CTU CZECH TECHNICAL UNIVERSITY IN PRAGUE

REVIEWER'S OPINION OF FINAL THESIS

I. IDENTIFICATION DATA

Thesis name:	Energy Optimization of Robotic Cells using Machine Learning
Author's name:	Petr Ungar
Type of thesis :	master
Faculty/Institute:	Faculty of Electrical Engineering (FEE)
Department:	Department of Computer Science
Thesis reviewer:	prof. Ing. Jan Faigl, Ph.D.
Reviewer's department:	Department of Computer Science

II. EVALUATION OF INDIVIDUAL CRITERIA

Assignment — ordinarily challenging

Evaluation of thesis difficulty of assignment.

The assignment is structured into four tasks, each specified in sufficient detail and straightforward realization. The goal is to propose an approximation energy consumption function usable in the defined optimization method. The approximation is requested to be based on machine learning, and data to train a particular model are asked to be collected from simulation. The approximation of the energy profile is then requested to be compared with consumption from simulation (not necessarily different from the same set as training data). The assignment is thus a relatively straightforward application of regression techniques. Therefore, the assignment is considered ordinarily challenging.

Satisfaction of assignment — fulfilled with minor objections

Assess that handed thesis meets assignment. Present points of assignment that fell short or were extended. Try to assess importance, impact or cause of each shortcoming.

The assignment requests four tasks: survey, analysis, machine learning model, and comparison. The selected machine learning is based on piece-wise linear approximations for which particular segments are hand-tuned. Although it might be questionable how much it is a machine learning method, the reviewer did not find a comparison of the proposed method with the existing one(s), as asked in the fourth task. Since it is not clear what is mean existing approaches, as current simulation-based vs. existing approximations, the assignment is considered fulfilled with minor objections.

Method of conception — partially applicable

Assess that student has chosen correct approach or solution methods.

The student follows the recommended literature and forces himself to linear approximation, further justified by the Mixed Integer Linear Programming (MILP) model employed in optimization. The requested approximation of the energy profile is reduced to profile ranking, and it is claimed that the precision of the approximation is not the primary goal of the work. The student presents static and dynamic features; however, the problem of profile approximation and profile rankings is not formally introduced. In the presented features, it is unclear what the variables forming the degrees of freedom are and what the observation's characteristics are. Since it is understood the assessment of the profile is demanding, the problem can be formulated as finding the most suitable variables (for regression) and the most suitable characterization to rank the profiles in the way the optimization would yield the most energy-efficient solution satisfying the desired cycle time. It is not sufficiently and clearly described in the text. The methodology used is considered partially applicable because it fails to clearly formulate the objective function being addressed in the work. It is reduced to the energy profile (3.1) without a proper introduction of the symbols used and the optimization of energy consumption using MILP, which is defined in Section 3.4. The formal objective function with the hyper-parameters to be found is not presented in the text.

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Technical level	E - sufficient.

Assess level of thesis specialty, use of knowledge gained by study and by expert literature, use of sources and data gained by experience.

The assignment explicitly asked for machine learning methods, which are quickly reduced to polynomial and further linear predictors. It might be considered sufficient; however, it is not formally defined, which does not provide supportive evidence that the student used the knowledge from the machine learning courses.

Formal and language level, scope of thesis	C - good.

Assess correctness of usage of formal notation. Assess typographical and language arrangement of thesis.

The first part of the text is readable, but then it becomes talkative. The student used future tense, which is not easy to follow as it is unclear if the described parts have been done or will be done. The text contains many cross-references that do not support smooth text flow. In general, referring to previous parts in the first sentence of a new section indicates that the text structure needs to be improved.

Selection of sources, citation correctness	B - very good.

Present your opinion to student's activity when obtaining and using study materials for thesis creation. Characterize selection of sources. Assess that student used all relevant sources. Verify that all used elements are correctly distinguished from own results and thoughts. Assess that citation ethics has not been breached and that all bibliographic citations are complete and in accordance with citation convention and standards.

The student follows the suggested works from the assignment that are further enlarged, but more machine-learning methods might be discussed.

Additional commentary and evaluation

Present your opinion to achieved primary goals of thesis, e.g. level of theoretical results, level and functionality of technical or software conception, publication performance, experimental dexterity etc.

From the presented text of the thesis, it is not clear the target of the work has been to develop a particular solution or rather methodology how to replace simulation-based assessment of energy consumption in the existing optimization framework.

III. OVERALL EVALUATION, QUESTIONS FOR DEFENSE, CLASSIFICATION SUGGESTION

Summarize thesis aspects that swayed your final evaluation. Please present apt questions which student should answer during defense.

In the thesis, the student elaborated on the problem of energy optimization industrial robots with the aim of addressing the demanding evaluation of the energy profile to assess its energy consumption. The problem is described, and the requested machine learning methods are reduced to polynomial regression and further simplified to linear approximation. The student employed the model in validation scenarios, showing possible benefits. Some parts of the work deserve to be more elaborated or justified. Therefore, I evaluate the handed thesis with a classification grade

C - good.

I have the following questions for the students.

- Since a single robot is considered in the work, can you formally define the problem of finding the energy profile as a problem of trajectory planning? In particular, what are the problem specifications and parameters, such as the robot's configurations, velocity, acceleration limits, and possible payload weight?
- What are the limitations to developing/employing high-fidelity simulation of the digital twin?

Date: 26.1.2024 Signature: