Design and Model of a Prosthesis for Hand

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Abstract. This paper presents research results on a prosthesis for human hand, focused on the need to be light weight and user friendly, with relatively low costs and enabling people have almost normal life. The idea to have a customized hand prosthesis, whose dimensions and aspect look as much as possible to that of the real hand pointed to the reverse engineering technique. The authors’ concept of prosthesis for hand is that of three phalanges finger and, mainly, two rotational motions for each of the fingers. Considering the 3D model of the hand prosthesis, with phalanges lengths and joints, there has been done kinematic analysis so that trajectories of fingers were determined and plotted. For the research presented by this paper, are evidenced the 3D models and stages of rapid prototyping fused deposition models (FDM) of the index finger phalanges. Motion control has been modelled using fuzzy logic. The studied motion is that of getting closer to an object in order to take / grip it. Further development of the research will be focused on: all mechanical components detailed design; complete design of the command and control system for the mechatronic parts; prototyping; test and validation of the prosthesis prototype.

1. Introduction

The lack of any part of the human body, even caused by accident, or by birth, is a serious problem for the person involved. Most of the times it generates psychological and social integration obstacles. In fact, the ability to touch things and to make movements specific to everyday life stands as a crucial issue for life independence and satisfaction of any people. Based on the real need of a teenager who lost her right arm in an accident and is integrated into the youth social protection system, the authors intend to design and, further, obtain a prototype for the right hand, at affordable price and with accurate and reliable motions.

There are many hand prostheses available on the market, enabling different types of finger motions and thus, various degrees of independence for user’s life. For example, the i-LIMB is a “myoelectric, multi-articulating prosthetic hand with five individually powered digits. Electronically rotatable thumb, with manual override, automatically switches between lateral and oppositional positions” [1] – see figure 1.
Figure 1. i-LIMB prosthetic hand [2].

Another type of prostheses are the ones produced by BeBionic, (owned by Ottobock). As mentioned by the producers: “Comfortable, intuitive and precise – the bebionic hand is transforming the lives and abilities of amputees around the world. From helping them to perform simple tasks like tying their shoelaces, to giving them back their control and self-esteem (…). With 14 different grips and hand positions, the bebionic hand makes it easy to carry out day-to-day activities such as eating meals, carrying bags, opening doors, switching on lights and typing” [3]. Images of a BeBionic hand are shown in figure 2.

Figure 2. BeBionic hand [3].

Much more research has been done by authors for accurate and updated documentation of the state of the art in prosthetic hands. Based on this knowledge, a new type of prosthesis for hand is developed, aimed at accurate and independent motions of each finger, friendly user interface, light weight, high sustainability and, not the least, affordable price.

2. Reverse engineering of the upper limb
A definition of reverse engineering (RE) is presented in [4] and refers to „a systematic methodology for analysing the design of an existing device or system, either as an approach to study the design or as a prerequisite for re-designs”. Usually it includes four steps, as follows: evaluation and verification; technical data generation; design verification; project implementation. A schematic representation of the reverse engineering process is shown in figure 3.
The idea to have a customized hand prosthesis, whose dimensions and aspect look as much as possible to that of the real hand, involved the reverse engineering technique. The existing good upper limb of the „pacient” has been scanned and the obtained data further processed. The MetraSCAN system from CADWorks [6] was the “tool” for scanning and obtaining the 3D model of upper limb surface.

Images of the process and the obtained 3D model are presented in figure 4.

**Figure 4.** Reverse Engineering of the upper limb: (a) laser 3D scan of existing upper limb of the „pacient” – with MetraSCAN 3D; (b) 3D model of the upper limb surface; (c) „slicing” the 3D model surface – to determine the dimensions of fingers.

3. **Kinematic analysis of the fingers**

The “kinematic analysis of a mechanism consists of calculating position, velocity and acceleration of any of its points or links”. For this analysis it is essential to know the “linkage dimensions as well as position, velocity and acceleration of as many points or links as degrees of freedom the linkage has” [7].

The authors’ concept of prosthesis for hand is that of three phalanges and, mainly, two rotational motions about OX and OZ axes for each of the fingers. The 3D model is evidenced in figure 5.
Considering the 3D model, there has been determined the kinematic schemes for each of the fingers. For example, figure 6 points out the one determined for the index finger.

The position vector, \( \vec{r}_T \), of T (tracer point) is generically defined by relation (1):

\[
\vec{r}_T = s_1 \vec{e}_1 + a_1 \vec{n}_1 + s_2 \vec{e}_2 + a_2 \vec{n}_2 + s_3 \vec{e}_3 + a_3 \vec{n}_3 + s_4 \vec{e}_4 + a_4 \vec{n}_4 + s_5 \vec{e}_5 + a_5 \vec{n}_5 + s_6 \vec{e}_6 + a_6 \vec{n}_6
\]

where:

- \( s_i \) stands for the distance between normal vectors \( \vec{n}_{i-1} \) and \( \vec{n}_i \), measured positive along the \( \vec{e}_i \) axis;
- \( a_i \) stands for the distance between the axes \( \vec{e}_i \) and \( \vec{e}_{i+1} \), always with positive values.

Considering the structure of each finger, the length values for phalanges and aided by MATLAB software, there were determined joints trajectories (and further the velocities and accelerations) – see figure 7.

Figure 5. 3D model of the hand prosthesis.

Figure 6. Kinematic scheme of the index finger.

Figure 7. Trajectories of fingers’ phalanges.

4. Printing the prototype of index finger
The whole prototype of hand prosthesis will be obtained once all prosthesis’ components and its command and control system are completely defined. As intermediary step, it has been considered useful first having prototypes of the thumb and the index finger. This section evidences main aspects of FDM (Fused Deposition Modeling) prototyping of the index finger.

As mentioned by Stratasys [8], the “FDM Technology works with specialized 3D printers and production-grade thermoplastics to build strong, durable and dimensionally stable parts with the best accuracy and repeatability of any 3D printing technology”.


For this research, it was used the Creality Ender 3-Pro printing equipment and the printed material was PLA (Polyactic Acid - fully biodegradable thermoplastic polymer). The 3D models of index finger phalanges to be prototyped are presented in figure 8.

Simulation of the printing process is done by equipment software and enables correct position of parts to be printed into the building enceinte, estimation of the material consumption and of the printing time. An example of this simulation for printing the intermediary phalanx of the index finger is evidenced by figure 9.

![Figure 8. Index finger 3D model: (a) individual phalanges; (b) index finger.](image)

![Figure 9. Simulation of the FDM process: (a) position of the phalanx into the building enceinte; (b) estimation of the prototyping time; (c) printing process parameters.](image)

The printed prototype is shown in figure 10.
5. Fuzzy model

“Fuzzy logic can deal with information arising from computational perception and cognition, that is, uncertain, imprecise, vague, partially true, or without sharp boundaries” [9]. The fuzzy logic is a mean enabling to deal with uncertainty in engineering and has proved to be efficient enough in control of different systems, such as: obstacle’s avoidance by NAO robot [10], altitude of spacecraft, efficiency of automatic transmissions, etc.

For the designed hand prosthesis, motion control has been modelled using fuzzy logic, in MATLAB software. The studied motion is that of getting closer to an object in order to take / grip it.

Input variables considered are as follows: the temperature of the object to be taken, \( T \) [°C] and the distance from the prosthesis up to the object, \( d \) [mm]. The output variable is the acceleration of the motion toward the object, \( a \) [mm/s²]. Example of how fuzzy variables were defined is presented in figure 11.
The output variable for the fuzzy model are shown in figure 12 – for two of the simulated cases.

![Figure 12. Output values generated in fuzzy logic.](image)

6. Conclusions
The paper presents research results on a prosthesis for human hand. The concept is that of light weight and user-friendly customised prosthesis, with dimensions similar to that of the existing upper limb. This is the reason that reverse engineering technique has been applied.

3D prosthesis model and, further, trajectories of fingers’ phalanges have been determined. FDM printed prototype of the index finger stands as real model for sensors preliminary tests. Motion control of the prosthesis toward an object to be taken has been modelled by fuzzy logic.

Further development of the research will be focused on components detailed design, command and control of all mechatronic parts; prototyping the whole prosthesis; tests and validation of the prototype.

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