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MEASURING EQUIPMENT IN THE RESEARCH AND THE DEVELOPMENT OF HYDRAULIC ABOVE – KNEE PROSTHESIS

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Abstract: Climbing the stairs in natural manner still presents a big problem for an amputee using commercial above-knee (AK) prosthesis. The main problem with common AK prostheses is the lack of knee and ankle joints, since climbing the stairs requires overcoming large forces and moments. The main aim of the project of developing the new hydraulic AK prosthesis is to find a way to enable unilateral trans-femoral (TF) amputees to climb the stairs in as much as possible natural manner by developing prosthesis with externally powered knee and ankle joints. In order to test prosthesis functionality, various experiments need to be conducted, and for that purpose motion measuring equipment is needed. The equipment at disposal is TrakSTAR WIDE-RANGE. As this measuring equipment will be used for the first time for testing the prosthesis, it is necessary to test it prior to using it in final experiments. For that purpose preliminary test was done by simulating climbing the stairs of sound person.
Keywords: experiments, Hydraulic AK Prosthesis, measuring equipment

1. INTRODUCTION

The aim of the Hydraulic Above-Knee (AK) Prosthesis project is to develop an AK prosthesis that would enable unilateral above-knee leg amputees to perform various activities that are integral part of their everyday's lives. The main goal, and the hardest to achieve, is to enable amputees to climb the stairs using Hydraulic AK prosthesis and perform it with ease and as naturally as non-amputees.

Advanced microprocessor controlled AK prostheses that are available on the market enable amputees to walk on levelled and inclined ground, to descend the stairs and even to ride a bicycle and to do various other activities. In order for amputees to climb the stairs in a way that would be, by its kinematics and dynamics, approximate to natural climbing of non-amputees, external power is needed to substitute large number of muscles needed to perform such an activity [1]. However, climbing the stairs can now be achieved, but it is usually performed in an unnatural "step by step", where amputees (unilateral) mostly progress to the next step with their sound leg, followed by pulling their prosthesis to the same step. This means that progressing to a next stair is always made with same leg.

The development of initial physical prototype of Hydraulic AK prosthesis with two hydraulic actuators, in the knee and in the ankle, is in a stage of testing in order to assess all assumptions from the research conducted up to now. Also, it needs to be determined if the chosen power unit has the appropriate to power to overcome forces while climbing the stairs and to determine if hydraulic actuators are adequately chosen and positioned within the prosthesis design. For that purpose, there is a need of conducting experiments of climbing the stairs in multiple phases, and adequate measuring equipment is needed in order to be able to measure achieved results.

2. PROJECT OF DEVELOPMENT OF HYDRAULIC AK PROSTHESIS

Initial research and development of Hydraulic AK prosthesis has lasted for long period of time, starting at Faculty of Mechanical Engineering and Computing, University of Mostar, Bosnia and Herzegovina. It was carried out in several phases and each of these phases represented a new progress which demanded proving the results through the appropriate experimental testing. These phases were conducted mostly as a part of master or doctoral research under the mentorship of professor PhD RemzoDedic, who was the initiator of the project of Hydraulic AK Prosthesis. Since all the research was conducted by different researchers, and on different locations, with certain time period passed between them, in all phases and experimental testing different measuring equipment was used. The reason for that is not only that different aspects were tested, but also because of the unavailability of attaining the same equipment in each time-separated phase.

2.1 Previous research and development of Hydraulic AK Prosthesis

The first experimental research of Hydraulic AK prosthesis with integrated hydraulic actuator in the knee was conducted at University of Glasgow, Scotland UK [2,3]. It was conducted in two phases. First phase was testing the prosthesis and kinematics of hydraulic actuator of the knee in laboratory conditions by simulating the mass of the rest of the human body by using an artificial weight. During the second phase, testing of the prosthesis and kinematics of hydraulic actuator was done in real operating conditions with an amputee, wearing this newly designed prosthesis and climbing onto a platform that simulated the stair.

(a)  (b)

Figure 1. Experimental testing of prosthesis with hydraulic actuator integrated in the knee: in laboratory conditions (a) and in real operating conditions (b) [2,3]

In the first phase of this research, the pressure was measured using pressure sensor TR—4002 which was connected to the MATLAB 5.3 software on a Pentium 3 computer via MRF INTERFACE.

For the second phase of testing, hydraulic measuring station with manometer and manual valve was used and pressure was measured. Knowing the characteristics of hydraulic actuator force that occurs in the hydraulic actuator was calculated.

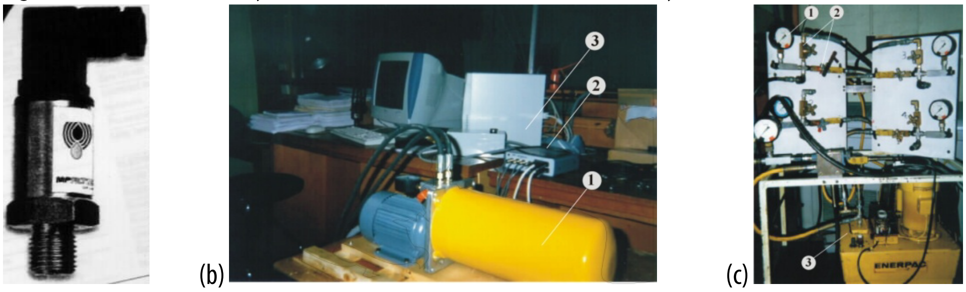
(a)  (b) (c)

Figure 2. Pressure sensor TR—4002 (a); MRF INTERFACE with Hydraulic power unit and computer (b); Hydraulic measuring station (c) [2,3]

The experiments of the second research [4] were performed at the Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Croatia. In this research, climbing the stairs of sound individuals was tested and measured in order to compare the obtained data with the previous research on prosthesis. Instead of using elevated platform to simulate the stair, real stairs were designed for this research. In order to get the precise data for comparison, with the same conditions used, climbing these stairs of amputee was also conducted.

In this research for measuring kinematic values BTS ELITE measuring system was used, and to measure reaction force of the ground KISTLER platform was used. BTS ELITE measuring system serves for motion analysis and uses video and software technique to detect and measure motion. It enables determining special coordinates for testing the points of interest on human body, or any other object, and for processing recorded signals in real time. Basic sensors for registering the scene and object in motion of BTS ELITE system are four video cameras, CCD 1/2" type, designed to be especially sensitive to infrared (IR) part of the spectrum and are equipped with special IR flashes. The points of interest, that need to be analysed, are marked with reflecting passive markers, 1 mm to 1 cm in size depending of analysed object and location of interest [4].

KISTLER 9281B type platform measures three components of the force that acts upon a platform and three components of the moment in regard to origin of the coordinate system of the platform [4].

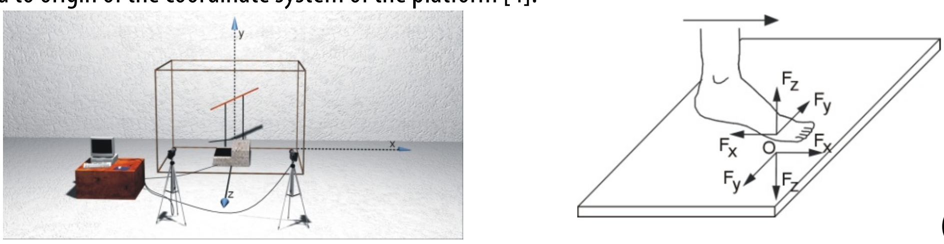
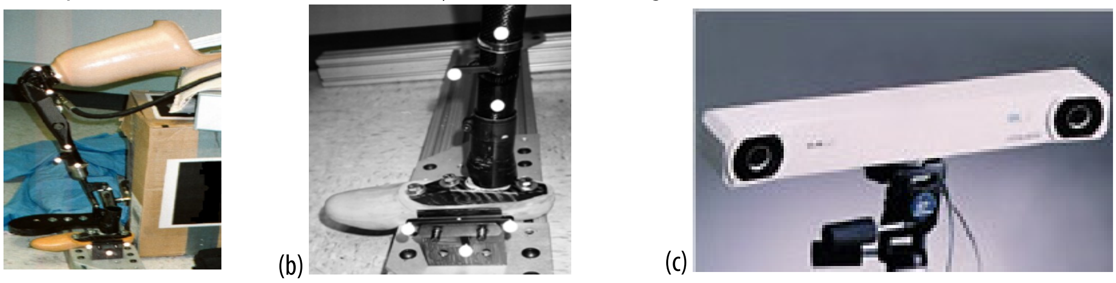
(a)  (b)

Figure 3. Depiction of equipment and working space used in second research [4]

In this research certain artificiality was noted in the process of climbing the stairs of an amputee, compared to the climbing of sound individual. It was discovered that besides the knee joint, the ankle joint is also the key factor in achieving more natural stair climbing.

The third research [3,5] was conducted at Carnegie Mellon University, Pittsburgh; Pennsylvania, USA. It was focused on testing the prosthesis with hydraulic actuator for the ankle joint integrated into a prosthesis design along with the actuator for the knee.

Hydraulic ankle actuator was positioned approximately in the place of biological ankle and testing in laboratory conditions was conducted by fixing the foot of the prosthesis to the ground and using weight to simulate the rest of the human body. Experimental testing was conducted both with and without hydraulic actuator of the ankle. Though the same experimental testing (without hydraulic ankle actuator) was conducted in the first research it had to be repeated since the different measuring equipment for the experiment was used. The equipment that was used was POLARIS, the passive system of optical measuring. It detects position of passive markers placed on the prosthesis by emitting IR light that reflects of markers and turns it back to its sensors. The experiment showed better results with hydraulic actuator integrated in the ankle.

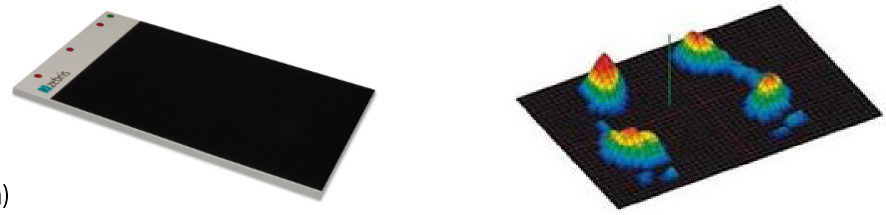


(a) (b) (c)

Figure 4. Experimental testing of prosthesis with/without ankle joint actuator (a); Placing of passive markers on prosthesis (b); POLARIS measuring equipment (c) [3,5]

Fourth research [6] was conducted in a way that kinematic data from second research and experiments on non-amputees [4] was transferred to CAD model of the prosthesis, with hydraulic actuators in the knee and the ankle integrated into a design, in order to mimic human gait while climbing the stairs. Using simulation testing, the position of hydraulic actuator of the ankle was optimized and detailed diagrams of dynamics and kinematics of both hydraulic actuators (knee and ankle) were obtained. In this research processing kinematic and dynamic data was done using Solid Works Cosmos Motion and MATLAB [6].

Additional to that, for measuring vertical component of reaction force of the ground and position of the centre of the pressure of the foot ZEBRIS FDM-S measuring platform was used. ZEBRIS is product of ZEBRIS Medical GmbH which enables static and dynamic analyses of the distribution of load underneath the feet during standing and walking. Results of the measuring are sent to computer and are processed using WinFDMS software [6].



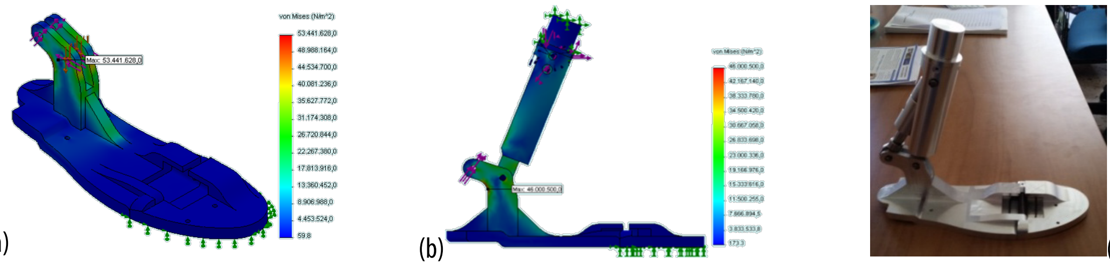
(a) (b)

Figure 5. Measuring platform ZEBRIS FDM-S (a) [7]; distribution of load display (b) [8]

2.2 Current research and development of Hydraulic AK Prosthesis

The current research [1,9,10] is being focused on prosthetic foot development. This prosthetic foot has the ability of joint flexing of the frontal section of the foot (toes), mimicking dorsal hyperextension of the biological foot.

For that purpose prosthetic foot was 3D designed, and before producing physical prototype, the 3D model was tested using Solid Works Simulation in order determine if it can endure sufficient load.



(a) (b) (c)

Figure 6. Load simulation of prosthetic foot in Solid Works Simulation [10] (a, b) and first physical prototype of prosthetic foot for Hydraulic AK prosthesis (c)

The ongoing research is concentrated on acquiring the suitable hydraulic system and actuators as well as on study of how to coordinate their movement according to knowledge obtained from the previous research. Hydraulic actuators are calculated and dimensioned, it is only necessary to find manufacturer with the ability to produce such small-sized cylinders.

3. MEASURING EQUIPMENT IN CURRENT RESEARCH AND DEVELOPMNET ON HYDRAULIC AK PROSTHESIS

For testing the prosthesis functionality, outside of laboratory conditions and simulation environment, the experiment of climbing the stairs of unilateral AK amputee using Hydraulic AK Prosthesis with two hydraulic actuators in the knee and in the ankle in real operating conditions needs to be conducted. Since in this research entirely new measuring equipment will be used, some of the previous experiments will need to be repeated in order to get more precise results by using the same measuring equipment in all tests.In order to obtain and measure and finally compare the data from experiments, there needs to be high quality measuring equipment and software involved in the experiment. The equipment at disposal is TrakSTAR WIDE-RANGE motion measuring equipment (property of DICGIM, University of, Palermo, Italy) described in the next section

3.1 TrakSTAR WIDE-RANGE motion measuring equipment

The 3DGuidance trakSTAR (WIDE-RANGE model) equipment provides real-time measurements of an object's position and orientation in free space. It is composed of a transmitter that generates DC magnetic fields for wide-range tracking of miniaturized sensors, up to 16 in total.

(a) (b)

Figure 7. trakSTAR WIDE-RANGE measuring equipment with DC magnetic field transmitter [11] (a); remote sensor during measuring experiment (b)

Each sensor provides full 6DOF position and orientation (Euler angles or quaternions) with respect to a reference coordinate system centered in the transmitter.

Each sensor operates over a 2 m range and in wired to a central hub directly connected to the transmitter. Acquisition rate is fully adjustable and the system is capable of up to 240 Hz operation with the static accuracy of 3.8mm RMS (root-mean-square) on position and 0.5 degree RMS on the orientation. Static resolution is 0.5mm on position and 0.1° on orientation. Accuracy is not uniform over the entire workspace and is known to be optimal in the so-called performance motion box (from 90 cm to 140 cm in front of the transmitter, and up to 30 cm along other directions). Drivers and APIs are available for all major operating systems, as well as toolkits for Matlab and labVIEW.

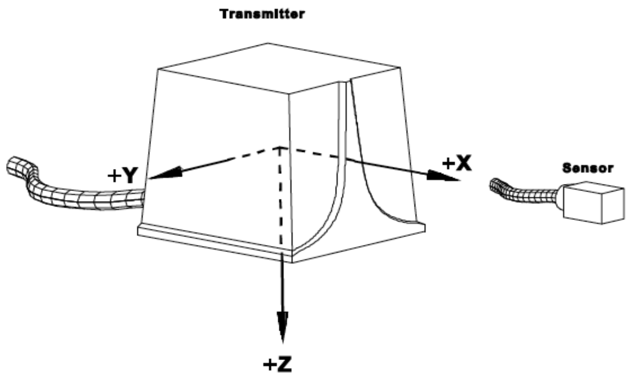


Figure 8. trakSTAR WIDE-RANGE measurement reference frame [12]

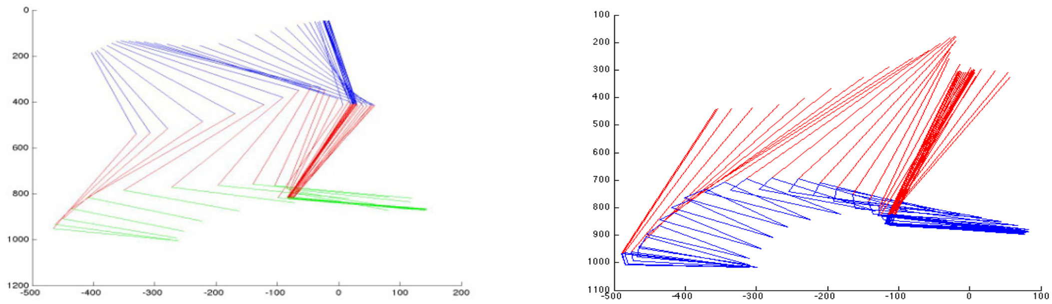

(a) (b)

Figure 9. Results of the TrakSTAR WIDE-RANGE equipment testing: Sensor placed on hip (a) and sensor moved to heel (b)

3.2 Preliminary testing of trakSTAR WIDE RANGE motion measuring equipment

As this measuring equipment is used for the first time it is necessary to test it prior to using it in final experiments. For that purpose preliminary test was done by simulating climbing the stairs of sound person. Experiment was conducted in a way that elevated platform was used in order to simulate the stair, and sensors were attached to the key points of the test subject's leg. There are only four outputs for four sensors on the equipment, and there needs to be at least five sensors to be put on the leg (hip, knee, ankle, heel, and toe) in order to fully test the legs motion. Because of that, there were two series experiments conducted. In the first series of tests one of the sensors was first put on the hip, and in the next series of tests it was moved to heel. Experiments were conducted with three sound male subjects belonging to different categories of male population divided by their height and weight.

4. CONCLUSION

The results of the conducted preliminary experiment with TrakSTAR WIDE-RANGE measuring equipment gave quite rough diagrams which cannot be considered as satisfactory to be used in the research of Hydraulic AK Prosthesis. However, it was not because of the measuring equipment used, but because of the conditions during the testing. Since this was only testing of the equipment, certain rules of conducting the experiments involving human kinematics were not followed.

Firstly, detecting equipment was not placed ideally parallel to the tested subject's motion and therefore could not give accurate results. Secondly, testing subjects were not properly prepared for the experiment and sensors were not properly fixed to the points of interest of subjects' leg.However, measuring equipment showed quite precise results, with sensitivity of 1/1000 of millimeter and frequency of 240 Hz, which is more than enough precision for the experiments on Hydraulic AK Prosthesis.

Having in mind that further experiments will be conducted in proper way, it can be concluded that TrakSTAR WIDE-RANGE measuring equipment can be used for measuring in future experiments on Hydraulic AK Prosthesis. TrakSTAR WIDE-RANGE motion measuring equipment can also be upgraded to use four more sensors, which would be optimal for measuring motion of human leg and Hydraulic AK Prosthesis.

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