BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gh. Asachi", Iaşi
Tomul LI (LIV)
Secţia
CONSTRUCŢII DE MAŞINI
Supliment Mecanică Teoretică
2005

HUMAN HAND MODELLING

BY

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Abstract. The first step in the process of obtaining a better hand prosthesis is to model one. The human hand is a highly articulated system, submitted to natural anatomical restrictions. In order to model the fingers' joints and links, the kinematic chain of each finger should be represented. This paper presents the kinematic model of the human hand, and the constraints to which the model was submitted in order not to make arbitrary gestures. The motion of this model was studied using MATLAB and SimMechanics, thus the trajectories of the fingertips during the extension and flexion motions of the hand being obtained. One can observe that this model is an anatomical one, having the same elements, the same motions, and being submitted to the constraints of the natural model.

Key words: human hand prosthesis, human hand constraints, automatic system.

1. Introduction

The human hand is a very good example of how to implement a complex system capable to fulfill various tasks using a combination of mechanisms, sensors and control functions. An impressive number of prosthesis for human hand has been developed until present days, but none of them can perform as many tasks as the natural model, mostly due to the lack of degrees of freedom [6], [7]. The first step in the process of obtaining efficient hand prosthesis is the study of the natural model. Human hand has five fingers, all of them having approximate equal lengths, three phalanges and the same kind of motion, except the thumb able to move in opposition with the other fingers (Fig. 1).

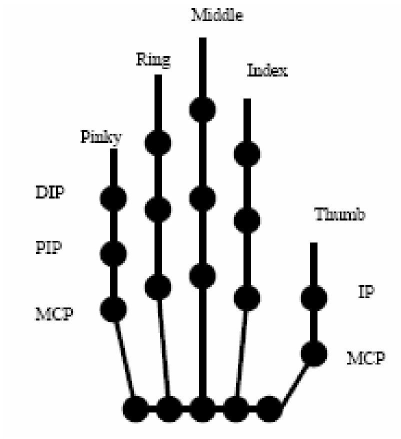


Fig. 1 – The model of the human hand.

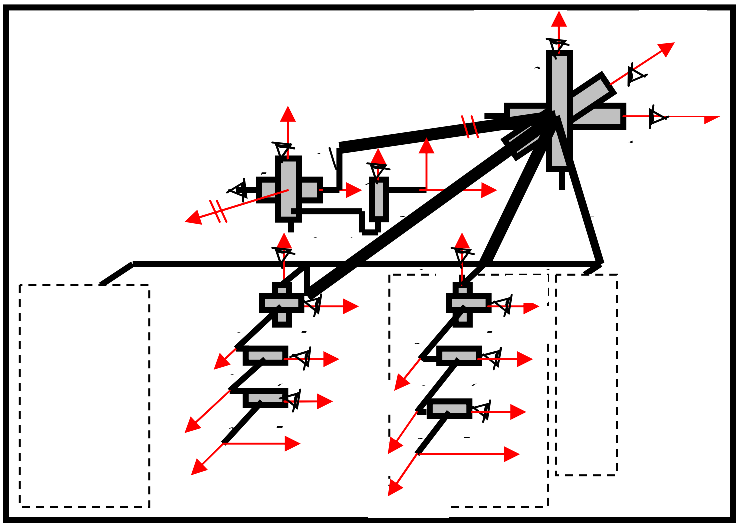


Fig. 2 – The kinematic model of the human hand.

2. The Kinematic Model

The kinematic model of the human hand (Fig. 2) was realized by considering:

- wrist as a superposition of three independent, orthogonal and simple revolute joints;
- metacarpophalangeal (MCP) joint as a superposition of two independent, orthogonal and simple revolute joints;
- proximal interphalangeal (PIP) joint as simple revolute joint.
- distal interphalangeal (DIP) joint as simple revolute joint;

Based on Denavit-Hartenberg convention [1], the geometrical parameters are obtained (Table 1), which were used to determine the correspondent transfer matrices. One can observe that, in the case of the lateral fingers (meaning pinky, ring and index), the kinematic chain is the same, the only difference being the distances L_x. In Table 1, q_1, q_2, q_{3x}, q_{4x}, q_{5x}, q_{6x}, q_{7x} are joint variables, p is the length of the palm, and f_{1x}, f_{2x}, f_{3x} are the lengths of the finger's phalanges.

The general transfer matrices (one for each finger) result by multiplying the corresponding transfer matrices. Each column of a general transfer matrix represents one of the kinematic equations describing the corresponding finger motion (axes orientations and origin positions of the reference frame attached to the finger tip) with respect to the general coordinate system, placed on the first revolute joint of the wrist.

3. Modelling the constraints

Assembly palm&fingers model motion is constrained because the real hand cannot make arbitrary gestures. Hand constraints can be divided into three types [4]:

- type I constraints are the limits of finger motions as a result of hand anatomy (static constraints)

- type II constraints are the limits imposed on joints during motion (dynamic constraints) [3]
- type III constraints, which are applied in performing natural motion.

Table 1

The geometric parameters of the hand

No	θ_i	L_i	d_i	α_i	No	θ_i	L_i	d_i	α_i	No	θ_i	L_i	d_i	α_i
1	q_1	0	0	90	1	q_1	0	0	90	1	q_1	0	0	90
2	q_2	0	0	90	2	q_2	0	0	90	2	q_2	0	0	90
3_o	q_{3o}	L_1	d_3	-90										
4_o	q_{4o}	0	0	90										
5_o	q_{5o}	f_{1o}	d_5	0										
6_o	q_{6o}	f_{2o}	0	0										
					3_m	q_{3m}	p	0	0					
					4_m	q_{4m}	0	0	-90					
					5_m	q_{5m}	f_{1m}	0	0					
					6_m	q_{6m}	f_{2m}	0	0					
$d_3, d_5 = negatives$					7_m	q_{7m}	f_{3m}	0	0					
										3_l	q_{3l}	$L_{2,3}$	0	0
										4_l	q_{4l}	0	0	-90
										5_l	q_{5l}	f_{1l}	0	0
										6_l	q_{6l}	f_{2l}	0	0
										7_l	q_{7l}	f_{3l}	0	0

The type I constraints necessary for a natural motion of the fingers are expressed using the inequalities (1):

$$-90^\circ \le q_1 \le 90^\circ \quad -15^\circ \le q_2 \le 15^\circ \quad -15^\circ \le q_3 \le 15^\circ \quad -15^\circ \le q_{4x} \le 15^\circ$$
(1)
$$0^\circ \le q_{5x} \le 90^\circ \qquad 0^\circ \le q_{6x} \le 110^\circ \qquad 0^\circ \le q_{7x} \le 90^\circ$$

The type II constraint considered is based on the fact that in order to bend the DIP joint, the PIP joint must also be bent for the middle finger. The relation can be approximated as:

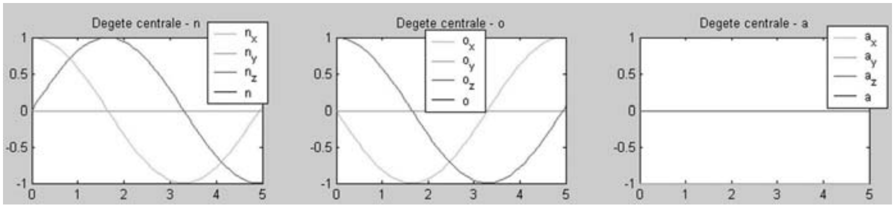
(2)
$$q_{DIP} = \frac{2}{3} q_{PIP}$$

The type III constraints are imposed by the naturalness of hand motions and are more subtle to detect.

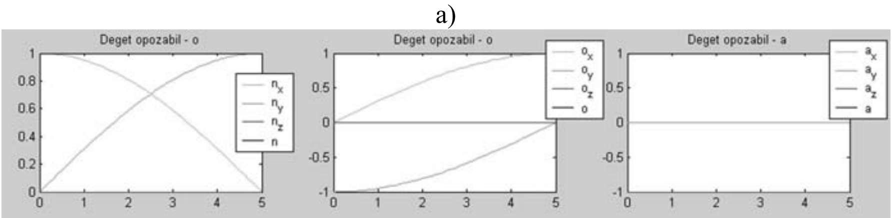
4. Motion study using MATLAB

In order to study the motion of the fingertips with respect to the general coordinate system, the kinematic equations were translated into MATLAB. The motion is studied on a time slot of 5s, divided in slices with a step of $s = 0.1$. For each slice, the current position of the fingertip is calculated using the correspondent values of the joint variables (for example, the case of the middle finger).

```
                  s=0.1;
                  t=0:s:5;
                  n=length(t);
                  vq1=-pi/2:pi/(n-1):pi/2;
                  vq2=-pi/12:pi/(6*(n-1)):pi/12;
                  vq3=-pi/12:pi/(6*(n-1)):pi/12;
                  vq4=-pi/12:pi/(6*(n-1)):pi/12;
                  vq5=0:pi/(2*(n-1)):pi/2;
                  vq6=0:(11*pi)/(18*(n-1)):(11*pi)/18;
                  vq7=0:pi/(2*(n-1)):pi/2;
for i=1:n,
    [vnx(i), vny(i), vnz(i), vox(i), voy(i), voz(i), vax(i), vay(i), 
vaz(i), vpx(i), vpy(i), vpz(i)] = middle_finger_equations(vq1(i), 
vq2(i), vq3(i), vq4(i), vq5(i), vq6(i), vq7(i));
end
```

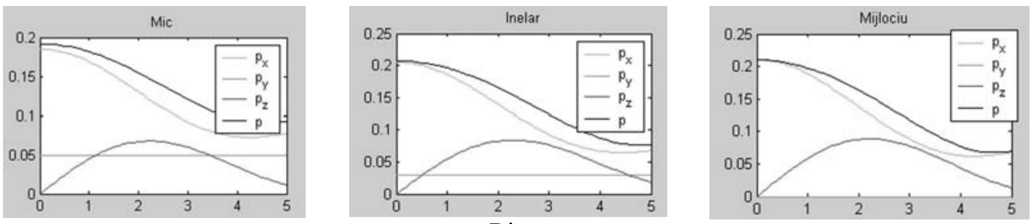


a)

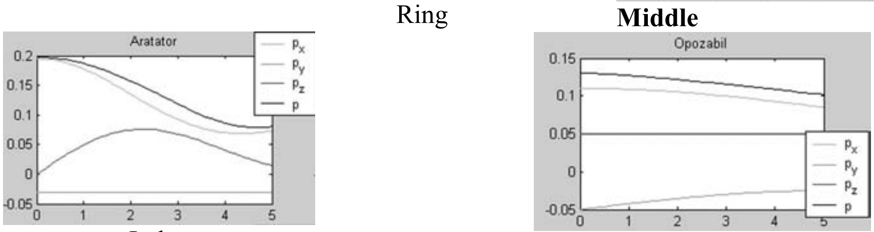


b)

Fig. 3 – The orientation of the coordinate systems attached to the fingertips of a) central fingers and b) thumb.



Pinky Ring **Middle**



Index Thumb

Fig. 4 – The trajectories of the fingertips in flexion motion of the hand

To study the flexion and extension motions of the hand some considerations were made. The wrist motion is irrelevant in this situation, so the wrist is considered rigid, meaning that q_1, q_2, q_3 joint variables are forced to be zero. The adduction/abduction movement is also irrelevant, so the q_{4x} joint variables are forced to be zero too. To perform the flexion movement, the others joint variables start from the lowest possible value (full extension) and increase until the highest possible value is reached (full flexion), when the motion stops. To extend the fingers, the movable joint variables start from the highest possible value (full flexion) and increase until the lowest possible value is reached (full extension), when the movement stops. Fig. 3 presents the orientation of the coordinate systems attached to the fingertips, and Fig 4 presents the fingertips trajectories for each finger in flexion motion.

5. Modelling by Simulink

The model was created using the SimMechaniks Tools of Simulink, which presumes every system made of bodies connected through joints. The first body of the hand is the palm and links together the wrist and the proximal phalange of every finger, which is the second body of each kinematic chain of the system. The wrist allows the rotation of the hand with respect to the arm, meaning three degrees of freedom (DoFs). Metacarpophalangeal (MCP) joint allows two kind of motions (two DoFs) to the proximal phalange of the fingers: adduction/abduction (in the palm plane), and flexion and extension (with respect to the palm). The third body of each chain is the middle phalange and is linked to the proximal phalange through distal interphalangeal (DIP) joint. The last body of each chain is the distal phalange, linked to the middle phalange through the proximal interphalangeal (PIP) joint. The kinematic chain of the thumb has only three bodies: the palm, the proximal phalange, and the distal phalange, and two movable joints: the MCP (two DoFs) and IP (one DoF).

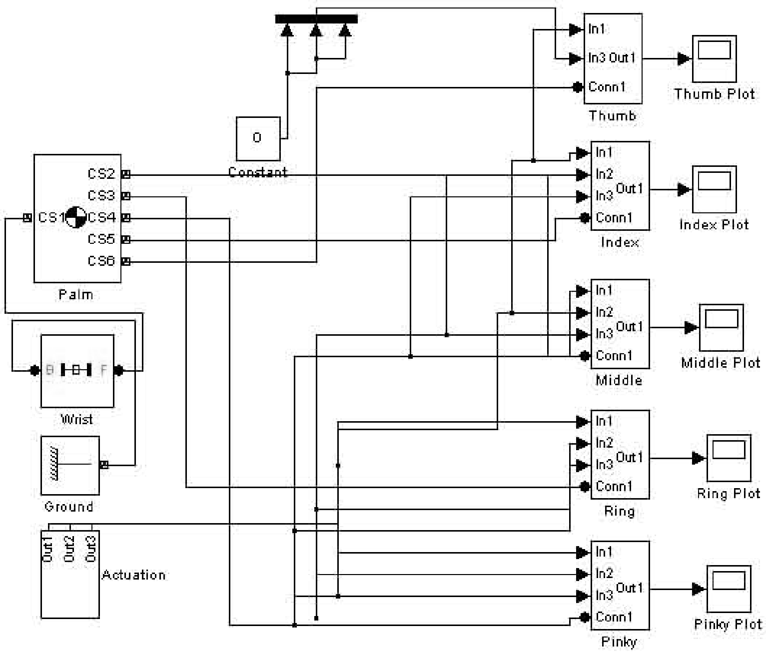


Fig. 5 – The Simulink model of the hand

The model from Fig. 5 can be used to simulate de flexion and extension motions of the hand. This is the reason why the wrist is modeled by a Weld block which provides no DoFs, the MCP joint is modeled using a Revolute block which provides only one DoF (no adduction/abduction motion), and the PIP and DIP joints are modeled using Revolute blocks, also (Fig. 6). The palm and the phalanges are modeled using Body blocks, which provide the orientation with respect to the general coordinate system (the Ground block), the length, the mass etc. Every joint has to be actuated using a Joint Actuator block, which provides the value of the rotation angle. The motion of each fingertip is captured using a Position Sensor block and plotted using a Scope block. The anatomical constraints of the natural system motion where fulfilled:

- the movable joints are actuated using the correct angular value, generated by the block named *Actuation*;
- the actuation is made simultaneously for all movable joints for a natural motion.

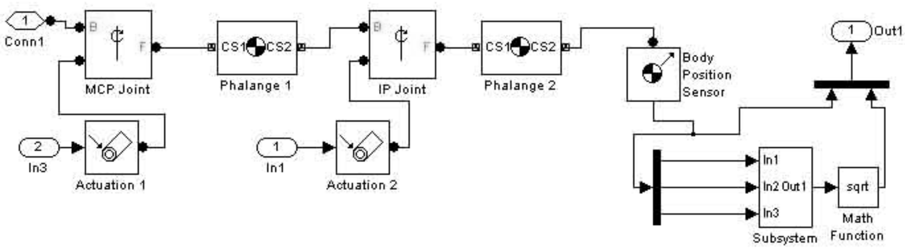


Fig. 6 – The Simulink model of the thumb

The curves for flexion motion of the hand, obtained using the model form Fig. 5, are depicted in Fig. 7. It can be seen that they are identical with the one from Matlab simulation meaning that the model is good, and respects the natural motion constrains.

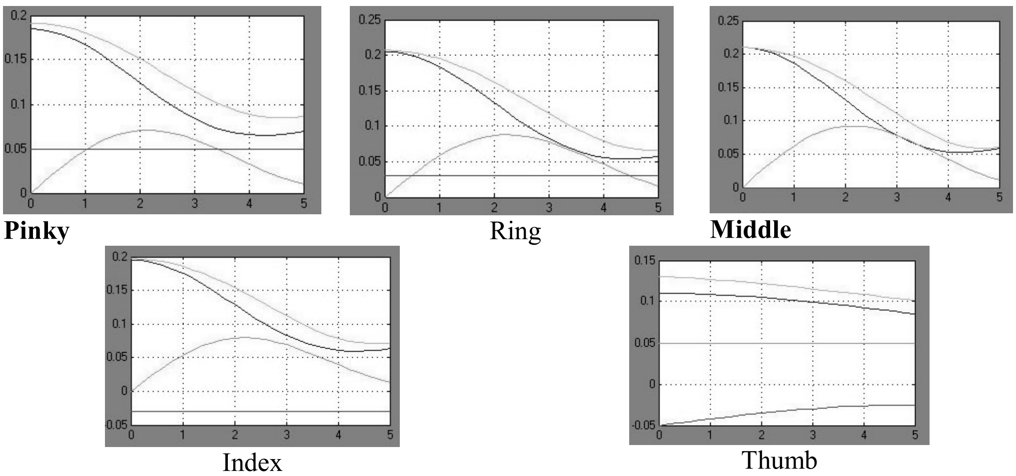


Fig. 7 – The trajectories of the fingertips in flexion motion of the hand

One of the greatest facilities of Simulink is that it can provide graphical visualization of a model. So, Fig. 8 plots four phases from the flexion motion of the finger, between full extension a) and full flexion d).

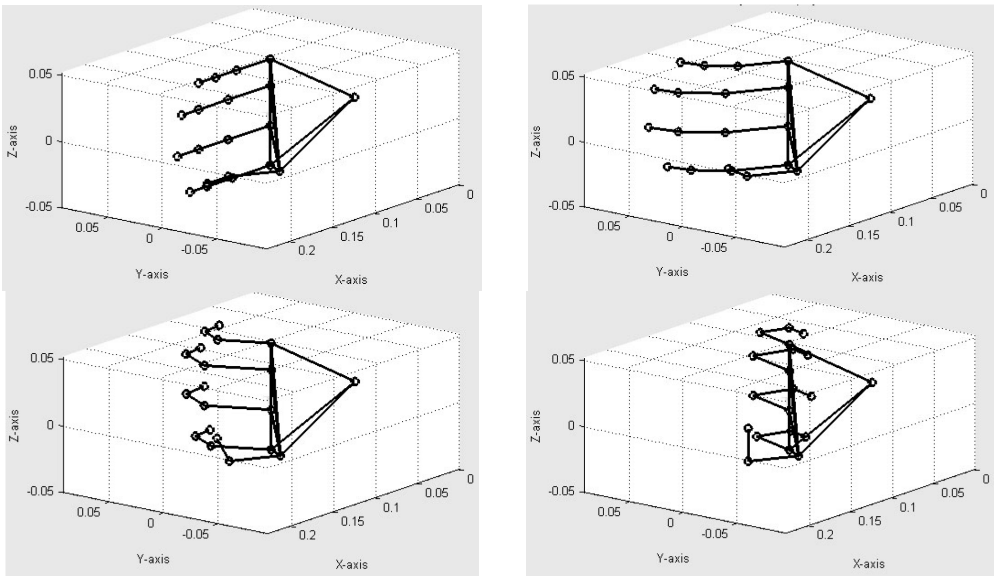


Fig. 8 – The flexion motion of the hand

From Fig. 8 it can be seen that the motion of the system is natural like. To flex the fingers starting from the full extension (when on *Ox* it can be seen the length of the system) every movable joint is actuated with a corresponding value and every phalange is moving accordingly until the full flexion.

6. Conclusions

1. The kinematic study of the human fingers is very useful to conceive a basic prosthetic device because the mass of phalanges is very small and the dynamic model is not necessary. The only problem is to choose the appropriate actuators able to assure the laws of motion and to manufacture the phalanges and the joints, as anatomical as possible, in a light material like Aluminum, Titanium, rigid plastic material, etc.
2. The model presented in this paper is an anatomical one, having the same elements and the same motions. It can be successfully used to develop a functional prototype capable to copy as much as possible the natural model.

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MODELAREA MÂINII UMANE

(Rezumat)

Primul pas în încercarea de a obţine o proteză mai bună pentru mâna umană constă în realizarea unui model virtual. Mâna umană este un sistem foarte articulat, supus la constrângeri anatomice. Pentru a putea modela degetele unei mâini, trebuie determinat modelul cinematic al fiecărui deget. Lucrarea de faţă prezintă modelul cinematic al mâinii umane şi constrângerile la care acest model a fost supus, pentru a se împiedica realizarea unor gesturi arbitrare. Mişcarea acestui model a fost studiată cu ajutorul MATLAB şi SimMechanics, obţinându-se traiectoriile vârfurilor degetelor în mişcările de extensie şi de flexare a mâinii. Se poate observa că acest model este unul anatomic, având aceleaşi elemente, aceleaşi mişcări şi fiind supus la aceleaşi constrângeri ca şi modelul natural.