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EXPERIMENTAL KINEMATICS OF HUMAN AND ARTIFICIAL FINGER

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Abstract: *In this paper, the flexion-extension angles of the three rotating joints of the HF of a sample of 5 participants and of an AF belonging to a mechanical hand-forearm system designed based on the average anthropometric data of the human sample, are measured and analyzed by using the Biometrics data acquisition and processing system and SIMIMotion software. The average cycles of the flexion-extension angles of the three finger joints are obtained for each experimental test performed by each participant and by the AF belonging to the hand-forearm mechanical system. A comparison is made between these cycles. Obtain and compare the phase plans corresponding to each joint of the human and AFs.*
Key words: *HF, AF, anthropomorphic hand, flexion-extension, phase-plane.*

1. INTRODUCTION

Stroke can cause brain damage, body impairment or even death. Stroke is a major cause for long-term disability and, in particular, could cause many problems of human body mobility. According to the Center for Disease Control, in USA every year 785000 people suffer from stroke [1], while the costs related to stroke reached almost 46 billion USD during 2014-2015 [2]. In Europe, in 2017, stroke accounted for the cause of 438,000 deaths, while stroke cost of the 32 European countries was 60 billion Euros. In this context, robotic devices could be one of the solutions that many clinicians and doctors can use with good results.

Many researchers have designed, simulated, analyzed and optimized robotic devices or exoskeletons for the recovery of the human hand and fingers [3-10] for the rehabilitation of human upper limb [9-16] as well as of lower limb [17-28]. In [3] the authors proposed a hand rehabilitation system, a robotic hand and a remote monitoring system, which control system is based on force and position sensors. Takahashi et al. have used a hand-wrist robot for the rehabilitation of patients after stroke [4]. In [5] a portable spring-guided exoskeleton whose fingers have a structure with 4 Degree Of Freedom (DOF) is presented. Authors in [6] developed a simple and easy-to-manufacture 1–DOF finger exoskeleton based on a linkage mechanism for rehabilitation of the HF after an injury or tendon surgery. In [7] the researchers proposed a pneumatic actuated finger rehabilitation robotic structure for training, and an orthotic device is presented in paper [8].

The aim of our study is to measure the flexion-extension (flex / ext) angle of the three joints of the HF and an AF designed with dimensions similar to those of HFs. Experimental tests are performed by a number of 5 subjects and a finger of the artificial hand-forearm system, designed as a prosthetic system or as the final effect of a humanoid robot. Medium cycles of flex/ext movement are obtained for each of three finger joints, for each experimental trial, performed by each subject and by the AF. A comparison between them are performed. The phase-planes corresponding to experimental flex/ext movements of the AF and HFs joints are obtained.

2. PROTOTYPE OF ARTIFICIAL FINGER

The design and functionality of the patented artificial hand-arm system found in the laboratory of Biomechanics and shown in Fig.1, is presented in detail in [9, 10]. The assembly was designed in order to be used as a prosthetic system or as an end-effector of a humanoid robot. It consists of forearm and a hand with 5 fingers similar with those of human hand, with 16 degrees of freedom, and a forearm containing five electric actuators, each of them driving independently each of five fingers by means of cable-pulley transmissions in their flex/ext movements.

An AF is made by 3 phalanges, 3 bolts and 6 pulleys for routing. The mechanical system hand-forearm is manufactured from aluminium alloy in order to obtain low masses and adequate mechanical stresses. The actuation system creates the flex/ext movement and transmits it to the hand joints by a cable-pulley transmission system (Fig.2). Each finger is actuated by one DC servomotor.

The artificial hand-arm system is composed of: the mechanical model, the actuation system consisting of 7 actuators (5 are used for the flex / ext movements of the 5 fingers, 1 is used for abduction-adduction of the thumb and 1 for flex / ext of the wrist), the sensor system (5 pressure sensors and 1 proximity sensor), the command and control system.

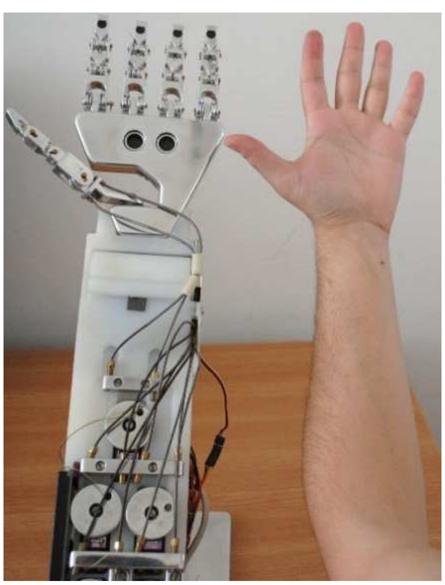


Fig. 1 Artificial and human hand-forearm

Four AFs are made from three phalanxes, while the thumb is made from two phalanxes.

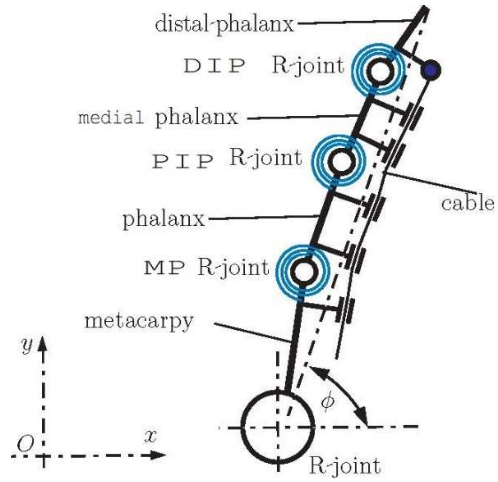


Fig.2 Transmission schema for an AF

3. EXPERIMENTAL PROTOCOL

3.1. Data acquisition systems

Experimental data are collected during tests with electrogoniometer sensors belonging to the biomechanical data acquisition and processing system, Biometrics [29]. In previously published articles, the Biometrics system was the basis for experimental studies in the field of biomechanics, recovery after surgery, rehabilitation of biomedical engineering, clinical medicine and, respectively, rehabilitation of human movements based on prosthetic, orthotic or robotic systems [3, 7- 10, 12-25, 30-33].

Figure 3a) shows the portable device DataLOG MWX8 [11], which ensures the collection from sensors of analog and digital data and which is conveniently attached to the body of the subject. The F35 goniometer is a single-axis goniometer that allows the flex/ext angles of the finger joints to be measured in a single plane (Fig.3b). The measuring range is 150^{o}.

a) b)

Fig.3. a) Goniometer F35; b) DataLog unit

Flex / ext angles are simply measured by rotating one end block relative to the second around an axis [11]. The F35 sensors are characterized by high flexibility, ease, their design allowing easy mounting over the finger joint.For a correct montage, the goniometer must be fully extended when the finger joint is fully flexed.

Fig.4. Biometrics system mounted on a human and AF

3.2. Participants

A sample of five subjects performed the experimental tests in the Biomechanics laboratory of the INCESA Research Center of the University of Craiova. Each subject performed 3 trials of the same experimental test. All subjects agreed in writing to participate in the tests, to collect and process biomechanical data.

The experimental tests were carried out taking into account the restrictions imposed by the Research Ethics Commission of the University of Craiova.

The mean values and standard deviations of the anthropometric data at the sample level are: Age - 36.5 (2.31); Height - 182.22 cm (1.91 cm); Weight - 77.59 kg (3.1 6kg). Mean values and standard deviations of the length of the human phalanges are: distal phalanx - 24 (2.13) mm, medial phalanx -12 (2.63) mm and proximal phalanx - 43 (3.27) mm. The lengths of artificial phalanges are similar to human ones.

A number of three F35 electrogonimeters are mounted on the finger joints of each subject, one for each joint: metacarpal joint (MP), proximal inter-phalangeal joint (PIP), distal inter-phalangeal joint (DIP). Another three F35 electrogonimeters are mounted on the similar joints of an AF in the hand-forearm system. Human and AFs perform the flex/ext movements synchronously. Each test was performed during 1 minute, approximately 24 complete cycles being performed. The biomechanical data collected simultaneously by the 6 electrogonimeters at a sampling rate of 50 Hz were transmitted in real time to the Biometrics system software to be processed and then analyzed (Fig.4).

A number of 54 time series were collected (3 joints * 3 trials * (5 HFs belonging to the 5 participants in the experiment + 1 AF) representing perfectly synchronized consecutive cycles of flex/ext of the MP, PIP and DIP joints. Graphs of the experimental flex/ext angles, represented graphically on the experimental data collected from the F35 sensors are obtained in real time by the Biometrics software for each attempt of each subject and of the AF of the mechanical system.

A sequence of consecutive flex/ext cycles collected by the biometric system for the AF joints are displayed in Fig.5.

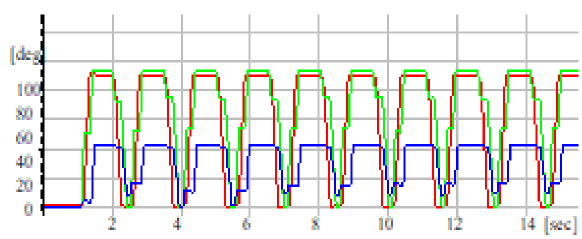


Fig. 5. Experimental variation of flex/ext angles for AF joints: green color – PIP joint; red color – DIP joint; blue color – MP joint

4. RESULTS

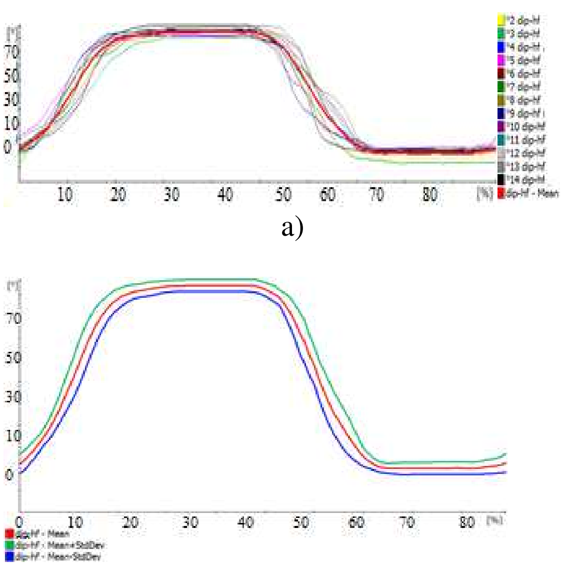
Taking into account the natural biological variability of human movements, in order to

obtain the most accurate and valid results, each data file was cut on both sides of the movement sequence, eliminating 10 cycles and fourteen cycles were kept for analysis. consecutive.
The variability of human movement requires the normalization of the cycles in the preserved sequence of motion, using the SimiMotion software to import the experimental sequence of motion preserved for normalization.

Normalization assumes that each cycle of motion, regardless of the length of the period of that cycle, is normalized on an abscissa of 100 percent, thus ensuring a correct overlap, in the same graph, of the 14 complete cycles. The data processing steps obtained from the measurements were observed for all 54 biomechanical data files collected, obtaining the average flex/ext cycles for MD, PIP and DIP joints for all participants (P) in the experimental sample.

In Figure 6 a) are represented graphically the fourteen normalized cycles obtained for the human DIP joint, while in Fig. 6 b) mean cycle, mean + standard deviation (stdev) and mean-standard deviation for the human DIP joint of Participant P5 at test 1. For each test, using the same algorithm, similar diagrams were obtained.

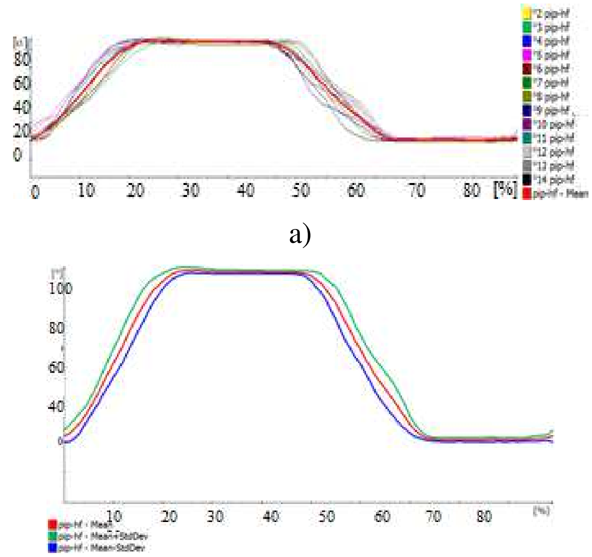
In Fig.7 a) and b) are presented the fourteen normalized cycles and, respectively, the average cycle, the mean + stdev cycle and the mean-stdev cycle for the DIP joint of the P5 participant.



a)

b)

Fig.6. Human DIP flex/ext angle a) Fourteen consecutive normalized cycles of flex/ext



a)

b)

Fig.7. Human PIP flex/ext angle a) Fourteen consecutive normalized cycles; b) Mean, mean+stdev and mean-stdev cycles

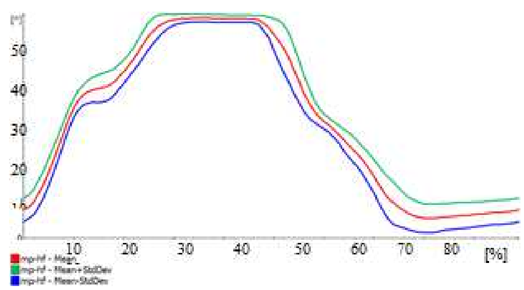
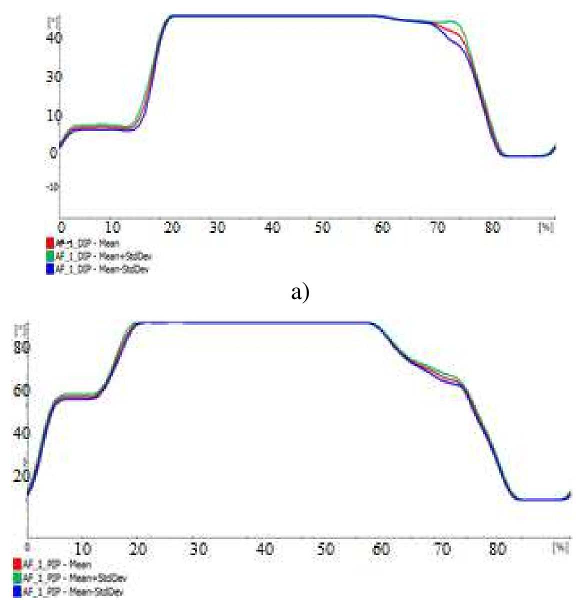


Fig.8. Human MP flex/ext angle: Mean, mean+stdev and mean-stdev cycles



a)

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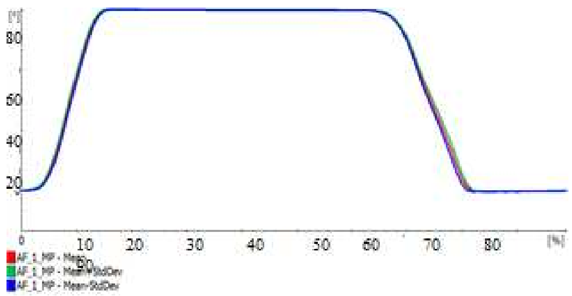

c)

Fig.9.AF joints' flex/ext mean cycles: a) DIP joint; b) PIP joint; c) MP joint

Figure 10 shows the normalized mean cycles of the flex/ext angles of the AF joints

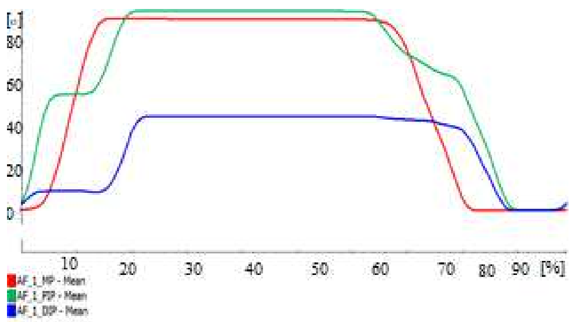

Fig.10 Mean normalized cycles of flex/ext angle of AF DIP, PIP and MP joints

In Fig.11 and Fig.12 are displayed diagrams of mean cycles of flex/ext angle of MP joint, respectively, of PIP joint of the fingers of the 5 participants and of the AF resulting as averages of the mean cycles from all trials.

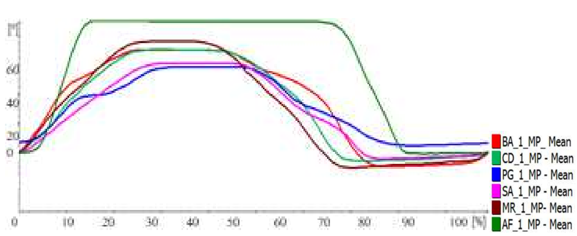

Fig.11 Comparative mean cycles of flex/ext angle of human and artificial MP joints

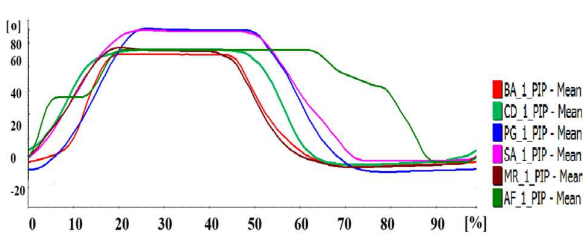

Fig.12 Comparative mean cycles of flex/ext angle of HF and AF' s PIP joint

Analyzing the diagrams presented in the previous figures, we can see that the shape of the average cycles of flex/ext angles of each joint of human and AF are similar, with some differences in shape and maximum values caused by the restrictions imposed by the design of the hand-forearm mechanical system.

In order to characterize the kinematics of a system, in different works phase portraits are used [9, 30, 31], which are suggestive graphs with values of angles on the abscissa, while on the ordinate, they have values of corresponding angular velocities. In our study, the phase plain portraits corresponding to the three joints: MP, PIP and DIP, for the AF and for the HF of all participants in the experimental sample are calculated using MATLAB. Figure 13 presents the phase plain portraits corresponding to the AF joints and to the HF joints of Participant 5 (P5). Similar graphs are obtained for each participant

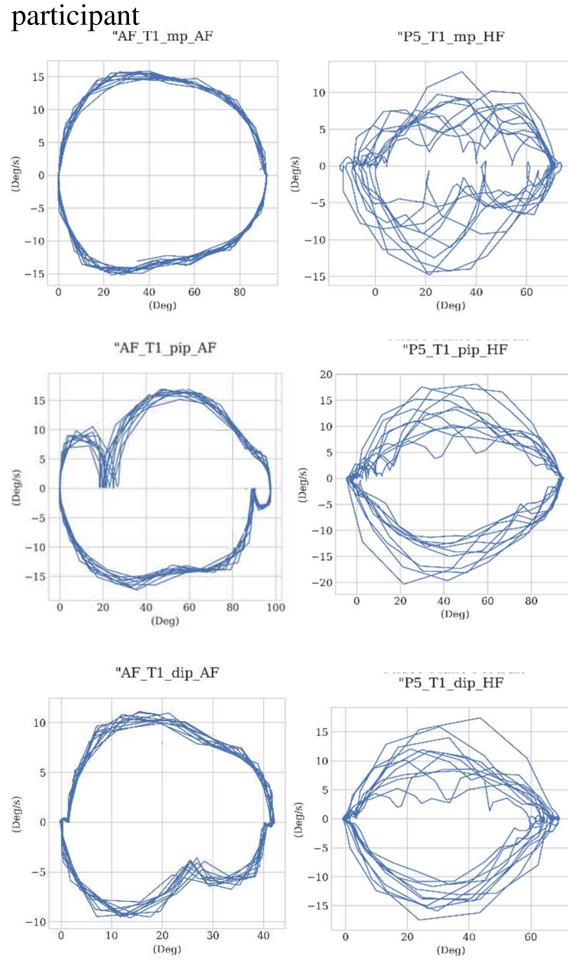

Fig.13. Phase plane portraits of flex/ext movements of AF and HF joints

5. DISCUSSION AND CONCLUSIONS

In the present paper, a kinematic study based on the Biometrics data acquisition system based on wearable sensors, namely electrogoniometers, to compare the flex/ext movement of HF and AF joints is presented. The kinematic data of the fingers joint flex/ext angles for HFs and AF were analyzed with Biometrics and SIMIMotion software. The mean cycles of flex/ext movements for each: DIP, PIP and MP joints, for each of the 3 trials performed by each of 5 participants in the sample and by the artificial hand-forearm system, were obtained. A comparison of the cycles shapes and amplitudes was realized. The shapes are similar, but the amplitudes differ by about 12-18 degrees between the corresponding human and artificial joints. The explanation lies in the design and manufacturing restrictions imposed on the artificial hand. To complete the kinematic analysis, phase plane portraits were computed. It can be seen that for the AF, which is a robotic structure, the phase planes are more compact, with less divergence in their trajectories, the amplitude being constant, features that characterise a cyclic movement. The phase plane portraits corresponding to the joints of the HF are characterized by greater divergence, they are spread and the amplitudes and speeds vary in a certain range of values, their trajectories not being compact, they do not overlap.

The similarity of the shape and the close values of the angular amplitudes of the HF and AF joints validate the approach in the design and construction of the artificial hand-forearm system. The results obtained can be used as a database for future studies on the normal movement and abnormal movement of these joints, offering the possibility of early identification of their diseases. At the same time, this study may be the basis for the design of orthotic or prosthetic devices that allow the recovery of the movements of a single finger or a single joint of the finger.

6. ACKNOWLEDGMENT

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CINEMATICA EXPERIMENTALA A DEGETELOR UMANE SI ARTIFICIALE

Rezumat: În această lucrare, unghiurile de flexie-extensie ale celor trei articulații de rotație ale degetului uman ale unui eșantion de 5 participanți și ale unui deget artificial aparținând unui sistem mecanic mână - antebraț proiectat pe baza datelor antropometrice medii ale probei umane, sunt măsurat şi analizat prin utilizarea sistemului de achizitii si prelucrari de date Biometrics şi a softare SIMIMotion. Se obțin ciclurile medii ale unghiurilor de flexie-extensie ale celor trei articulații ale degetelor pentru fiecare probă experimentală efectuată de fiecare participant şi de degetul artificial aparținând sistemului mecanic mâna-antebraț. Se efectuează o comparație între aceste cicluri. Se obțin şi se compară planurile de fază corespunzătoare fiecărei articulații a degetelor umane şi artificiale**.**

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