REVIEWER'S OPINION OF FINAL THESIS

I. IDENTIFICATION DATA

Thesis name:	**Gait Adjustment of Hexapod Walking Robot after Leg Damage**
Author's name:	**Jan Feber**
Type of thesis:	master
Faculty/Institute:	Faculty of Electrical Engineering (FEE)
Department:	Department of Computer Science
Thesis reviewer:	Doc. Mgr. Matěj Hoffmann, Ph.D.
Reviewer's department:	Department of Cybernetics

II. EVALUATION OF INDIVIDUAL CRITERIA

Assignment **ordinarily challenging**

Evaluation of thesis difficulty of assignment.

The assignment involved developing and testing controllers on a simulated hexapod robot.

Satisfaction of assignment **fulfilled**

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 was fulfilled. No experiments were performed on a real robot, but that was an optional part of the assignment.

Method of conception **correct**

Assess that student has chosen correct approach or solution methods.

The method of conception was probably correct even if I'm not convinced that all the effort – extensive experiments and their analyses – was spent in the most promising direction.

Technical level **C - good.**

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

I was not convinced that the author understood the large body of literature completely well and chose the most interesting problem to tackle. Alternatively, the author did not manage to explain very clearly what has been done and why. Some comments:

- It seems that only the coordination between the 6 legs – the phase lags were optimized. If one leg is taken as the basis, there are 5 phase lags to optimize. Moreover, the author was making use of gait patterns observed in insects (tripod, ripple…). Then, the space of parameters is even smaller. Why is this difficult to optimize?
- The fact that other parameters – amplitudes and offsets of the joint movements, possibly frequency – were fixed puts the approach in question. Only a small volume of the state space of effective controllers was available.
- Chapter 2 – Background and Related work.
    a. The overview of the literature on walking robots was hard to understand. In my opinion, the two main classes are reflex-based controllers and Central Pattern Generators (CPGs). Both control approaches are used by animals. Reflexes seem not to be covered here. Within CPGs, the pattern can be set either with explicit dependence on time – the target position to the motors is equal to e.g. Amplitude * sin (2 π f t + phase_lag) + Offset – or it is a dynamical system defined by differential equations (e.g. Phase, Hopf or other oscillator). In this case, if one leg is blocked, it will continue where it left off when it is free again and not try to catch up. Synchronization is achieved through coupling terms (or through interaction with the environment). I was not sure the author's understanding is the same when reading 2.2.2.2 Dynamic system controllers and the Problem statement. Eq. (1) in Chapter 3 seems to be a differential equation; yet there are terms with explicit dependence on time.
    b. 2.2.2. Bio-inspired controllers. The author picked Evolution Algorithms (EA) and Reinforcement Learning (RL) as two main approaches. I found it partially confusing. One approach is optimization of the gait patterns to maximize a cost function (speed, stability, cost of transport…). This can be achieved with

different algorithms – local or global, with or without gradient descent / EA, simulated annealing, particle swarm optimization…. RL is also a possibility, but it was not clear to me how it was used here. Was a policy being learned – different action parameters depending on a state?

- 7.3. Limitations and future work
    a. "the straightforward approach to optimize the GP by tunning 3996 parameters (one servo motor position command for each servo motor for each iteration within the MC), which would reduce to 15 * 222 = 3330 parameters…" – it seems naïve to optimize the target motor wave form in this way.
    b. "The motion primitives, activated in the right moments given the GP rhythm, could be parametrized by only two numbers for each servo, representing the range of movement for the respective servo motor, i.e., 18 * 2 = 36 parameters, or 15 * 2 = 30 parameters for case of one amputated leg. Therefore, the introduced reduction yields in total 35 parameters10 for locomotion after amputation of one leg, significantly reducing the search space." This number can be further reduced by considering symmetries – legs of an intact pair would have the same motion range etc.

Formal and language level, scope of thesis **B - very good.**

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

The thesis is extensive, and the methods used are thoroughly described using mathematical notation. The list of abbreviations – which the author makes heavy use of – is handy. However, what I was lacking as a reader was a high-level description of what has actually been done. With a single read-through, I quickly got lost in the formalisms. The key chapters – 3 Problem Statement, 4 Proposed Method, 5 Evaluation Methodology – contain just text and formulas – almost not figures or tables. I would have liked to see the gait patterns and the signals sent to the servomotors visualized. I would have also liked to see a clear overview of the parameters that are being optimized and their ranges. Including videos would also be useful (delivered by the author upon my request which I appreciate).
The English language is not perfect, but can be understood well.

Selection of sources, citation correctness **A - excellent.**

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.

There are 57 references cited and this work is put in the context of them.

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.

Comments on the title, abstract and motivation:

- The title and abstract talk about a hexapod robot without mentioning that it was only simulated.
- The work is motivated by mentioning that robots in search & rescue and similar contexts need to work and hence also recover from damage autonomously. That can be debated – robots in disaster scenarios are often teleoperated. Moreover, the fitness function in the current work (e.g., velocity) cannot currently be measured by the robot itself.

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.

ČVUT
ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE

REVIEWER'S OPINION OF FINAL THESIS

Questions for the defense:

1) It is mentioned that the main drawback of Evolutionary Algorithm (EA) was that it would take too long to compute (9 hours). Have you considered other, simpler algorithms, like Simulated Annealing? With 5 parameters to optimize, it is possible to use it online.
2) The fact that other parameters – amplitudes and offsets of the joint movements, possibly frequency – were fixed puts the approach in question. Only a small volume of the state space of effective controllers was available. Can you comment on that?

I evaluate handed thesis with classification grade **B - very good.**

Date: **22.1.2024** Signature: