REVIEWER'S OPINION OF FINAL THESIS

I. IDENTIFICATION DATA

Thesis name:	**Real-Time Teleoperation of a Robot Arm for Self-Contact**
Author's name:	**Adam Rojík**
Type of thesis :	master
Faculty/Institute:	Faculty of Electrical Engineering (FEE)
Department:	Department of Cybernetics
Thesis reviewer:	Dr.-Ing. Jan Kristof Behrens
Reviewer's department:	CIIRC CTU

II. EVALUATION OF INDIVIDUAL CRITERIA

Assignment **challenging**

Evaluation of thesis difficulty of assignment.

The student was assigned the task of developing an experimental setup that requires teleoperating a robot arm based on human arm motions captured by a professional motion capture system. Special attention must be given to safety because humans operate the robot via their arm motions and the robot makes direct physical contact with the human. The task is conceptually not trivial because standard teleoperation techniques might not be usable in the self-touch experiments. The task is technically challenging because a system spanning several computers and hardware need to be integrated where especially the robot control code has tight real-time requirements.

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 student meets the requirements from the assignment. However, I was a bit surprised to see that the proposed control algorithm only allows the control in a single direction (Cartesian x-axis). From the title I would have expected that something is added to state-of-the-art teleoperation to account for the specific challenges of self-touch. Instead, the teleoperation was restricted to fit the experiment scenarios.

Method of conception **correct**

Assess that student has chosen correct approach or solution methods.

An important part of this thesis should have been an analysis of what is required (from a technical perspective) to conduct the self-touch experiments using the teleoperated robot. The topic of latency is discussed thoroughly such that a clear target of 15-25 ms delay was identified as acceptable. From this, the author concluded that the 1 kHz control cycle of the robot must be used to meet the reactiveness target (correct). However, the selection of position control seems to be not justified enough. I would have expected that Cartesian Impedance Control based on the low-level torque controller to be more suitable. This would strictly be necessary, if the compliant tip of the robot was replaced by anything stiff. Unfortunately, this is not discussed.
The topic of safety was well analyzed (although the initial risks in table 4.2 are too low). However, the analysis should be presented before the measures are listed.

Technical level **B - very good.**

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

The student created a working experimental setup with significant technological depth. This must not be underestimated. The student claims to work according to agile development strategies. This implies for me test-driven development, of which I could not spot anything in the code base.

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

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

The thesis is generally written well, but the quality between the parts varies. The Introduction and the conclusion do not fulfill their purpose. The abstract, the introduction, and the assignment share text passages nearly word by word. Fig. 4.3

could be used to explain the problem in the introduction. The conclusion reads like a (biased) meta-analysis of the student's work habits. The main content chapters are written well. Throughout the thesis, some grammar and spelling mistakes are scattered. The plots and typographic arrangement of the thesis are great. The citation style is fine.

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.

I miss a discussion of MoveIt Servo and other teleoperation approaches. Some assumptions about control could be justified by suitable citations. For example, the stated frequency requirements in hierarchical controllers are not backed by the literature. In fact, a 1 kHz robot motion controller will only be able to track a reference signal with 100 Hz or slower.

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.

The student achieved the requirements of the assignment. However, the title of the thesis could mention that a special experiment is developed. A working system of hardware and software was presented. Results generated were submitted to a conference.

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.

The implementation of such a system and the validation in actual experiments is a contribution that (i) enables more experiments and (ii) led already to a paper submission.

Questions:

1) What are the differences between teleoperation for self-touch and conventional teleoperation?
2) How could the Manipulator Jacobian be used to solve the presented problem while avoiding solving the Inverse Kinematic problem?
3) What is important when solving the IK problem to control the robot?
4) How noisy is the arm tracking data acquired by the mocap system and how do you avoid that the robot tries to follow the input signal too rigidly?
5)

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

Date: **6.6.2023** Signature: