Virtual Human Hand: Wrist Movements

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Abstract. Hand model with 25 Degrees of Freedom (DOF) was developed and implemented considering forward and inverse kinematics. However, the model, after some experience and use need to add new DOF. The proposed model is with 29 DOF, these new DOF serve to simulate the arc of the palm in the part of the wrist.

Once we locate a new coordinates system in the end of the radius close to scaphoid we apply Denavit-Hartenberg for all the joints. Forward and inverse kinematics will be applied. Ligaments to apply restrictions in wrist movement are included. This affect to the fingertip position.

New model of virtual human hand with more accuracy in presented and validated with a Cyberglove™ and Leap Motion.

Keywords: Human Hand·Wrist·29 DOF· Forward and Inverse kinematics

1 Introduction

Author's hand with 25 Degree of Freedom (DOF) was proposed in [1]. With the forward and inverse kinematic for all the fingers, they proposed a realistic virtual simulation. However, the wrist not was included in the model. Today, several authors proposed in the literature that the wrist has a relative movement between the two rows of bones with eight bones. [2] discuss a comparison of four joint coordinates systems previously described in the literature. [3] proposed a helical movement of wrist bones in distal movements. During thumb oppositional motion, internal rotation of the first metacarpal occurred, with the palmar base rotating primarily with respect to dorsal base. This is one of conclusions achieved by [4], and it follows that first metacarpal flexes and pronates with the dorsal base as the center. However, [5] do not consider in their work a significant factor as the pisiform, which plays a minimal role in wrist kinematics.

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When comparing healthy with osteoarthritic subjects, the minimal joint space was slightly higher during the neutral, adduction, extension and lateral key pinch configurations than during the abduction, flexion, power grasp and jar twist configurations is analyzed in [6].

[7] and [8] have detail description of taxonomy for the hand. [9] studied the movement between different bones of the wrist, i.e. the movement of the radio-capitate joint during wrist flexion–extension and radio-ulnar deviation. [10] considered the motion of the scaphotrapezio–trapezoidal (STT) joint.

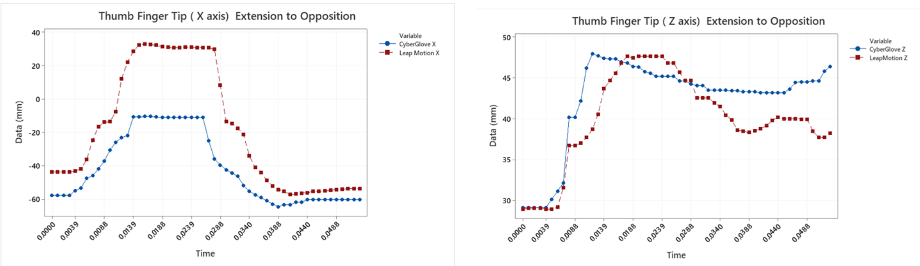

Fig. 1. For the X axis (left) we observed a big difference between the capture with Cyberglobe and Leap Motion. Similar for the Z axis (right).

Fig.1 shows a big difference in the thumb fingertip, red line (more realistic) is captured with the system of Leap Motion. The blue line is captured by Cyberglobe with eighteen sensors and adapted to model of 25 DOF. Based in this difference the need to remodeled the thumb based in the wrist movement is presented below.

From the aforementioned research, it is possible to conclude that the virtual human hand with 25 DOF will improve adding 4 DOF in the thumb chain.

Paper is organized as follow, in section 2 material and methods is exposed. In section 3 we show the results with a discussion. In section 4 the conclusions are finally shown.

2 Material and Methods

All of joints in the hand are revolute and if we use a generalized coordinate q_i that represents one degree of freedom, then the generalized coordinate vector can be represented by $\boldsymbol{q} = [q_1, \dots, q_{29}]$. However, the movements of fingers have some natural constraints (e.g. the middle finger cannot flex over 60 degrees). Table 1 represents the joint limits, for the thumb, where they have units in radians. We avoid the other fingers because they are presented in [11] and [12].

Fig.2 shows a model proposed with 29 DOF.

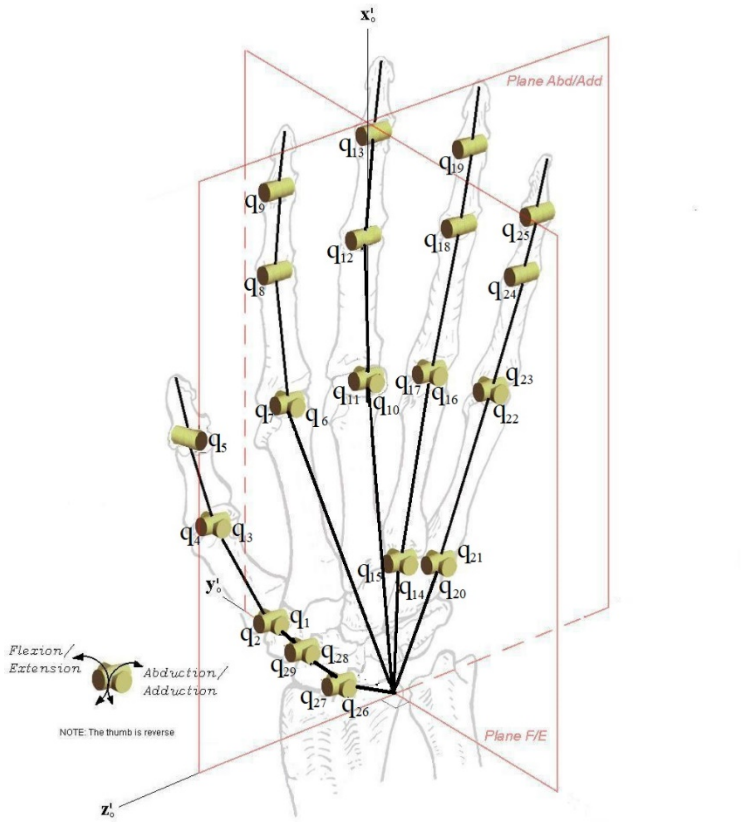

Fig. 2. Dorsal view right hand model.

Table 1. Joint limits for the thumb.

	Min.	Max.
q_1	0	π/3
q_2	-5π/36	7π/36
q_3	0	π/3
q_4	-π/18	11π/36
q_5	-π/12	4π/9

DENAVIT-HARTENBERG (D-H) METHOD

To study forward and inverse kinematics we adapted Denavit-Hartenberg method (D-H method) [13] from robotics field to define the positions of the fingertips with respect to each local coordinate system. D-H parameters are defined as follows:

- θ_k is the angle of rotation from x_{k-1} to x_k measured about z_{k-1}.
- d_k is the distance from the origin of frame L_{k-1} to point b_k measured along z_{k-1}.
- a_k is the distance from point b_k to the origin frame L_k measured along x_k.
- α_k is the angle of rotation from z_{k-1} to z_k measured about x_k.

The transformation matrix ${}^{i-1}T_i$ is shown below and the subscript $i = 1 \dots 29$

$$ {}^{i-1}T_i = \begin{pmatrix} \cos\theta_i & -\cos\alpha_i \sin\theta_i & \sin\alpha_i \sin\theta_i & a_i \cos\theta_i \\ \sin\theta_i & \cos\alpha_i \cos\theta_i & -\sin\alpha_i \cos\theta_i & a_i \sin\theta_i \\ 0 & \sin\alpha_i & \cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{pmatrix} $$

D-H method is implemented in the thumb and Fig. 3 shows the sketch of D-H method and Table 2 shows the D-H parameters.

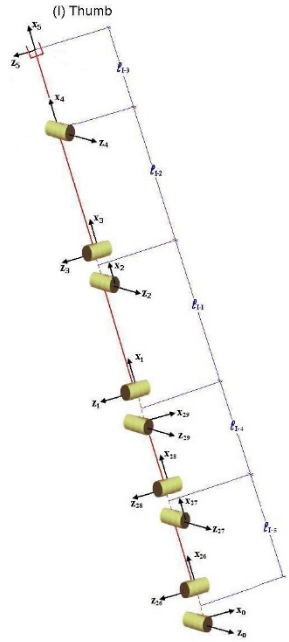

Fig. 3. Model for the thumb.

Where l_{I-1}, l_{I-2}, and l_{I-3} an found in [12]. $l_{I-4} \approx 11$ mm and $l_{I-5} \approx 22{,}7\ mm$ extracted from [14].

Table 2. D-H parameters.

	θ_i	d_i	α_i	a_i
26	$q_{26} + \pi/2$	0	0	$-\pi/2$
27	q_{27}	0	l_{I-5}	$\pi/2$
28	q_{28}	0	0	$-\pi/2$
29	q_{29}	0	l_{I-4}	$\pi/2$
1	q_1	0	0	$-\pi/2$
2	q_2	0	l_{I-3}	$\pi/2$
3	q_3	0	0	$-\pi/2$
4	q_4	0	l_{I-2}	$\pi/2$
5	q_5	0	l_{I-1}	$-\pi/2$

With these parameters we can have define the position vector, which is defined by $\boldsymbol{p}(\boldsymbol{q}^I)$ with respect to the local coordinate system by

$$\begin{bmatrix} \boldsymbol{p}(\boldsymbol{q}^I) \\ 1 \end{bmatrix} = {}^0T_{26}\,{}^{26}T_{27}\,{}^{27}T_{28}\,{}^{28}T_{29}\,{}^{29}T_1\,{}^1T_2\,{}^2T_3\,{}^3T_4\,{}^4T_5 \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

where $\boldsymbol{q}^I = [q_{26}\ \ q_{27}\ \ q_{28}\ \ q_{29}\ \ q_1\ \ q_2\ \ q_3\ \ q_4\ \ q_5]^T$. If we want to represent the position vector with respect to the global coordinate system (wrist) there is one transformation matrix for the thumb defined by

$$ {}^0H_I = \begin{bmatrix} cos\,\gamma_I & -sin\,\gamma_I & 0 & -l_{Io} sin\,\gamma_I \\ sin\,\gamma_I & cos\,\gamma_I & 0 & l_{Io} cos\,\gamma_I \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

where γ_i is the angle between the ray (finger) i $(i = I, II, III, IV, V)$ and the global $y_0^{'}$ axis shown in the Fig. 2. In this case we only are talking about the thumb.

Therefore, the position vector with respect to the global frame is defined by

$$\begin{bmatrix} \mathbf{w}(\mathbf{q}^i) \\ 1 \end{bmatrix} = [{}^0\mathbf{H}_i] \begin{bmatrix} \mathbf{p}(\mathbf{q}^i) \\ 1 \end{bmatrix}$$

The missed subindex $i = 6 \ldots 25$ are for the other joints, they do not change for the old model. For more information see [12].

3 Results

The algorithm has been implemented in a virtual hand environment. Table 2 presents neutral position of one hand.

Table 2. Angles for the neutral position of hand (in degrees).

Neutral gesture of the hand				
Thumb	Index	Middle	Ring	Little
q_1=0	q_6=0	q_{10}=0	q_{14}=0	q_{20}=0
q_2=0	q_7=30	q_{11}=30	q_{15}=2	q_{21}=5
q_3=30	q_8=30	q_{12}=30	q_{16}=0	q_{22}=0
q_4=0	q_9=10	q_{13}=10	q_{17}=30	q_{23}=30
q_5=30			q_{18}=30	q_{24}=30
q_{26}=0			q_{19}=10	q_{25}=10
q_{27}=0				
q_{28}=0				
q_{29}=0				

By the forward kinematics we can obtain the position vectors of fingertips (millimeter) corresponding to the neutral gesture of the hand shown in Table 3.

Table 3. Fingertip positions corresponding to the neutral gesture (with respect to the global coordinates).

Neutral gesture of the hand					
Position	Thumb	Index	Middle	Ring	Little
x	-109.9	3.14	16.28	36.34	55.37
y	79.3	158.25	159.71	145.73	118.74
z	-15.8	-69.5	-77.44	-79.3	-68.14

4 Discussion

The hand arches in two parts of the palm, that means, the two bones trapezium and scaphoid wrist bones move relative between them and the thumb metacarpal bone have movement with respect to the trapezium [4]. Scaphoid bone moves between the trapezium and the radius. Global coordinates system is located in the radius shown in Fig.4. The other bones located in the wrist, trapezoid, capitate and lunate don't have movement between them and the hamate, pisiform and triquetum have relative movement between then. However, these movements are not significant for the position of the fingertip.

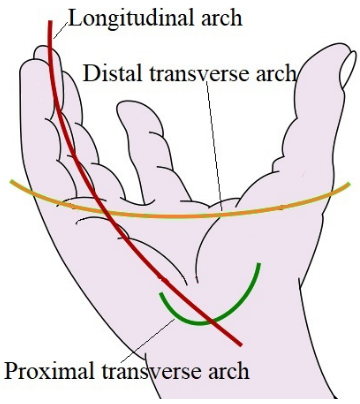

Fig. 4. Palm arch.

The action of the ligaments of the wrist are not trivial. The ligaments contribute to stabilize the bone. As a future work is interesting to study the influence of each ligament, observing which ligament is working when there is some movement of the hand, like opposing thumb to finger, palmar abduction, or retroposition.

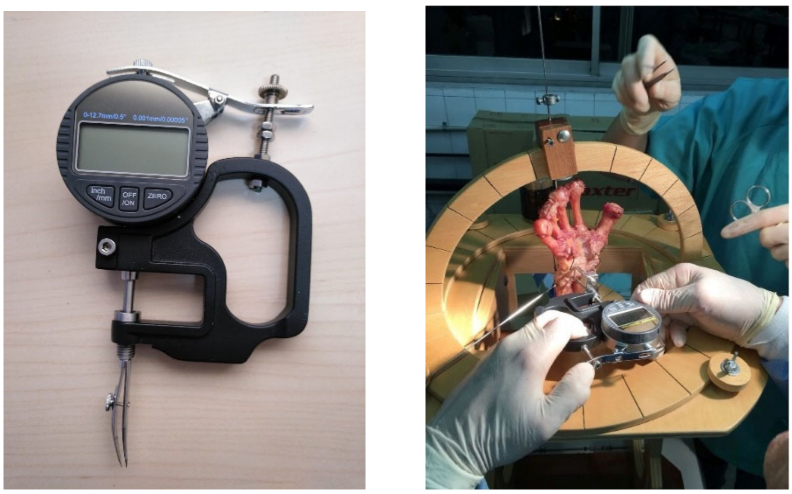

Fig. 5. Left, apparel to measure the ligament displacement. Right, jig designed by physicians of Univertitat Autonoma de Barcelona (UAB).

Fig. 5. shows the testing used to investigate ligament synergies in the loaded wrist, described in [3], and adapted system shown in the right.

5 Conclusions

New hand model with 29 DOF is developed to simulate more realistic movements of the fingers, specially the thumb. Thumb is adjusted to permit movements of the palm arcs in different sections of the hand. Proposed new studies are in process, like a proposed apparel to measure the displacements induced isometrically loading the wrist or by axially distracting the metacarpal bone away from the radius.

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