Improved Kinematics for Upper Limbs Prostheses

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Abstract

Gripping an object remains the main weakness of most modern prostheses even though they offer a greater degree of freedom than ever before. By examining the kinematics of gripping on healthy limbs and comparing them with the prostheses kinematics we can determine the restrictions of the prosthesis and propose solutions to eliminate them. The aim of the study was to find the differences in grasping an object between a healthy hand and with prosthesis. Creating a virtual model of the prosthesis and healthy hand allowed for the identification of limitations in the function of the prosthesis. Using the videographic method the difference in kinematics during the grasping motion of two different objects was investigated. Based on different trajectories, two model variants are constructed in the ADAMS/View software. A control strategy system in the program ADAMS is proposed to correct the kinematic limitations of the prosthesis and mimic the kinematics of a healthy hand. By improving the prosthesis kinematics, its function can more closely imitate a healthy human limb.

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1. Introduction

Most tasks people perform with the hands require a differentiated movement of all its parts [1]. In particular the fingers and opposing thumb often play different roles individually to create shapes and hand gestures for communication, exploring the environment, grasping objects in diverse shapes, and manipulate various objects [2]
The loss of a hand or a limb is a very difficult situation for people to handle [3]. The upper extremity is a coordinated, multiarticular system where the combined motion of each articulation contributes to the overall function of the hand.

When the upper extremity is replaced with a prosthetic device, people may need to compensate for lost motion at a distal articulation by excessive motion of other parts of the arms. A huge emphasis is based on controlling [4], the shape, weight and the comfort of an actual prosthesis as the patient uses it as a part of their own body.

A number of measurement methods have been developed to measure the biomechanical properties of the human body, static and dynamic effects [5], [6], and measurement of muscle activity [7]. The biomechanics of movements is important to get the kinematics of specific activities [8], (grasping, swimming, walking) as well as identify the forces that are produced in the joints [9]. To validate the virtual model simulations used results from measurements. The kinematic analysis [10], the analysis of control concept [11] and the anatomical analysis of the human hand are the basis for the creation of the virtual model. Modern software packages already include human musculoskeletal anatomy [12]. In this study, MATLAB and ADAMS/View software are used.

### Nomenclature

| Abbreviation | Definition |
|--------------|------------|
| EMG          | Electromyography |
| IP           | Inter-phalangeal |
| PIP          | Proximal-inter-phalangeal |
| R            | Radius |
| TMR          | Target Muscle Reinnervation |

### 2. Methods

The videographic method for obtaining trajectories of different parts of the limbs in the hand was used to obtain kinematic data while grasping two objects of different radius. Measurements of a healthy human hand where taken as well as with a prosthetic hand grasping the same objects.

Two cylindrical objects were used with a radius of R1=17 mm and R2=25 mm rigidly attached to the background, in order to prevent displacement of the object when recording videography. Forearm muscles were used to control myoelectric prosthesis. Prosthesis was controlled by orthopedic technician from the company Otto Bock.

The measurement was carried out as follows: Hand and prosthesis had to be firmly pressed against the objects so to avoid as much as possible further displacement. Markers had to be perpendicular to the axis of camera. Recording and post-processing was performed using MATLAB software environment.

- 10 reps grasping radius R1 with prosthesis.
- 10 reps grasping radius R2 with prosthesis.
- 10 reps grasping radius R1 with healthy limbs.
- 10 reps grasping radius R2 with healthy limbs.

Data obtained from this method were processed in MATLAB, where the parameters of interest are compared. The obtained data were used for model verification build in ADMAS/View.

Simultaneously with the videographic method, EMG (electromyographic) signal of forearm muscles was recorded during grasping objects [13], [14] with healthy hand and with prosthesis. For correct use of prosthesis had to be set by control AxonSoft software from Otto Bock [15], [16], [17]. With this software, we were able to evaluate muscle signals and optimally set:

- switch signal,
- working ranges,
- gain the signal.
Data transfer between prosthesis and PC was done via Bluetooth and software. Type 13E202 of EMG electrodes was used for measuring and was placed on the forearm muscles of orthopaedic technician. Output signals are shown in Fig. 1 to 3. Differences between muscle activities needed for grasping objects with healthy hand and with prosthesis. During videographic method we measured fast and slow motion of grasping. Higher muscle potential was needed for faster grasping motion and for slower grasping lower muscle contraction.

Fig. 1. EMG of healthy hand during grasping object.

Fig. 2. Muscle contraction during fast grasping.
2.1. Materials

Background was uniform color – black, which contrast the color of the marker – white, R=0.5cm; furthermore the subject wearing the marker had clothing – black gloves.

Video recording was performed using a video camera Creative. Parameters and specifications of the camera:

- Video resolution - HD720p (1,280 x 720 pixels)
- Image Resolution: 5.7 megapixels
- Frame Rate: 30 frames / s in HD 720p
- Interface: USB 2.0 Hi-Speed
- Focal length: fixed

This study considers a patient with transradial amputation.

The prosthesis used in the experiment allowed only for flexion and extension of the fingers in one plane. The fingers rotate parallel to the wrist plane. Prosthesis movement is therefore considered to be planar and the use of two or more cameras is unnecessary.

Parameters and specifications of the prosthesis used in the experiment are:

- Voltage: 6/7.2 V
- Max. open width: 100 mm
- Proportional speed: 15-300 mm / sec
- Proportional grip force: 0-100 N
- Weight: 460 g
- Power: Otto Bock EnergyPack 757B20/757B321

In Fig. 4 the comparison of trajectories between a healthy hand and prosthesis when grasping an object with a radius R1 and R2 can be seen. It is clear that there are differences in the trajectory of a healthy hand and that of the prosthesis. These differences are based on the geometry and function of the joints. The prosthesis does not grasp the object with all the phalanges as a healthy hand does because it is incapable of rotation in the IP joints.
2.2. Virtual model

To create the virtual model the ADAMS/View modelling software was used. Kinematic data obtained from the experiment were used as an input for the model.

The differences in displacement are larger when grasping a smaller object (Fig. 5). These displacements are created due to the prosthesis more powerful grasp on the object.

To validate the model, the trajectories of the model, created in ADMAS/View, were qualitatively compared to the trajectories obtained from the experiment. During the development of the prosthesis model, obtaining kinematics similar to a healthy hand was emphasized.

In Fig. 4 the limitations of the prosthesis can be seen. The first limitation is the range of motion. However, increasing the maximum range of the fingers and the thumb is not of great importance as for grasping large objects. Patients tend to use other kinds of grip and the prosthesis would have to exert more energy to maintain grip.

Another option to increase the kinematics is to allow rotation in the IP joints. Since the prosthesis has phalanges that are in mild flexion because of its natural look, two adjustments to the model are proposed:

1. PIP joint are allowed to rotate. Other joints used values of relaxed prosthesis.
2. All IP joints are allowed to rotate. The starting point of joint rotation is in a neutral mode.
3. Results

In Fig. 6 and 8, the purple trajectories represent those obtained from the experiment. The black trajectories correspond to the first variation of the model (Fig. 6) and the blue trajectories represent the second variation of the model (Fig. 8).

The first model variation (Fig. 6) was designed as a reaction to the current state of the art of modern myoelectrical prosthesis [18]. This model allows flexion/extension in the PIP joint, which should permit grasping of smaller objects.

The second model variation (see Fig. 7) gives the prosthesis a much greater range of motion (Fig. 8). Trajectories are more natural looking and qualitatively resemble trajectories obtained experimentally for a healthy grasping hand.
Model control in ADAMS/View was done by using a simulation script. The simulation script is designed so as to protect fingers. For example, during grasping, all phalanges of the fingers first contact the object. The next step is to rotate the first joint of the thumb. When grasping smaller objects, it may happen that the fingers are closed into a fist. A force sensor in the first phalange records contact with phalange of the index finger and passes the IP joint flexion until the distal phalange senses contact with the index finger.

4. Discussion

The aim of this work was to experimentally detect differences in the kinematics of a healthy hand and a prosthesis during grasping. For detection of kinematics and range of motion, various methods can be used [5], [6], [8]. To obtain range of motion and trajectories of selected points the videographic method is used. Complicated movements, for 3D measurements, often utilize high-speed cameras.

The advantage of these measurement methods are their integrated systems for processing and post-processing measured data [19]. These systems, however, are expensive and therefore a less expensive variation of camera parameters is utilized. To process the video data a MATLAB code is generated. Geometry of the SenzorHand Speed prosthesis was used to create the virtual model in ADAMS/View. We developed two variations of this model. The first variation was created based on the current state of the art and smaller financial requirements for application. This model allows the prosthesis to grip even smaller objects. Its use is important for functionality. It introduces more function in the prosthesis. However, when comparing trajectories, there are not large difference between the measured prosthesis and the model.

Therefore, a second variation is proposed. This variation has the option of flexion/extension of all IP joints. This model more closely mimics the trajectories of a healthy human hand. Using the proposed grasping system, a virtual prosthesis was able to grasp smaller and bigger objects with all phalanges. This results in more contact point and therefore a more firm grasp of the object. Such a system could help patients grasp objects such as a toothbrush for example, or for better assistance for the second limb.

In this work we devoted part to EMG signals measurement. In our previous work [14] we addressed the proposed control strategies prosthesis using EMG signals for the virtual model created in ADAMS/View software. Research on EMG signal is over budget and therefore we measure the EMG signals in this work to give only a better understanding of control strategy of prosthesis. A difference in muscle activity can be seen in Fig. 1-3. Patient with prosthesis must develop a greater muscle potential than healthy hand when grasping the same object. Patient must concentrate on the muscle activity. This phase of control can be gradually removed with training.

A big plus of this measurement and the cooperation with Otto Bock Slovakia was the possibility to control the prosthesis (EMG sensors attached to my forearm muscles) using latest Axon-Bus control system. This control system has the possibility to receive and process signals from up to 8 electrodes at one time (as in TMR- Target Muscle Reinnervation). This experience also helped us to understand and control options of prosthesis.
5. Conclusion

The experiment was set up according to financial limitations. By using this method we investigated the difference in the kinematics of a healthy hand and the SenzorHand Speed prosthesis from Otto Bock for grasping two objects with a different radius.

The created model shows one possible direction in which prosthetic manufacturers could eliminate the undesirable robotic movement of prosthesis. It could help increase the mobility of the prosthesis and more closely imitate the function of a healthy extremity. The main advantage of the proposed prosthesis is that they do not need additional EMG electrodes to control grasping (the number of electrodes increases the price of the prosthesis). Fingers of the prosthesis perform naturally. In combination with TMR, more articulated, multiple simultaneous movements while grasping can be achieved.

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