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# On Using Virtual Reality Tools to Study the Motion of a Human Hand Artificial Model

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***Abstract* – The human hand is a complex mechanism, very difficult to model and to mimic. There are many fields, which require the use of a hand model: computer games, VR simulations, human hand prostheses design, etc. Depending on the domain, the hand model will be more or less similar with the natural model, every time some approximations being necessary. This paper presents a human hand model intended to be used as basis to design an artificial hand able to assure the prehension function. The motion model was studied using VR tools to determine the trajectories and the angles for various activities.**

***Keywords:* artificial hand, VR tools, kinematical and dynamical model of the human hand.**

## I. 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 [7]. Even with the technological advances, the human hand is the primary source of dexterous activities. Hand motions are also extensively used in high technology areas, such as virtual reality (VR) and remote operation [15].

The first step to obtain efficient hand prosthesis is the study of the real hand. The human hand has 27 bones (Fig. 1) [5], divided in three groups: the carpals (the wrist bones), the metacarpals (the palm bones), and the phalanxes (the fingers' bones). The first phalanges are connected to the metacarpal bones. All the fingers have the same number of phalanges (three), excepting the thumb having only two phalanges. The metacarpal bones represent the palm and are attached to the carpal bones. The motion of the carpals allows the rotation of the hand with respect to the arm. Also, the metacarpal bones present an asymmetry: a semi-spherical surface at the contact with the carpal bones and a spherical surface at the contact with the first phalanges.

The hand can make a large range of motions due to its joints: distal interphalangeal joint (DIP), proximal interphalangeal joint (PIP), and metacarpophalangeal joint (MCP). Each of these joints is characterized by certain geometry of the contact surfaces and by a maximum angle. The hand's motions can be of different types: each finger can move in the hand plane, to go closer to the medial axis (adduction), can move far from the axis (abduction), can flex, and can extend. The thumb is, also, able to move in opposition with the other fingers, very important for grabbing objects.

The ligaments from the palm connect the metacarpal and carpal bones. They can block some metacarpal's motions to assure a more rigid structure for the palm. All the phalanges are connected through reduced ligaments. The bones are moved by the action of the muscles, connected to the bones through the tendons. These tendons are made from collagen, so they are elastic, capable to reassure the initial posture of the fingers after the flexion.

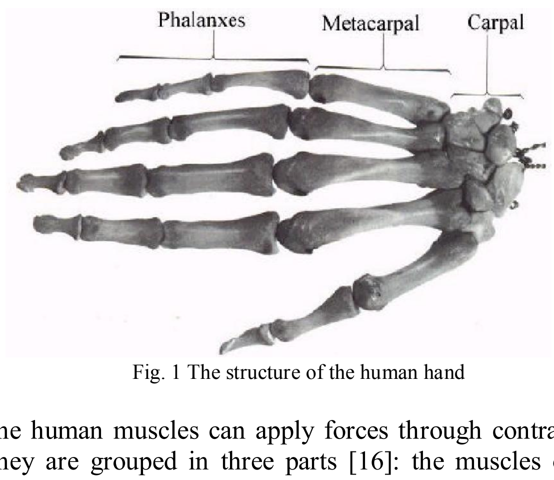


Fig. 1 The structure of the human hand

The human muscles can apply forces through contraction. They are grouped in three parts [16]: the muscles of the thumb, the muscles of the little finger, and the muscles of the palm. There are two kinds of muscles acting in the hand: extrinsic (localized in the arm) and intrinsic (localized in the hand). This last category is responsible with dexterity and flexibility of the hand. An intrinsic muscle attached to the proximal phalanges is acting as the flexor of the metacarpophalangeal joint and as the extensor of the interphalangeal joint. The motion of the thumb is assured by eight muscles, acting through the joint placed at its base. The human muscles are optimal for grabbing when flexing, not when extending. Because of that, there are more flexor than extensor muscles and the extensor muscles and their tendons are more compact and weaker than the flexor muscles [5].

The structure of the muscles is complex, being composed by fibers grouped in functional units named motor units [4]. Such a motor unit is formed by a motor neuron, its axon, and all the muscular fibers attached to it to receive a contracting signal. A muscle can have more than one motor unit. When the contracting signal from the brain is increasing, new motor units are recruited and, in the same time, the contracting frequency is increased in the already recruited units. By varying the number of active motor units, the brain can control the muscular contracting force. When a certain motor unit is contracting, it generates a short impulse of electric activity, named motor unit action activity—*MUAP* [4]. This signal can be detected using electrodes placed on the skin, close to the motor unit and can be used to drive a prosthesis through electromyography (EMG) [4].

### *A. Constraints of the Human Hand*

The human hand (Fig 2 [9]) is a highly articulated system with many degrees of freedom (DOFs). In the same time, the hand is submitted to a great number of constraints, generated by the dependencies between fingers and articulations. To model fingers' articulations, a description of the kinematical structure of the human hand is necessary. Each finger is considered a separate kinematical chain, having its base in the palm and its tip as end-effector.

Each of the four central fingers has four DoFs. The MCP joint (marked C in Fig. 2) allows two kind of motion (two DoFs) to the proximal phalanx of a finger: adduction or abduction (in the palm plane), and flexion and extension (with respect to the palm). The PIP joint (marked D in Fig. 2) connects the proximal and medial phalanges and has one DoF. The DIP joint (marked A in Fig. 2) connects the medial and distal phalanges and has also only one DoF.

The thumb has a different structure and has four DoFs, one for the interphalangeal (IP) joint (marked D in Fig. 2), one for MCP joint (marked C in Fig. 2) and two for trapeziometacarpal (TM) joint (marked E in Fig. 2), both due to flexion or extension and abduction or adduction motions. The thumb is able to move in opposition with other fingers.

The palm links together the wrist and the proximal phalanx of each finger. The wrist (marked in red, in Fig. 2) allows the rotation of the hand with respect to the arm, meaning three DoFs for the system. With the general coordinate system placed on the wrist, the whole system has a total of 23 DoFs.

The motion of a finger can be represented through a set of joints variables and is submitted to some constraints so the hand cannot make arbitrary gesture. For example, a finger cannot bend towards the exterior of the hand, or the little finger cannot be bent without moving in the same time the ring finger. Some of the hand's constraints have a mathematical representation, being often used in computer animations of the human hand. Unfortunately, many of the hand's constraints cannot be formalized, being very difficult to implement them in an artificial model.

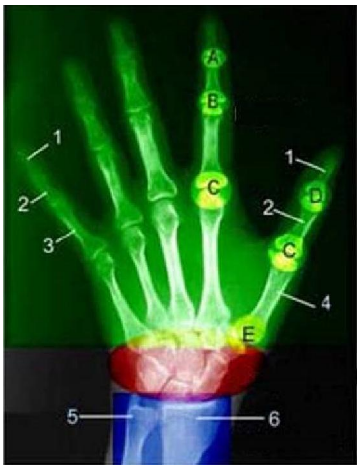


Fig. 2 The human hand's structure: 1) distal phalanx, 2) middle phalanx, 3) proximal phalanx, 4) metacarpal bone, 5) ulna, 6) radius.

The human hand's constraints can be grouped in three categories [8]:

— Type I constraints: the motion limitations imposed into a finger due to hand's anatomy (static constraints);

— Type II constraints: the limitations impose in joints during motion (dynamic constraints);

— Type III constraints: the limitations necessary to impose a natural motion.

## II. THE KINEMATICAL MODEL

Modeling the hand is a very difficult task because it has to contain the behavior of 44 different muscular units, 24 bones, at least 16 articulations which allow 23 DoFs (or more, depending on the representation). Scientists know many things about human hand, but only few things about the way its composing mechanisms work together to assure its functionality [10]. This is the reason way, to create a model of the human hand, one has to use approximations suitable to the needed purpose.

A human hand model is presented in [6], part of the HUMANOID data structure, with the goal of assuring a complete human skeleton structure. The authors paid a special attention to the hand's model due to the complexity of wrist-palm region, where the fingers are articulated. So, they assured a small flexing mobility at the metacarpal level to model the palm deformation. The model has all the five fingers. Excepting the thumb, which is modeled in a different way than the natural model, for the other fingers the standard approach was used.

A hand model based on Denavit-Hartenberg convention is proposed in [13]. All the central fingers have the same structure. Again, the thumb is modeled in a different manner, having 6 DoFs to assure its complex activity. The whole model has 26 DoFs, which can be reduced by applying the motion constraints. The general coordinate system to study the system's motion is placed on the wrist.

A new approach to model the human hand, which takes into considerations the motion constraints, is proposed in [14]. The hand model is composed by a skeleton and a skin model. The skeleton model is used to describe the hand posture using the 3D coordinates of the wrist with respect to a general coordinate system. The position of each kinematical chain connected to the wrist is described using a vector in a local coordinate system. The skin model assures the natural aspect of the hand. The model is suitable for computer graphic animations.

In order to study the motions of the human hand, we created a kinematical model based on Denavit-Hartenberg convention. The palm is considered as a parallelepiped body and all the phalanges as cylinders. The model has 22 degrees of freedom (DoFs) materialized by the joints coordinates $q_i$ (i=1, … , 22) revolute joints whose motions can reproduce the human hand gestures (Fig. 3 [1]).

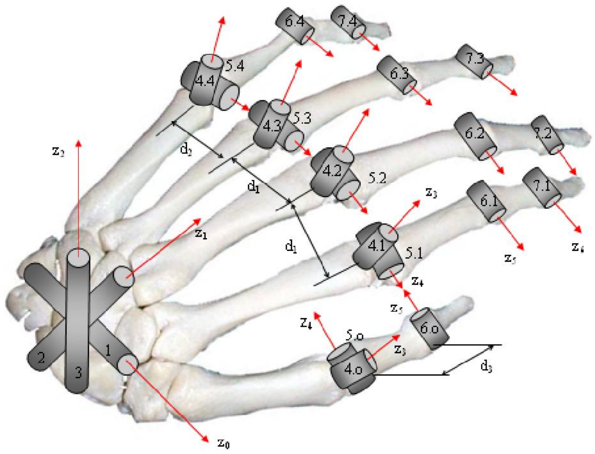


Fig. 3 The kinematical model of the human hand

The central fingers have the same structure as the natural model and they are linked to the palm at the metacarpophalangeal articulation. The thumb has a different description, having only three DoFs, to simplify the modeling process and the design of the artificial hand that we want to implement. Nevertheless, it is capable to move in opposition with the other fingers, assuring the main activity of the hand, prehension [2, 3, 11].

## III. THE VR MODEL

Based on the kinematical model we created a SimMechanics model of the hand in order to study its motion [2]. To improve the study and better observe the results, we created a representation of the hand in a virtual world, defined in VRML, and connected this virtual world to the SimMechanics model using a Virtual Reality Toolbox. This toolbox allows the user to directly connect the SimMechanics signals to virtual models to visualize the model as a 3D animation.

Using V-Realm Builder, a very powerful and intuitive application to create 3D objects and "worlds" to visualize these objects, we created a model for the human hand according to the kinematical model: the central fingers have the same structure (three phalanges), but different sizes, and the thumb has only two phalanges and a pre-established position with respect to the palm to assure the prehension. We connected this VR model to the SimMechanics model using a VR Sink block, able to take the needed signals from the SimMechanics model and to send them in the VR model for animation purpose.

Because the kinematical model of the human hand contains rotational joints, only the computed angular values are needed to visualize the system's motion. In a virtual world, the rotation is defined as a four-element vector. The first three elements specify the rotational axis (i.e., if the rotation is made around *Oz* axis, those three elements will be [0, 0, 1]) and the last element represents the angular value. When all the needed connections are set, the simulation is started and the motion can be studied. Fig. 4 presents the way the flexion motion is executed. For this case we considered the situation when the central fingers wrap around the thumb. One can very easy observe that the motion is very natural.

We, also, used this VR model to study the behavior of the hand when grabbing objects. For this, a dynamical study of the hand was needed [12]. The resulted SimMechanics dynamical model was connected to the VR model of the hand. We placed different type of objects in the vicinity of the hand (a ball, a parallelepiped, a pen, etc.) and wrapped the fingers around the objects until they were securely grabbed. Fig. 5 shows how the hand grabs a pen and Fig. 6 presents the captured angular value for this motion. It can be seen that all the fingers have the same motion but the thumb, which moves in opposition to sustain the object.

## III. CONCLUSIONS

This paper presents the way we obtained the kinematical model of the hand studying the natural model. Although our model has less DoFs than other existing models, it is capable to grab objects and to move in a natural way. We created this model having in mind to design an artificial hand able to assure the most important function of the natural hand, namely the prehension. The motion study of the resulted model was more than necessary to observe its correctness and to obtain the trajectories and angular values, useful to design the driving part of the artificial hand. The VR model generated motions and results easy to observe and to compare with the natural model. Using VR tools we proved the correctness of our kinematical and dynamical models, so they were successfully used to design an artificial hand.

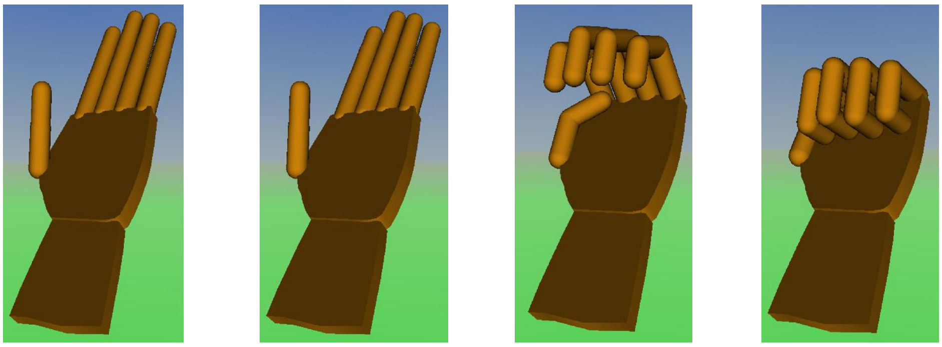

Fig. 4 The flexing motion of the hand

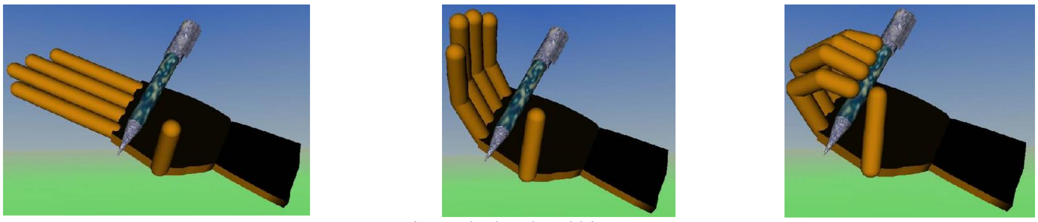

Fig. 5 The hand grabbing a pen

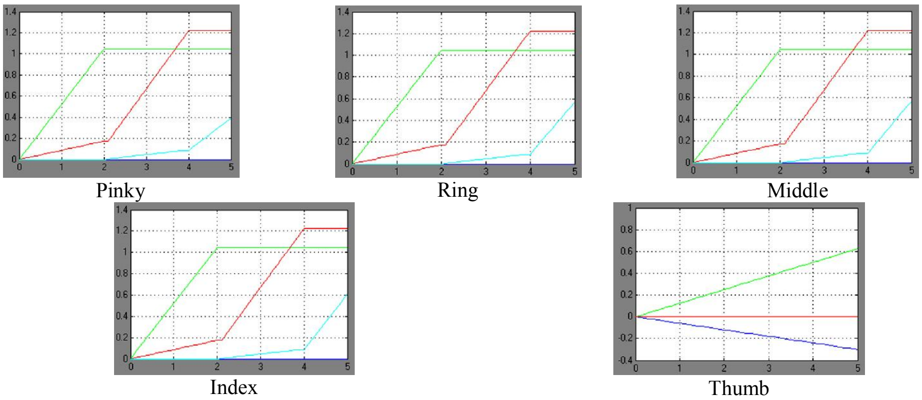


Fig. 6 The angular values when grabbing a pen

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