable definition of the cost function and subsequent optimization with respect to it. In case of chaotic systems any choice of the cost function usually leads to highly nonsmooth irregular optimization problem unsolvable via conventional methods, like gradient descent. The only way is the more or less systematic search within variables space. Evolutionary algorithm are good choice in that respect and are especially suitable for optimization problems related to chaos controllers tuning. This disertation greatly contributes to prove and promote this opinion.

It concentrates on two basic chaos control methods: OGY (Otto-Grebori-Yorke) method that uses linearization of Poincare map and delayed feedback control method (called also as Pyragas method). For both methods, the crucial issue is the selection of a suitable cost function. The methodology achieved by this thesis and the related experiments regarding cost function selection are of great interest and use. Though the methods are tested extensively on rather basic examples of discrete-time chaotic systems, it is clear that extension to a more complicated systems, even without their models explicite description is possible. Selection of simple systems is thereby motivated by the possibility to compare computational methods of thesis with the classical ones. Numerous and very carefuly performed, sorted and presented experiments shows superiority of algorithms developed in thesis. Moreover, while the classical methods are limited to those simple cases, the evolutionary based methods could be extended to control more general chaotic systems, as mentioned above.

The paper consists of shorter theoretical part and large experimental one. There are quite clear conclusions regarding computational aspects of various versions of evolutionary algorithms (SOMA,DE), nevertheless, it would be nice to see some conclusions regarding properties of chaotic systems as well, made based on these experiments. In other words, is the new contributions in algorithm adaptation, i.e. in computers science, or rather in new knowledge regarding chaotic systems?

These questions would be interesting to answered during the defense. Nevertheless, that does not in any way diminish the contribution of the paper which is sufficiently novel for PhD thesis defense. Therefore, in my opinion, the author of the thesis proved to have an ability to perform research and to achieve independently novel scientific results in the specialization of his PhD study and thereby it fulfills the corresponding legal requirements. As a consequence, I am happy to recommend the thesis for the defense with the aim of receiving the degree of PhD.

Prague, May 27th, 2008.

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Review of the Dissertation thesis.

Thesis name:	Optimal Control of Deterministic Chaos.
PhD. Candidate:	Ing. Roman Šenkeřík.
Supervisor:	Assoc. Prof. Ivan Zelinka, PhD.
Study Branch:	Technical Cybernetics
Place of work, where defense takes place:	Tomas Bata University in Zlín, Faculty of Applied Informatics Nad Stráněmi 4511, 760 05 Zlín

The Topicality of the subject proposed in Thesis.

In the thesis there is a short description of problem statement in the area of „deterministic chaos control". PhD. Candidate designed, described and verified evolutionary algorithm used for the optimization of deterministic chaos control.

I consider the selected theme of the thesis as highly actual. Thesis content fully belongs to the doctoral studies discipline called "Technical Cybernetics". Place of work where the thesis was realised, is in the long term known for very good results in application of evolutionary algorithms in the area of automatic control and meets the top criteria. This is clearly seen in the right methodical process as well as on very good standard of the Thesis. This Thesis is one of the first in Czech and Slovak Republic, which is orientated to the new and interesting area called "controlling chaos", which confirms good scientific trend of supervisor and place of work.

Fulfilment of the goals formulated in the thesis.

The thesis has altogether 8 parts. First one is a short introduction and state of the art. Goal of the thesis is formulated in part 2. These theses are convenient for dissertation thesis. The core of the thesis is found in chapter 6 (Optimisation of Chaos Control) which is the largest part of the thesis. I appreciate chapter 8 "Appendix" (at chapter 6), which contains overview of cost function surfaces for seven case studies and desired periodic orbits in both controlled chaotic systems used for goals of thesis verification. Chapter 7 "Conclusion and discussions", discusses original contributions from candidate's point of view.

The processing of all the parts of the Thesis is on good level and experimental parts (chapter 6 and 8) are excellent, although they could be better organised. The goals of the Thesis are met and are convenient for dissertation thesis. From my point of view the thesis proves, that evolutionary algorithms (EA) are able to find optimal solution in case of chaos control as proposed and verified by the author. These findings expand the area of future application of evolutionary algorithms and possibilities of controlling Chaos.

I state, that the PhD. Candidate is thoroughly acknowledged with the area of „Controlling Chaos" and more so he is capable to formulate proceedings and methods in theoretical analysis of the problem and its practical realisation.

Selected working methods used in the thesis.

The methods of processing the Thesis meet the criteria of doctoral theses. It contains I description of the problem statement with quotation of the literature used. The biggest part of the Thesis is author's input to the problematic described. Details are listed elsewhere in this expertise. Part named „Experimental part", contains verification of well formulated inputs. To verify thesis goals proposed, author applied also EA named SOMA (Self Organising Migrating Algorithm), which was developed by his supervisor, and documented candidate's own working methods applicable in the Thesis.

The working methods in the Thesis document, that the candidate possesses abilities to work all by himself and in a scientific way.

The results of the thesis and new knowledge acquired.

The results of the Thesis are described in the part 7 named „Conclusion and discussions" and can be resumed as following:

- Proof that EAs are able to find optimal solution in case of chaos control.
- Test of several examples of chaotic systems and testing of stabilisation for various states or higher dimensional periodic orbits.

For verification of thesis goals large scale of simulation experiments have been done, which proves candidate's good knowledge in theoretical area and skills in practical programming. Realisation of so many simulation experiments was doubtlessly time challenging.

Proving that two EAs are able to find optimal solution of chaos control I consider as new knowledge in the "Technical Cybernetics" area. This new knowledge may be widely applied for controlling chaos and EAs application, as were documented in Thesis.

Which are signification of results for praxis and further progress of science?

Although practical application for optimal control of deterministic chaos is not commented in the Thesis at all, results which are verified and commented are important for further progress of science in the area of "controlling chaos". Importance is in the verification, that algorithms SOMA and DE are applicable not only for controlling chaos but even for its "optimal" control. This finding is new in this scientific area. I recommend to PhD. candidate to mention some practical applications of controlling chaos during his defence.

Remark:

- State of art is focused only to the "controlling chaos through feedback (OGY, Pyragas's)". Others methods are represent by 5 rows on page 31. During defense I recommend short survey also from "controlling chaos without feedback" and "synchronization of chaos".
- During defence I recommend also short survey about "engineering implementation" from the area "control of deterministic chaos".
- Description of the most known examples of chaotic systems in part *number four* is very broadly without citation of original references.

- In description of "state of the art" where OGY and Pyragas method are commented, missing very important reference to the Romeiras, Grebogi at all:*Controlling chaotic dynamical systems. Physica* D, 1992, 58,165, Elsevier.
- Comparison with classical control method – OGY is in part 6.3.4 on Fig. 6.26, 6.27. Some table for comparison will be also useful. Also comparison for p-4 orbit, and for example for case study 7 and addition this comparisons to the part 6.10 "Conclusion of all result.

Conclusion.

Ing. Roman Šenkeřík as PhD. candidate proved in his Thesis that evolutionary algorithms are able to find optimal solution in case of controlling chaos.

New scientific knowledge which was introduced into the area of "Controlling Chaos" is:

-Evolutionary algorithm SOMA and Diferential Evolution are able to find optimal solution in chaotic systems control.

-It is not possible to propose cost function which gives "universal results" suitable for simulation with wide range of initial conditions because chaotic systems are extremely sensitive to proper setting of control algorithm.

Author of the thesis published 15 publications, 14 in the international conferences and 1 in scientific journals (all of them were published with supervisor). I confirm that Ing. R. Šenkeřík is talented and perspective scientific worker.

On base of mentioned facility and comfortable with § 47, section 4 of decree No. 111/98 Sb. and the article No. 52 of the Study and examination rules of Tomas Bata Univerzity in Zlín,

I recommend the thesis on defence.

V Žiline, dňa 14. 6. 2008

Prof. Ing. Mikuláš ALEXÍK, PhD.