CHALMERS

October 26, 2022

## Evaluation of Martin Ron's PhD thesis
## *Pattern Discovery, Learning and Detection in Time Series*

This is an interesting thesis, including a number of significant contributions to the area of machine learning, more specifically applied to pattern extraction, learning and detection in time series. The initial motivation was energy reduction for robot cells, which was then generalized to general repetitive behavior in industrial machines. The results are general and very useful, and can therefore be used in many application areas. Some conclusions on the achieved results are however, in my view, too much in favor of the own results, compared to alternative and existing strategies. Examples are given in the detailed list below.

Concerning the text, I appreciate the clear description of notations in the beginning of the thesis, followed up by comments on specific notations in the individual chapters. At the same time, it is rather obvious that some text has not been updated to be a part of this monograph. It is simply copied from a paper, see more detailed comments in the list below. Generally, the text is well formulated, but sometimes there are simple errors that could have been avoided.

Additional questions and comments:

- P 7 - Why using the Euler approximation instead of a correct discretization based on the matrix exponential exp(Ah), where A is the continuous system matrix? In Matlab this corresponds to the routine c2d.
- P 17 - "In the Fig. 3.7 is the example how the boundaries of operations are located. Red vertical lines depicts where operation starts or ends" How are these boundaries determined?
- The type of energy function including an optimization method mentioned in [2], and referred on p 20, also shown in Fig 3.9, was suggested already at IEEE CASE 2011. It was then called energy signature, and it was published by the same authors in Vergnano, A. ; Thorstensson, C. ; Lennartson, B. ; Falkman, P. ; Pellicciar, M. ; Leali, F. ; Biller, S. (2012). Modeling and optimization of energy consumption in cooperative multi-robot systems. IEEE Transactions on Automation Science and Engineering, 9(2), pp. 423-428.
- P 27 - What does time-warping mean in this context?

Chalmers University of Technology
*Department of Electrical Engineering*
SE 412 96 Gothenburg Sweden

Visiting address: Hörsalsvägen 11
Phone +46(0)31-772 3722
Email: bengt.lennartson@chalmers.se
VAT No: SE5566479559801
www.chalmers.se/en/departments/e2/

- P 29 - Is the birthday paradox unique or not in this area? The paradox is obviously well know related to hash tables.
- On p 36 it is mentioned as a comment on Fig 4.2 (real-life data sets) that "For data sets with a lower motif frequency corresponding to a lower coverE, our algorithm is faster than the others." What I can see, this is only the case for the Robot [68], while both CHIME and SCRIMP++ are more than ten times faster for the Oven [68], and SCRIMP++ is four times faster for the ASTRO case.
- P 39 - "Especially robotic applications have been getting higher attention recently because the robots consume about 25% of electrical energy in highly robotized industries such as car production." This number is surprisingly high, and what is 25% related to? For instance, lighting in a factory consumes a lot of energy. In the referenced article [70] it is stated that "An average of 200-kg-payload body shop robot consumes a yearly 8 MWh and robots overall consume approximately 8% of the total electrical energy in production processes".
- The model in (7.1) was presented already in Chapter 2, but partly with other notations. This formulation indicates that the text in this chapter is based on a self-contained paper, but this chapter is a part of a monograph. Sometimes it is even written "this paper" instead of "this chapter", see for instance the last line on p 52.
- A final reflection is that many improved machine learning methods are presented in the thesis. On the other hand, more or less nothing is mentioned how to apply these methods on the original problem, reducing energy for robot cells. In Chapter 3 it is discussed how the power-consumption signal can be used to "recognize behavior patterns corresponding to individual robotic operations", and in the beginning of Chapter 5 it is said that "robots consume about 25% of electrical energy in highly robotized industries such as car production". However, in the end of the thesis nothing is mentioned about how the proposed methods can be used to save energy for any type of machines. Thus, I'm asking for some reflections on how the proposed method can be applied more specifically for energy reduction of robot systems.

Finally, follows some quick comments on the questions given in the review invitation letter.

- To what extent is the subject of the thesis relevant to the current needs of the scientific community? Answer: very relevant.
- To what extent have the main objectives of the work been fulfilled? Answer: The main objectives have been fulfilled, but the relation between the proposed methods and the original problem on energy reduction could be more clearly explained.
- To what extent are the methods used in the thesis appropriate? Answer: very relevant.
- What are the main results and contributions of the work? Answer: see my initial text.

- To what extent is the work important for the further development of science? Answer: very relevant, machine learning is today one of the most important research areas in applied science.

To summarize, the author of the thesis has proven to have an ability to perform research and to achieve scientific results. Hence, I do recommend the thesis for presentation with the aim of receiving a Ph.D. degree.

Yours sincerely,

Bengt Lennartson

Professor in Automation