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To:

UNIVERSITÉ PARIS-SACLAY

REPORT

Concerning the Doctoral Thesis **"Prosthesis Testing Machine for Transtibial and Transfemoral"** proposed by **Khaled FOUDA** to the **Université Paris-Saclay, Université de Versailles Saint-Quentin-en-Yvelines**, in pursuit of obtaining the scientific title of **"Doctor"**.

Prof. Luige VLĂDĂREANU, Romanian Academy, Institute of Solid Mechanics of Romanian Academy, Ph.D. rapporteur, after due consideration of the work, have deemed significant the following:

Chapter I. Relevance and actuality of the proposed theme.

This thesis treats a complex subject of scientific research concerning the dynamics of the human body aiming develop testing procedures for either passive or active prosthesis and to build a testing machine for transtibial and transfemoral prosthesis.

Testing machine vary in their level of sophistication but, however, Prosthesis Testing Machine for transtibial and transfemoral play an important role in adaptability and adjustment of the fitting prosthesis. The goal is to build by applying recent advancements in technology a complex robotic system that systematically test a given prosthesis in a maximum set of real conditions parameters.

The actuality and relevance of the doctoral thesis, as results from the ample bibliographical study presented by the author, is justified through the significant impact that transtibial and transfemoral prosthetic, including energy expenditure, body image, voluntary control within a transfemoral prosthetic

system, prosthesis fit and design, component selection, and alignment, has over of quality of life, mobility and rehabilitation of the patient back into the normal life of his community, offering in addition differing theories and practical implementation techniques for transfemoral prosthesis design, suspension, and clinical application.

Fundamental proven prosthetic principles are never outdated, only the methods to accomplish them are refined. Ideas are endlessly being recycled from the past. Concepts that may have been impractical at the time of their inception, become possible with developments in scientific research, materials and technology.

The ideal goal for any prosthetic device is for the user to feel that the device is part of his or her body. Irrespective of the prosthesis design, an optimal fit should be intimate to the contours of the residual limb and assist the user in controlling the prosthesis. Beyond these basic criteria, an optimal fit of a transfemoral prosthesis is poorly defined and has not been standardized. However, if users do not feel that they have control of the prosthesis, they likely will not fully use the prosthetic device. This is the main contribution of the thesis, allowing the possibility of identifying and determining the optimal fit of a transtibial and transfemoral prosthesis using prosthesis testing machine developed by the author.

From heavy, immovable limbs to lighter, more functional limbs, prosthetics has come a long way. Today, modern materials such as plastics, carbon fiber, and strong but lightweight metals like titanium and aluminum, are water resistant and better able to withstand harsh environments. These materials are now widely used along with complex designs and advanced prosthetic testing techniques, both of which allow the patient to expend less energy.

The issues solved by **Mr Khaled FOUDA**, according to the chosen research direction, are important both through their modern characteristics, as well as through the numerous interdisciplinary aspects present throughout the paper, which have led to an innovative solution in the development of the transtibial and transfemoral prosthesis testing machine by simulation all the dynamics of the human body for testing procedures of the passive or active prosthesis.

In conclusion, through the content and treatment of the proposed theme, the doctoral thesis reflects, beyond doubt, both the actuality of the research, as well as its use to the larger field of knowledge.

Chapter II. On the content of the thesis

The subject matter's approach outlines the research strategy implemented by the author leading to the paper being organised into five chapters, a list of references, publications and annexes, which are logic and coherent.

Chapter 1 defines the motivation and problem of the work, research objective and presents thesis overview.

Chapter 2 state of art of the lower limb prothesis and current trends in development of the prosthesis in correlation with available PTM, and their limitations are presented. They are studied and

analyzed amputation – causes, social aspects of amputation, the prosthesis - prosthesis evaluation and classification, manufacturing technologies and, finally technologies for testing a prosthesis. The author draws the conclusion that no existing PTM which is able to reproduce the dynamic behavior of the body to carry out testing procedures. This is thesis motivation - building of the PTM for emulate exactly the movement of the human body such as walking or running and not just simple repetitive movement.

Chapter 3 is dedicated biomechanical analysis. Are studied and analyzed the dynamics and natural human movements, human body kinematics and kinetics through prediction of the joints position and of the center of mass, force acting , velocity and angular acceleration, force and torque of each segment. Are demonstrated human body movements from the natural walking by studying the normal gait cycle, and human gait parameters which leads to features identification of the running cycle, transition from standing to walk, stair gait cycle. Are synthesized the most required ranges of motions for the human body necessary for designing the Prosthesis Testing Machine. The goal of this chapter and the results obtained by the author allow use all the biomechanical data as input to emulate the human gait and run for first step and, continuing with designing the PTM.

Chapter 4 is a defining part for the thesis regarding the theoretical and applicative scientific research aimed at PTM Modeling. Three solutions are analyzed in orde to implement the prosthesis testing machine: articulated robot arm, cartesian manipulator and Stewart Platform (SP). It's identified planar parallel mechanism and are analyzed successively Inverse Geometric Mode (IGM), Direct Geometric Model (DGM) and is proposed a Closed-Form Solution of direct geometric model technique for planar parallel robot using only 3 rotary sensors. To evaluate the proposed method were analyzed the sensitivity of the equations, level of the output errors related to both the input errors and the sensors resolution. The virtual model using Sim mechanics to test the direct geometric calculations was designed. Using Sim mechanics model and virtual model was identified the workspace of the of planner parallel mechanism and the workspace for specific angle of rotation. An important component in developing an innovative solution for PTM is 6-6 DOF Stewart Platform (SP). By integrating SP into PTM architecture a Novel Closed-Form Solution of Direct Geometric Model using the rotary sensors instead of liner length of the hydraulic actuators has been developed and achieved.

Chapter 5 is dedicated to implementing the innovative solutions from chapter 3 related to PTM Modeling. Are presented preliminary results using virtual model to validate the Novel PTM architecture, simulation with Simulink and simmechanics. Successive are presented and analyzed - software for testing the novel closed-form for DGM, virtual model using Sim mechanics, PTM simulation in Simulink & Simmechanics. Results obtained using virtual model simulator validates the author's research, and confirms the achievement of the proposed goal to build a Prosthesis Testing Machine (PTM) that reproduce the same dynamic and kinematics conditions applied on the normal use, to evaluate any transtibial or transfemoral prosthesis.

Chapter III. The scientific and applicative value of the thesis

The scientific value of the doctoral thesis, defined by the research undertaken with regard to the development of dynamic and kinematic simulation techniques for the evaluation of transtibial or transfemoral prosthesis in order to develop a new testing machine, is relevant through its multiple approach of a theoretical and applicative nature. The documentation is ample, with over 80 bibliographical references, including high impact factor papers, used as benchmarks for the treatment and analysis of the important aspects discussed in the work.

The doctoral thesis is well structured, its concepts and ideas expressed clearly, gradually and logically. In putting together the work, the doctoral candidate shows a well-founded, systemic vision. The paper is clearly laid out and its graphical representations are expressive. The thesis content is well edited, in accordance with established norms in technical literature.

The thesis contains a series of results which have been published in national and international papers and scientific symposia, attesting to the doctoral candidate's enduring regard to the field of applicative scientific research. The candidate has authored, presented, published or has accepted for publishing, a number of 8 scientific papers in the thesis field with high impact factor, 2 papers published in conference proceedings and 4 papers as research posters.

The doctoral thesis authored by **Mr Khaled FOUDA** is original and presented in a clear manner. The thesis highlights a number of original contributions, of which should be particularly noteworthy: biomechanical analysis and models for prediction of segment mass and moments of inertia of the natural human movements and its dynamics, emulate the normal human gait and run applied to transtibial and transfemoral prosthesis testing machine, novel Closed-Form Solution of Direct Geometric Model Technique for the 6-6 Stewart Platform using the rotary sensors instead of liner length of the hydraulic actuators, Controlling a Robot Arm Using Virtual Reality, etc.

Taking into account the demonstrated capacity for analysis and synthesis, the multitude of conclusions and original contributions, I put forth that the doctoral thesis of **Mr Khaled FOUDA** is based on a high quality research activity, with significant results in the fields of biomechanics and robotics, recognised as emergent fields of scientific research and advanced technology.

General Conclusions

The doctoral thesis **"Prosthesis Testing Machine for Transtibial and Transfemoral"** elaborated by **Mr Khaled FOUDA** to the **Université Paris-Saclay, Université de Versailles Saint-Quentin-en-Yvelines**, under the scientific leadership of **Prof. Fethi Ben Ouezdou**, PhD Advisor and **Dr. Samer AlFayad**, Co-Advisor, from **Laboratoire d'Ingenierie des Systemes de Versailles**, constitutes a high level scientific work with significant theoretical and applicative contributions, fulfilling all requirements to further public presentation.

In this context, the author's professional aptitude and his maturity as a scientific researcher is revealed,

and I put forth that, following the public presentation of his work, the title of **DOCTOR** be awarded to **Mr Khaled FOUDA**. I would also congratulate, on the occasion, his scientific coordinator, **Prof. Fethi Ben Ouezdou**, PhD Advisor and **Dr. Samer AlFayad**, PhD Co-Advisor, for their approach and leadership of the candidate's activity and especially for their entire scientific accomplishments.

Bucharest,

November 30th 2017

R E F E R E N T,

Prof. Luige Vlădăreanu

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