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DESIGN OF BIOMECHANICAL SYSTEM FOR HAND

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Abstract: *Persons with missing limbs are willing to have a, relatively, normal life. Various type of prostheses, more or less complex and, consequently, more or less expensive have been developed and are available on the specialized market. This paper presents the results of research on customized upper limb prosthesis, being focused on hand prosthesis. It points out the relevant aspects on concept and design of the hand biomechanical system, kinematic analysis and finger prototype. Further research development is also mentioned.*

Key words: *hand prosthesis, biomechanical system, reverse engineering, kinematic analysis, rapid prototyping.*

1. INTRODUCTION

Human body is so complex and each part of it has well defined function and importance. Unfortunately, it happens sometimes an accident that hurts the body irreversible. Doctors, psychologists, scientific researchers, engineers and, not the least, hurt person (child / adult) do their very best to help recovery toward a, relatively, normal life.

In [1] there are presented the design and myoelectric control of an anthropomorphic prosthetic hand, usually mounted on the residual limb and can be controlled by surface electromyography (EMG) signals. SEMG signaling is a non-invasive electrical biosignal that can represent muscle activity. By extracting information from sEMG and assessing muscle contraction, EMG control has been widely used to control peripheral deviation [2,3], especially in prosthesis [4].

A mechanism with three finger joints with active degrees of freedom (DOF) is presented in [5]. The proposed mechanism consists of a link with five bars in the proximal phalanx and a mechanism containing two parallel flat links and four rods in the middle phalanx. This mechanism allows the corresponding parts to rotate simultaneously in the plane before coming in contact with the object and can completely surround the object, even if some phalanges are blocked. The four parallel bar connection mechanism is adapted to improve the gripping capacity of the distal phalanx.

An optimal design of the finger is presented according to the trajectories of the anthropomorphic phalanx and the maximized gripping forces. The functionality of the proposed finger mechanism is verified by multiple simulations and grasping experiments using a prototype finger (see figure 1).

A relevant analysis of human fingers and, furthermore, hand arm kinematics is presented in [6], [7].

In the paper [8] it is mentioned that for object recognition, contact detection and manual control, it is better not to use trained neural networks for each task, but a single whole network.

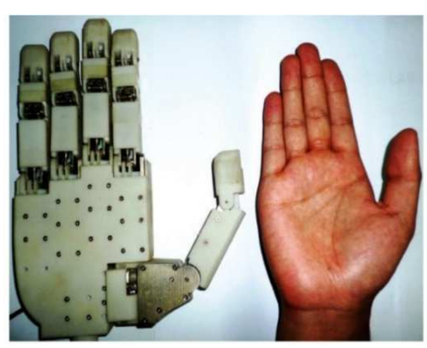


Fig. 1. Prototype and real hand fingers [5]

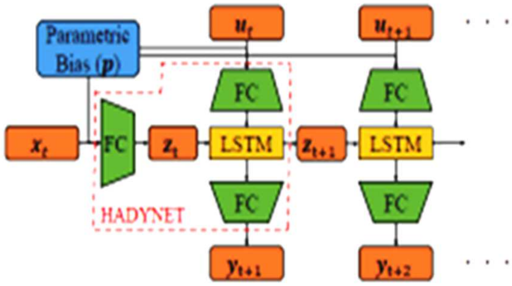


Fig. 2. Hand dynamics network structure [8]

Therefore, it was developed a method to obtain the equation of the sensory state of the musculoskeletal hand using a recurrent neural network with parametric bias. Using this network, the hand can identify captured objects, simulate, detect and control contact, and manage damage over time, irreversible initialization, and more by updating the parameter deviation.

In the study it was obtained an equation of state of the sensor represented by a recurrent neural network with parametric bias (Hand Dynamics Network, HADYNET), initially proposed in [9] (by J. Tani). It was used to recognize the caught object, simulate contact, detect and control (figure 2).

The focus of this paper is on the design of a biomechanical system for hand. It presents the relevant aspects on concept and design of the hand, kinematic analysis and finger prototype.

2. CONCEPT AND DESIGN OF THE HAND BIOMECHANICAL SYSTEM

The basic concept of the proposed biomechanical system for the upper limb is that of a system (see figure 3 and figure 4) with:

- input signals from the EMG sensors mounted on the residual limb (as it is on the assumption that the brain "knows" exactly what signals to send for grapping an object);
- output signals from the sensors (pressure, tilt, acceleration, temperature);
- motion driven by micro-motors

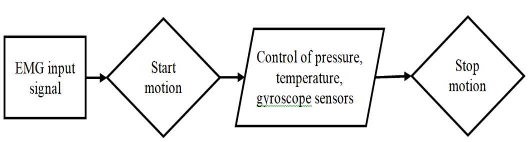


Fig. 3. Hand similarity algorithm scheme

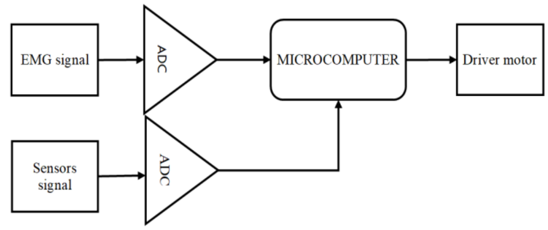


Fig. 4. Hardware platform scheme

System's working principle has to be close to the neuromotor principles of the human body and this is why working similarities have to be done, based on the algorithm presented in figure 3. According to this algorithm, there has been designed the structure of hardware platform, schematically shown in figure 4.

A step further in the design of the system is that of determining dimension of a real upper limb. The idea is that of ensuring size and dimensions of our designed system, as close as possible to that of real ones. Similarity with real hand is what it takes.

One modern technique used to determine dimensions of an existing object (body) is that of reverse engineering [10].

For the upper limb there was applied this technique and first, it was 3D scan of the limb, by MetraSCAN 3D scanner (see figure 5) [11]. In order to obtain limb surface, the mesh resolution was 0.1 mm and the number of measurements per second was 800,000.

The surface generated by 3D scan, with some errors initially, is shown in figure 6. The final surface was completely generated by 3 scans aligned, with overlapping areas for each of them.

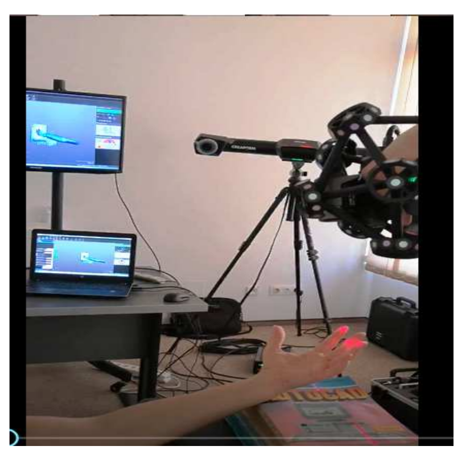


Fig. 5. 3D scan for reverse engineering

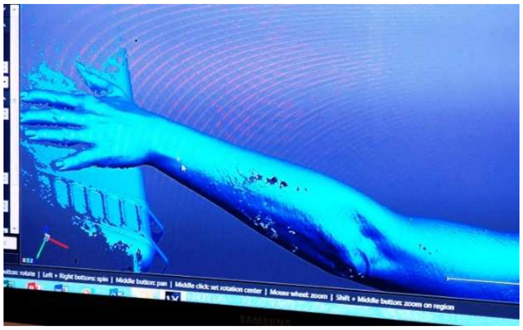
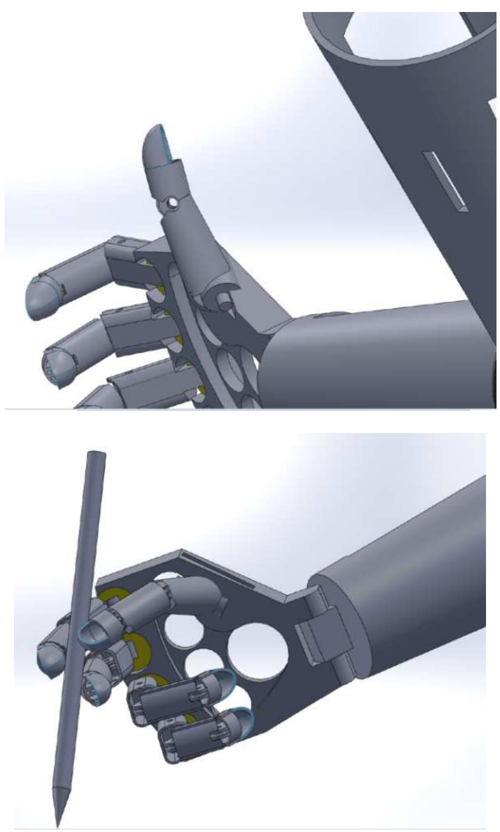


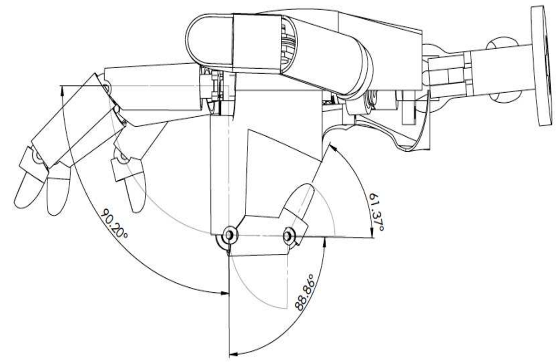
Fig. 6. Scan surface – with errors

Once the shape and size and dimensions of the real limb determined (by the Reverse Engineering Technique) there was taken the next step forward, that of design. The design of the whole biomechanical system, for the missing upper limb (including hand, fore arm and arm) assumes the residual limb to be used for fixing the prosthesis. The design of the arm, forearm and hand is to be noticed in figure 7 (a. and, respectively, b.).



a. forearm and arm design

Fig. 7. Biomechanical system design
(to be continued)



b. hand design - index finger bending angles

Fig. 7. Biomechanical system design

3. KINEMATIC ANALYSIS OF FINGER MECHANISM

The focus of this kinematic analysis is on index finger (see figure 8), with all his three phalanges, conventionally called P_1, P_2 and P_3. The fingertip is called T. The kinematic elements are, successively, named from 1 to 6 and the joints are named from A to G.

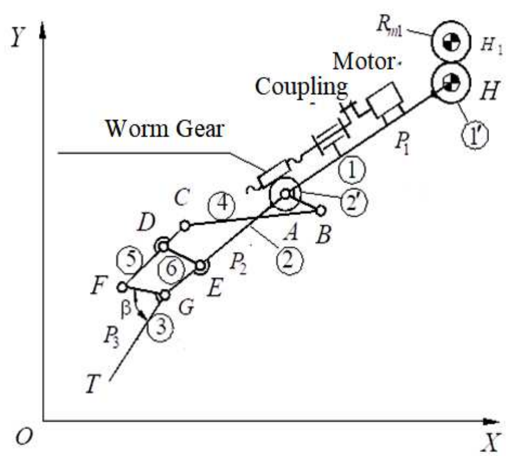


Fig. 8. Index finger's kinematic scheme

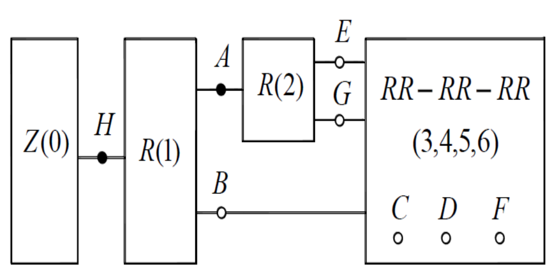


Fig. 9. Index finger modular scheme

Based on this schematic, there could be identified: the base, Z (0); the engine (motor) groups, R(1) and R(2); the triade, RR-RR-RR

(3,4,5,6) (see figure 9). The kinematic analysis has as result the values of position, speed and acceleration for each of the mechanism component elements (1, 2 and 3).

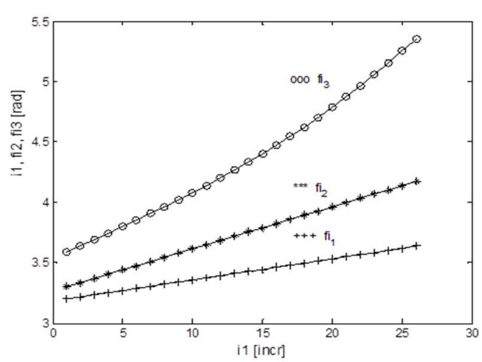
The program for performing this analysis calls for the specific procedures A1R_G, A1RALFA_G and tri1pva_G [12, 13]

The results for angles φ_i values (i = 1, .., 6) are shown in table 1 and the graphical representation of the obtained values for angles, φ_i, and angular velocities, ω_i, are presented in figure 10 (a. and, respectively, b.).

Table 1

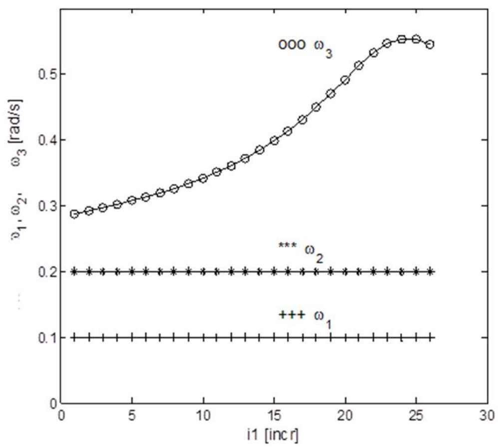
Values for the angles φ_i (i = 1, ..., 6)

poz	fi1	fi2	fi3	fi4	fi5	fi6
0	3.2000	3.3000	2.4504	2.7495	0.2101	2.171
1	3.2175	3.3349	2.5010	2.7831	0.2484	2.221
2	3.2349	3.3698	2.5524	2.8169	0.2870	2.271
3	3.2524	3.4047	2.6046	2.8510	0.3258	2.322
4	3.2698	3.4396	2.6577	2.8852	0.3648	2.373
5	3.2873	3.4745	2.7119	2.9198	0.4041	2.426
6	3.3047	3.5094	2.7670	2.9545	0.4437	2.479
7	3.3222	3.5443	2.8234	2.9896	0.4836	2.533
8	3.3396	3.5793	2.8809	3.0249	0.5239	2.588
9	3.3571	3.6142	2.9399	3.0605	0.5646	2.644
10	3.3745	3.6491	3.0003	3.0965	0.6058	2.701
11	3.3920	3.6840	3.0624	3.1328	0.6476	2.759
12	3.4094	3.7189	3.1263	3.1694	0.6900	2.819
13	3.4269	3.7538	3.1923	3.2064	0.7331	2.880
14	3.4443	3.7887	3.2605	3.2438	0.7771	2.942
15	3.4618	3.8236	3.3313	3.2816	0.8221	3.006
16	3.4793	3.8585	3.4049	3.3198	0.8683	3.071
17	3.4967	3.8934	3.4817	3.3584	0.9160	3.138
18	3.5142	3.9283	3.5619	3.3973	0.9653	3.206
19	3.5316	3.9632	3.6458	3.4364	1.0165	3.276
20	3.5491	3.9981	3.7334	3.4757	1.0701	3.347
21	3.5665	4.0330	3.8247	3.5149	1.1260	3.418
22	3.5840	4.0679	3.9188	3.5538	1.1845	3.489
23	3.6014	4.1029	4.0149	3.5921	1.2454	3.559
24	3.6189	4.1378	4.1115	3.6296	1.3082	3.626
25	3.6363	4.1727	4.2074	3.6663	1.3724	3.690



a. angles values, φ_i (i = 1, 2, 3)

Fig. 10. Kinematic analysis results (to be continued)



b. angular velocity values, ω_i (i = 1, 2, 3)

Fig. 10. Kinematic analysis results

4. FINGER MECHANISM PROTOTYPE

Prototyping is quite a challenge, as it is the road to validate the concept and design of the product. Basically, it was assumed to prototype the two fingers (thumb and index ones) and if it works, the whole hand system would do it, too.

One important aspect to take care in prototyping this hand mechanism is related to the dimensions and accuracy needed for its parts. Due to the dimensions of real hand (previously obtained by reverse engineering) the component parts have small dimensions (most of them, less than 30 mm).

In order to obtain accurate finger motion, the tolerances of gears and threads are extremely tight, as well as their specific dimensions (module of 0.6 mm; thread pitch of 0.5 mm).

These are aspects that require high precision manufacturing processes. The most suitable ones would be on CNC centers but the costs are estimated to be high.

This is why, an alternate solution was considered, that of rapid prototyping [14].

The Selective Laser Sintering (SLS) is used by Fuse 1 printer [15]. The SLS printing process uses a laser to accurately fuse the powder layer, in the case of the Fuse 1 print the material used is Nylon 12. The non-sintered material, standing as support material for the part built, can be reused by combining it with a minimum of 30% new material.

Main process characteristics, for the Fuse 1 printer are:

Fig. 11. Parts into the build chamber of Fuse 1

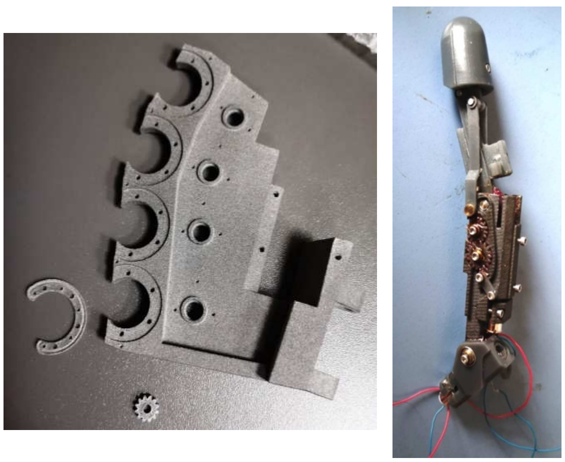


Fig. 12. Printed prototype

- laser spot - class 1 laser with wavelength of 1065 nm, the spot of 0.2 mm diameter;
- print build characteristics - layer height is by default set at 0.11 mm;
- printing process - the software platform used is Preform for the slicing process (see figure 11).

Printed parts, as components and assembled, are shown in figure 12.

5. DISCUSSION

The background of this research is represented by an unhappy real case, of a young teenager whose life has been completely changed when she had her left upper limb amputated. Of course she had to take psychotherapy but, finally she recovered pretty well and decided to accept a hand prosthesis.

There are many kinds of prostheses available but, most of them are very expensive and difficult to handle. For the moment she wears a prosthetic hand with minimal functionality.

The authors have launched a questionnaire to be fulfilled by people in need with prosthetics problem. It was available at https://docs.google.com/forms/d/1pnmfVUufkCCMqubNN0ry03w58ND0h6GOeSeHrTIU7_M/viewform?gxids=7628&edit_requested=true, and was intended to get information on the requirements which the biomechanical system would answer to.

6. CONCLUSION

The designed biomechanical system for hand is an innovative one, as it enables fast accurate and complex motions, it is easy to handle and it is estimated to be of moderate cost, affordable for many people who needs an active and, relatively, normal life.

Further research development is going to be focused on: command and control of fingers' motion; prototype of all components; tests on handling the prosthesis and on psychological aspects of the people wearing the prosthesis.

Affordable costs of materials and manufacturing techniques, as well user and environmental friendly biomechanical system stand as target, too.

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Proiectarea sistemului biomecanic pentru mână

Persoanele cu membre amputate doresc să aibă o viață relativ normală. Diferite tipuri de proteze, mai mult sau mai puțin complexe și, în consecință, mai mult sau mai puțin costisitoare, au fost dezvoltate și sunt disponibile pe piața de specialitate. Articolul prezintă rezultatele cercetărilor asupra protezei personalizate a membrului superior, focusat pe protezarea mâinii. Acesta evidenţiază aspectele relevante privind conceptul și proiectarea sistemului biomecanic pentru mână, analiza cinematică și prototipul degetului. Se menționează, aspecte privind dezvoltarea în continuare a cercetării.

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