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Review of the manuscript thesis proposed by Mr. Khaled Fouda

The manuscript presented by Mr. Khaled Fouda develops his contributions to prepare the doctoral degree of the Versailles Saint-Quentin-En-Yvelines University *Université Paris-Saclay* with Fethi Ben Ouezdou and Samer AlFayad as supervisors. The manuscript is entitled : **Prosthesis Testing Machine for Transtibial and Transfemoral**.

This document of 136 pages is written in English. The manuscript is composed of a message of acknowledgment message, an abstract in English, an abstract in French, a list of Figures, a list of Tables, a list of abbreviation, an introduction, 4 chapters, a conclusion, a bibliography, and two appendices. The document is well-written and well-structured. The style and the illustrations are very nice and beyond reproach.

Chapitre 1 : Introduction. This chapter recalls the statistics from the *Amputee Coalition Organization* to show how the amputation is a critical problem in the world. Many manufactures designed prostheses. However Mr. Khaled Fouda observes that there is a lack of standard machines and criteria to evaluate efficiently the performances of the proposed protheses. The purpose of this thesis is to build a Prosthesis Testing Machine (PTM). The demand of the prosthesis is currently increasing to overcome the amputations, which are caused by wars, car accidents or the disease. The PTM has to be able to reproduce all the dynamics from the brain of the human body such as walking, running, or going up and down stairs.

Chapitre 2 : Lower Limb Prothesis : State of Art. First Mr. Khaled Fouda lists in details several causes of an amputation, congenital problems, pathological problems, accidents (electrocutions, falls, use of machinery...) (20% of amputations), etc. The amputation is a trauma which can lead to a limitation of activity or a restriction participation in society. Thus if the patient accepts, a prothesis could be useful to rehabilitation. The idea to carry out a prosthesis is not new. A wooden toe attached to a mummy's foot was found. The main desired qualities fo a prothesis are solidity/plasticity, lightness, durability/wear resistance, comfort, cost, minimal rehabilitation period. Mr. Khaled Fouda presents the main families of protheses, active, passive, for an upper limb, a lower limb... At the end Mr. Kha-

led Fouda describes several existing test machines. This chapter is a very good introduction to present the topic of prosthesis.

Chapitre 3 : Biomechanical Analysis. Mr. Khaled Fouda describes the main characteristics of the process of the command sequence of a limb, starting from the brain, passing through the muscles, returning feedback to the brain again. All the physiological effects which are taken into account to create a motion are very complex. I regret may be a little lake of a general explanation about the relation between the moto-neurones of the central nervous system and the electromyography signals. However we can find here a lot of important information about the anthropometry of the lower human body, the mass and moment inertia of segments, the different centers of mass. Thanks to a Vicon system used by Mr. Khaled Fouda , data are provided about the range of motion of the most important joints, to calculate the torque accomplished with each joint. Mr. Khaled Fouda analyzes the human walking, running, transition from standing to walk, and stair gait cycle. All these provided bio-mechanical data will be very useful and pertinent for the design of the PTM. I appreciate very much this work.

Chapitre 4 : Proposed PTM **Modeling**. Three geometric structures have been explored for the PTM ; Articulated robot arm, Cartesian manipulator (parallel system), and Stewart Platform (SP). The serial structure has the great drawback to have law capability. Mr. Khaled Fouda does not keep this solution. The parallel system is not easy to control and the control law of its joint variables is strongly non-linear in the Cartesian space. Hybrid systems such as Cartesian robot arm and agile eye are also considered. But they are complex to manufacture and have a very high manufacture cost. Mr. Khaled Fouda finally chooses the SP structure. The test machine groups three elements SP, $HYDROiD$ hip, and treadmill. Let us recall that Hydroid is a remarkable humanoid robot designed by the laboratory in the framework of the ANR PHEMA. It is actuated with motors which use hydraulic as power supply fluid. The SP with six DoFSs emulates the center of mass of the human body of the patient. It exerts the same weight and torque effect on the prosthesis. The hip emulates the human hip, with similar range of motion and torques. The treadmill emulates the moving ground. The association $SP/Hydroid$ hip can be viewed as hybrid because it combines a parallel structure with a serial structure. The SP structure is well-known. However a useful and deep theoretical investigation is made about the workspace of a planner parallel mechanism. The inverse geometric model direct geometric of the SP is presented here. For the closed-form solution of the direct geometric model the strategy is to use the angles instead of the lengths. It is less expensive to install rotary sensors than linear variable displacement transducers. Six rotary sensors are attached at three universal joints. From these six

measured it is possible to determine the posture of the mobile plate. The rigorous proof is made using the usual geometric tools and the transformation matrices of rotation.

Chapitre 5 : Preliminary Results : Simulation and Prototype. To avoid any problems during experiments due to a bad control, the first tests are carried out with the developed model in simulation to evaluate the workspace. The experimental $PTM\ SP$, $HYDROiD$ hip, and treadmill is now assembled. Several results show that the workspace will cover the COM of the human body.

Chapitre 6 : Conclusion and Future Works. The future work is know to equip this experimental PTM with sensors at the thigh with the ambition to assess the comfort of the wearer at the contact point, to explore all the potential of the PTM. May be I should add to include a soft element in the $HYDROiD$ hip, which emulates the prosthesis, to observe the influence on the impacts with the ground (the treadmill). Furthermore it should be interesting to test unexpected changes of the ground surface to extend the possibility of this prosthesis test machine.

Contributions of this thesis.

1. A general and large survey of existing prosthesis.
2. A complete bio-mechanical analysis of Human.
3. A rigorous analysis of the inverse geometric model and an original adaptation of the closed-form solution of direct geometric model.
4. An active participation to the design of the Prosthesis Testing Machine.

My opinion is that Mr. Khaled Fouda provides a consequent work. This work is valued with two international communications and two accepted papers in journals. Thus I am extremely favorable to support Mr. Khaled Fouda to present his thesis in order to obtain the doctoral degree of the Versailles Saint-Quentin-En-Yvelines University *Université Paris-Saclay*.

Fait à Nantes, le 5 décembre 2017

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