Wrist model for the whole human hand

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Abstract

A hand with 25 degrees of freedom (DOF) was proposed with forward and inverse kinematics for all fingers, with a realistic virtual simulation. However, the wrist is not in the model. Today, several authors have proposed in the literature that the wrist has a relative movement between the two rows of bones with eight bones. Some authors discuss a comparison of four joint coordinate systems previously described in the literature. Others propose a helical movement of wrist bones in distal movements.

Objective: A new design the hand model of 25 DOF adding a movement of two rows and eight bones of the wrist.

Methods: Once we locate a new coordinates system in the end of the radius close to the scaphoid, we apply Denavit-Hartenberg for all joints. Forward and inverse kinematics are applied. We include ten ligaments to apply restrictions in the wrist movement, which affects fingertip position.

Results: A new model of a virtual human hand with more accuracy is presented and validated with a Cyberglove™ and Leap Motion.

Conclusions: This new model that includes wrist movement yields a more accurate virtual human hand. New DOFs are added to the 25-DOF hand model.

Keywords: virtual human hand, wrist, 29 DOF.

Introduction

Author's hand with 25 Degree of Freedom (DOF) was proposed in Peña_Pitarch et al. (2019). 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. Padmore et al. (2020) discuss a comparison of four joint coordinates systems previously described in the literature. Garcia-Elias et al. (2017) 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 Kawanishi et al. (2017), and it follows that first metacarpal flexes and pronates with the dorsal base as the center. However, Akhbari et al. (2019) do not consider in their work a significant factor as the pisiform, which plays a minimal role in wrist kinematics.

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 D'Agostino et al. (2017).

Kapanji (1996) and Tubiana (1981) have detail description of taxonomy for the hand. Neu et al. (2001) 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. Sonenbluma et al. (2004) considered the motion of the scaphotrapezio–trapezoidal (STT) joint.

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

Figure 1 shows a big difference in the thumb fingertip, orange line (more realistic) is captured with the system of Leap Motion. Axis system of Leap Motion is shown in Figure 4. 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 methods is exposed. In section 3 we show the results. In section 4 the discussion and conclusions are finally shown.

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 $\boldsymbol{q} = [q_1, \ldots, q_{29}]$. However, the movements of fingers have some natural constraints (e.g. the middle finger cannot flex over 60 degrees).

Figure 2 shows a model proposed with 29 DOF.

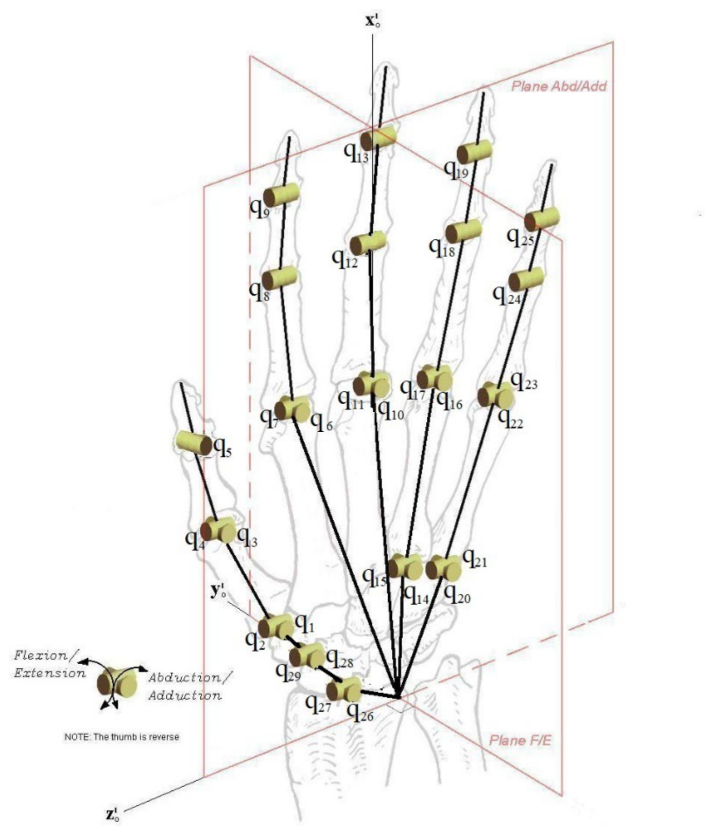

Figure 2. Dorsal view right hand model.

We validate the mathematical model doing experiments with healthy and poststroke patients, with the validate table Action Research Arm Test (ARAT), using Cyberglоble™, shown in Figure 3, and Leap Motion, shows in Figure 4.

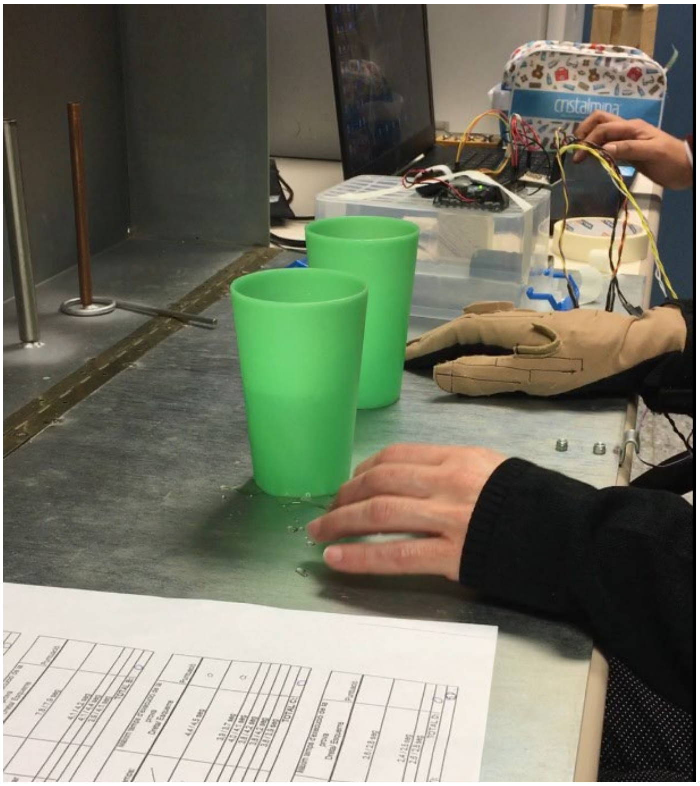

Figure 3. One moment of ARAT test experiments.

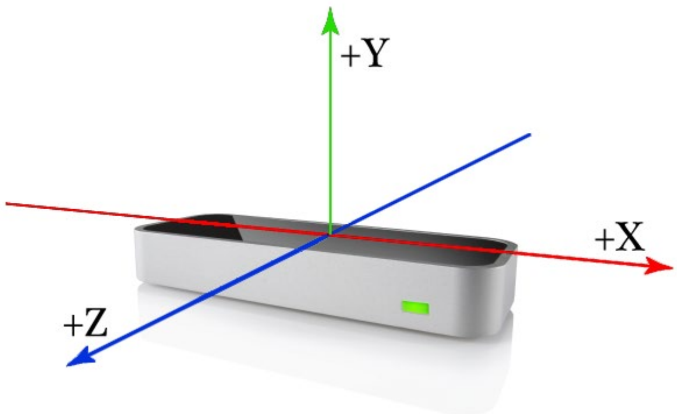

Figure 4. Axis system used in Leap Motion

Results

The algorithm has been implemented in a virtual hand environment. Table 1 presents neutral position of one hand.

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				

Table 1. Angles for the neutral position of hand (in degrees).

By the forward kinematics we can obtain the position vectors of fingertips (millimeter) corresponding to the neutral gesture of the hand shown in Table 2.

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

Table 2. Fingertip positions corresponding to the neutral gesture (with respect to the global coordinates).

Discussion and Conclusions

Figure 5 shows the palm arch. 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 (Kawanishi et al., 2017). Scaphoid bone moves between the trapezium and the radius. Global coordinates system is located in the radius shown in Figure 2. 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.

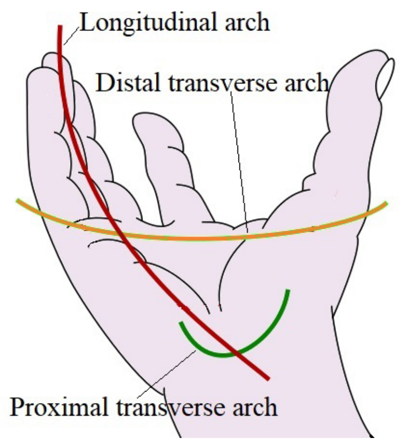

Fig. 5. Palm arch.

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.

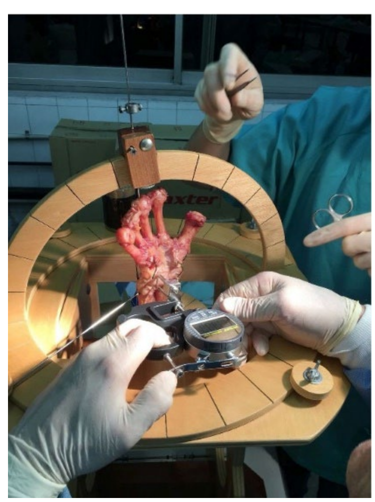

Figure 6. Left, apparel to measure the ligament displacement. Right, jig designed by physicians of Univertitat Autonoma de Barcelona (UAB).

Figure 6 shows the testing used to investigate ligament synergies in the loaded wrist, described in Garcia-Elias et al., (2017), and adapted system shown in the right.

As a conclusion, 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. Mathematical model is validated with Cyberglove^{TM} and Leap Motion. 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.

Acknowledgments

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