Modeling the Motion of the Human Middle Finger

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Abstract: The development of human hand prosthesis, which can imitate the human hand motion capabilities, is a very important research field in order to conceive the prosthetic devices. The first step in the process of obtaining a better hand prosthesis is the modeling one. The human hand and the fingers represent highly articulated systems submitted to natural anatomical restrictions. To model the fingers joints and links, the kinematic chain of each finger should be represented. This paper presents the kinematic model of the middle finger as part of the human hand as well as, the orientations and the origin position of the reference frame attached to the specified fingertip.

Keywords: Kinematics of hand prosthesis, Human hand constraints, Joints

1 Introduction

The research of the human body behavior can be seen as an attempt to copy the natural model or, at least, some of its main elements. The development of human hand prosthesis, which can copy as much as possible the human hand motion capabilities, is a very important goal of this field [4]. The first step in the process of obtaining efficient hand prosthesis is the study of the real hand. 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. This paper studies de motion of the middle finger as part of the human hand and presents a kinematic model to be used in a future construction of an artificial hand.

2 Kinematic Model

The kinematic model of the middle finger (Figure 1) 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;
- distal interphalangeal (DIP) joint as simple revolute joint;
- proximal interphalangeal (PIP) joint as simple revolute joint.

Based on Denavit-Hartenberg convention [1], the geometrical parameters are obtained (Table 1), used to determine the correspondent transfer matrices. In Table 1, q_1, q_2, q_3, q_{4m}, q_{5m}, q_{6m}, q_{7m} are joint variables, p is the length of the palm, and f_{1m}, f_{2m}, f_{3m} are the lengths of the finger's phalanges [7].

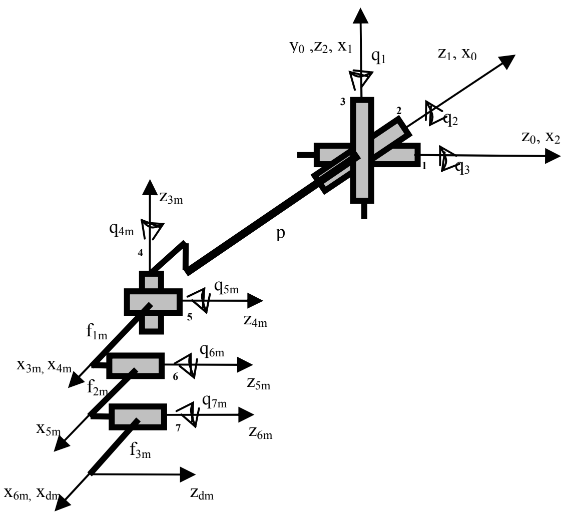

Figure 1
Kinematic model of the middle finger

Joint	θ_i	L_i	d_i	α_i
1	q_1	0	0	90
2	q_2	0	0	90
3	q_3	p	0	0
4	q_{4m}	0	0	-90
5	q_{5m}	f_{1m}	0	0
6	q_{6m}	f_{2m}	0	0
7	q_{7m}	f_{3m}	0	0

Table 1
Middle finger geometrical parameters

The general transfer matrix results by multiplying the transfer matrices. Each element of its columns represent one of the kinematic equations (1) describing the middle finger motion (axes orientations and origin positions of the reference frame attached to the fingertip) with respect to the general coordinate system, placed on the first revolute joint of the wrist:

- direction of the unit vector $\vec{n}$

$$n_x = \cos(q_1) \cdot [\cos(q_2) \cdot \cos(q_3 + q_4) \cdot \cos(q_5 + q_6 + q_7) - \sin(q_2) \cdot \sin(q_5 + q_6 + q_7)] + \\ + \sin(q_1) \cdot \sin(q_3 + q_4) \cdot \cos(q_5 + q_6 + q_7)$$

$$n_y = \sin(q_1)\cdot[\cos(q_2)\cdot\cos(q_3+q_4)\cdot\cos(q_5+q_6+q_7)-\sin(q_2)\cdot\sin(q_5+q_6+q_7)]-$$
$$-\cos(q_1)\cdot\sin(q_3+q_4)\cdot\cos(q_5+q_6+q_7)$$

$$n_z = \sin(q_2)\cdot\cos(q_3+q_4)\cdot\cos(q_5+q_6+q_7)+\cos(q_2)\cdot\sin(q_5+q_6+q_7)$$

- direction of the unit vector $\vec{o}$

$$o_x = \cos(q_1)\cdot[-\cos(q_2)\cdot\cos(q_3+q_4)\cdot\sin(q_5+q_6+q_7)-\sin(q_2)\cdot\cos(q_5+q_6+q_7)]-$$
$$-\sin(q_1)\cdot\sin(q_3+q_4)\cdot\sin(q_5+q_6+q_7)$$

$$o_y = \sin(q_1)\cdot[-\cos(q_2)\cdot\cos(q_3+q_4)\cdot\sin(q_5+q_6+q_7)-\sin(q_2)\cdot\cos(q_5+q_6+q_7)]+$$
$$+\cos(q_1)\cdot\sin(q_3+q_4)\cdot\sin(q_5+q_6+q_7)$$

$$o_z = -\sin(q_2)\cdot\cos(q_3+q_4)\cdot\sin(q_5+q_6+q_7)+\cos(q_2)\cdot\cos(q_5+q_6+q_7)$$

- direction of the unit vector $\vec{a}$

$$a_x = -\cos(q_1)\cdot\cos(q_2)\cdot\sin(q_3+q_4)+\sin(q_1)\cdot\cos(q_3+q_4) \qquad (1)$$

$$a_y = -\sin(q_1)\cdot\cos(q_2)\cdot\sin(q_3+q_4)-\cos(q_1)\cdot\cos(q_3+q_4)$$

$$a_z = -\sin(q_2)\cdot\sin(q_3+q_4)$$

- position vector $\vec{p}$ of the reference frame origin

$$p_x = [\cos(q_1)\cdot\cos(q_2)\cdot\cos(q_3+q_4)+\sin(q_1)\cdot\sin(q_3+q_4)]\cdot$$
$$\cdot[f_{3m}\cdot\cos(q_5+q_6+q_7)+f_{2m}\cdot\cos(q_5+q_6)+f_{1m}\cdot\cos(q_5)]+$$
$$+p\cdot[\cos(q_1)\cdot\cos(q_2)\cdot\cos(q_3)+\sin(q_1)\cdot\sin(q_3)]+$$
$$+\cos(q_1)\cdot\sin(q_2)\cdot[-f_{3m}\cdot\sin(q_5+q_6+q_7)-f_{2m}\cdot\sin(q_5+q_6)-f_{1m}\cdot\sin(q_5)]$$

$$p_y = [\sin(q_1)\cdot\cos(q_2)\cdot\cos(q_3+q_4)-\cos(q_1)\cdot\sin(q_3+q_4)]\cdot$$
$$\cdot[f_{3m}\cdot\cos(q_5+q_6+q_7)+f_{2m}\cdot\cos(q_5+q_6)+f_{1m}\cdot\cos(q_5)]+$$
$$+p\cdot[\sin(q_1)\cdot\cos(q_2)\cdot\cos(q_3)-\cos(q_1)\cdot\sin(q_3)]+$$
$$+\sin(q_1)\cdot\sin(q_2)\cdot[-f_{3m}\cdot\sin(q_5+q_6+q_7)-f_{2m}\cdot\sin(q_5+q_6)-f_{1m}\cdot\sin(q_5)]$$

$$p_z = \sin(q_2)\cdot[\cos(q_3+q_4)\cdot[f_{3m}\cdot\cos(q_5+q_6+q_7)+f_{2m}\cdot\cos(q_5+q_6)+$$
$$+f_{1m}\cdot\cos(q_5)]+p\cdot\cos(q_3)]-\cos(q_2)\cdot[-f_{3m}\cdot\sin(q_5+q_6+q_7)-$$
$$-f_{2m}\cdot\sin(q_5+q_6)-f_{1m}\cdot\sin(q_5)]$$

3 Modeling the Constraints

Assembly palm&finger model motion is constrained because the real hand cannot make arbitrary gestures. Hand constraints can be divided into three types [5]:

- 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.

The type I constraints necessary for a natural motion of the middle finger are expressed using the inequalities (2):

$$-90° \le q_1 \le 90° \quad -15° \le q_2 \le 15° \quad -15° \le q_3 \le 15° \quad -15° \le q_{4m} \le 15°$$

$$0° \le q_{5m} \le 90° \quad 0° \le q_{6m} \le 110° \quad 0° \le q_{7m} \le 90° \tag{2}$$

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:

$$q_{DIP} = \frac{2}{3} q_{PIP} \tag{3}$$

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 fingertip with respect to the general coordinate system, the kinematic equations (1) were translated into MATLAB. All the values necessary for the simulation are listed below:

$p = 10\ cm = 0{,}1\ m$

$f_{1m} = 5\ cm = 0{,}05\ m$

$f_{2m} = 3{,}5\ cm = 0{,}035\ m$

$f_{3m} = 2{,}5\ cm = 0{,}025\ m$

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.

```
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
```

This MATLAB sequence is used to generate the values for all joint variables and, for each moment of time, to calculate the current position of the fingertip using middle_finger_equations function, which describe de equations (1). The motion of the fingertip when every joint is moving (from the lowest possible value to the highest possible value, accordingly with relations (2) and (3)) is plotted in Figure 2.

To study the flexion and extension of the middle finger 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 motion is also irrelevant, so the q_{4m} joint variable is forced to be zero too.

```
vq1=zeros(1,n);
vq2=zeros(1,n);
vq3=zeros(1,n);
vq4=zeros(1,n);
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;
```

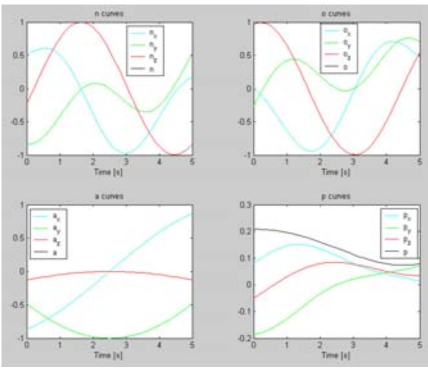

Figure 2
The motion of the fingertip when every joint is moving

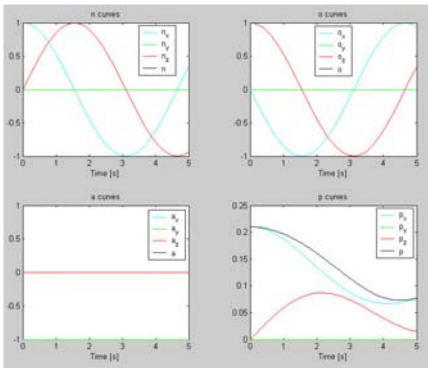

Figure 3
Middle finger flexion

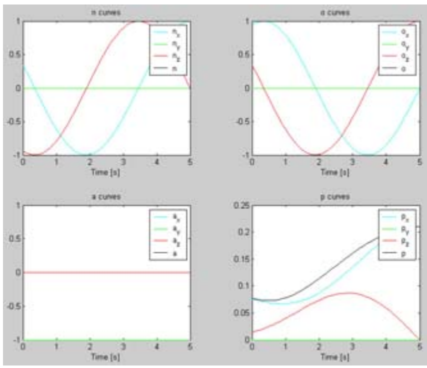

Figure 4
Middle finger extension

To perform the flexion motion, 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 (Figure 3).

```
vq1=zeros(1,n);
vq2=zeros(1,n);
vq3=zeros(1,n);
vq4=zeros(1,n);
vq5=pi/2:-pi/(2*(n-1)):0;
vq6=(11*pi)/18:-(11*pi)/(18*(n-1)):0;
vq7=pi/2:-pi/(2*(n-1)):0;
```

To extend the finger, 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 motion stops (Figure 4).

Conclusions

The human hand is an extraordinary example of how a complex system can be implemented, and how such a system is capable to perform very complex tasks using a combination of different elements. 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 described by the equations (1) and to manufacture the phalanges and the joints, as anatomical as possible, in a light material like Aluminum, Titanium, rigid plastic material, etc.

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