The new version of a hand rehabilitation device constructed with the use of the multibody formulation with natural coordinates

Antoni John and Agnieszka Musiolik

Department of Strength of Materials and Computational Mechanics, Silesian University of Technology

Konarskiego 18a, 44-100 Gliwice, Poland
e-mail: antoni.john@polsl.pl
e-mail: agnieszka.musiolik@polsl.pl

Abstract

This paper presents a short briefing on the anatomy and physiology of the hand for the better understanding of the mathematical model of the hand. Brief information on the common pathologies of the hand is provided here in order to show how important it is to help people who have a problem with every day life after suffering from diseases of the hand. The multibody model of the hand which is presented here, shows the most important properties of the hand. The collected data from the kinematics includes the position, the velocity and the acceleration of the fingers and the collected data from the dynamic analysis includes reactions and moments at joints. The computational model of a new rehabilitation device is constructed with the use of the multibody formulation with natural coordinates. This type of computational models is important in all phases of designing a new product, but its application is particularly relevant in the early design phase when no prototype is yet available.

Keywords: computational model, finger, prototype device,

1. Introduction

The function of the hand is crucially important in human life. That is why it is so important to quickly restore the maximum efficiency of hand function and movement for people who, as a result of an accident or disease, has being deprived of these faculties. People suffer from/undergo strokes every year. A stroke causes a wider range of disabilities than any other condition and this means stroke has a greater disability impact than any other chronic diseases. With a globally ageing population and hence more people suffering from the effects of stroke, it is becoming increasingly important to rehabilitate them to a position where they can gain more independence. The critical part of regaining independence is the use of the hand for tasks such as catching and keeping an object in order to manipulate it during everyday activities.

2. Anatomy of the hand

The computational model includes: distal phalanges, middle phalanges and proximal phalanges of the index, middle, ring and small finger and metacarpals, which are presented on figure 1.

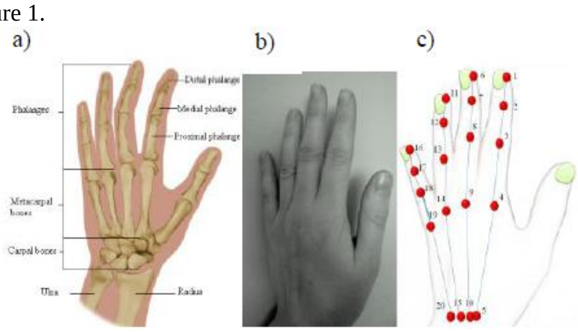

Figure 1. a) Anatomy of the hand, b) Human Hand c) distribution of markers

3. Pathologies of the hand

A brief description of the most common pathologies of the human hand is provided to allow a proper understanding of the problem of rehabilitation of the hand and the underlying concepts for the construction of the prototype of the hand rehabilitation.

There are many pathologies that can affect the human hand: congenital defects, several types of hand injures (including factures), tendon and ligament injures and hand diseases. All of these pathologies interfere directly with the hand function and movement as they produce damage in the neurological and musculo-skeletal structure of the hand.

4. Devices on the market

The fact that there are only a few devices on the market which can be used for the rehabilitation of the hand creates the need to find new solutions for a better and more efficient hand rehabilitation. It is from this perspective that the motivation for the work that develops other ones, appears. It is well known that any medical or rehabilitation device must be put to the test before it can be applied to help people with disabilities. With the current/updated computers and with the right computational methods, it is possible nowadays to construct reliable and accurate computational models that are able to analyze in an integrated way the performance of the device and the effectiveness of its action on the affected biological structure. This is even more important in the early stages of design when no prototype is available yet.

Hand rehabilitation can be accomplished using proper rehabilitation devices. These devices are able to improve hand function and movement, restoring (in many cases) its normal activity. There are already several different types of hand rehabilitation devices as described next in this article. Each device serves a specific purpose in hand rehabilitation.

Although a search for hand rehabilitation devices shows that there are already several different types of models available on

Table 1. The maximum linear acceleration at joints, $a_x[m/s^2]$

a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}
4	3	1.6	0.2	0.1	6	5	2	0.2	0.09
a_{11}	a_{12}	a_{13}	a_{14}	a_{15}	a_{16}	a_{17}	a_{18}	a_{19}	a_{20}
6	4	2	0,2	0.09	4.5	3	1.8	1.8	0.09

the market, each of them with a different function and purpose, it is also true that there is still a lot to develop in this field.

5. Methods

A computational model of a new rehabilitation device is constructed with the use of the multibody formulation employing natural coor-dinates. This type of computational model is important in all phases of the design of a new product, but its application is particularly relevant in the early design phase when no prototype is available yet.

The kinematic simulation encompasses the calculation of the position, the velocity and the acceleration of the system. It also permits one to detect collisions, study the trajectories of points, analyze the position of an element of the multibody system and calculate the rotation angles of the driving elements.

According to Newton-Euler equations, the equations of motion of such a system can be written as:

$$\mathbf{Mq=g} \quad (1)$$

where **g** is generalized external force vector and **M** is the mass matrix containing the mass and inertial characteristics of each rigid body.

The solution of the dynamics simulation encompasses the calculation of reactions and moments at the joints of the system.

This model has a 24 degrees of freedom, presented in figure 1.

All the data is used to create a prototype device for the rehabilitation of the hand.

6. New rehabilitation device

The rehabilitation device that is now proposed is particularly aimed to help patients with partial paresis of the fingers acquired after a Cerebral Vascular Accident (CVA), although more general applications can be considered.

In principle, the device mechanism mimics natural finger movement, helping the patient's fingers move with it. The range of the moving joint is very close to the range of movement by a healthy man, and of course every joint can move independently. The device can work in two modes. The first one is for collecting diagnostic data, for example the maximal range of the angle for each finger joint. The second mode is for rehabilitation of fingers. The device carefully mimics the approximate trajectory of the healthy hand motion. It can use the data collected in the first mode. All parameters can be exactly adjustable for a particular patient's needs. Using individual range of motions, the device can be used just to support movements. The device is equipped with a controller which compares the present position of the device to collected data. Fingers are connected with the device by special constructed carriages with can be adjusted for different sizes. The device

consists of a main electric stepping motor connected with Linear Slide by toothed belt, tension and angle sensors. It is capable of being adjusted for different finger dimenions. The purpose for creating this device is to assist therapists in treatment of the hand after an injury.

This prototype includes: 1 – Belt tensioner with a built in force sensor; 2 – Linear guide; 3 – Mechanism for finger mounting; 4 – Adjustment screw for different fingers length; 5 – Stepping motor with encoder.

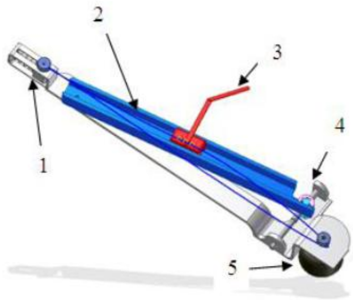

Figure 2. Part of prototype device

7. Results

The results presented in this article provide current biomechanical relevance and can be used in the present design phase of the rehabilitation device.

The data for the kinematic and dynamic analysis of the hand was taken from the laboratory in which the recording of the flexion and extension of the hand was made. Selected results from the kinematics include the linear acceleration at joints presented in table 1. Selected results of dynamics include reaction at the joint between the distal and middle phalanges of the indes finger and these are presented on figure 3. All results are used to project a new prototype device for the rehabilitation of fingers.

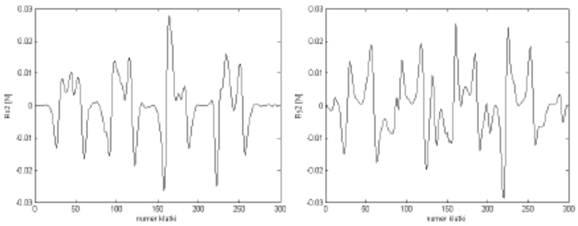

Figure 3. Reactions at the joint between the distal and middle phalange of the index finger

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