# ANALYSIS OF ANATOMIC – FUNCTIONAL CHARACTERISTICS OF HUMAN HAND FOR THE DESIGN OF AN ADVANCED ANTHROPOMORPHIC GRIPPER

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**Abstract:** *To evaluate the possibility to create a mechanism able to detect human hand motion, which can be then used to control an anthropomorphic gripper, anatomic and functional analysis of human hand is necessary. This paper presents a thorough analysis, based on study, already carried out, of the anatomic and functional structure of the human hand, to highlight useful aspects in achieving our goal that is obtaining an advanced system of command and control of an anthropomorphic gripper with five fingers via virtual gripping stimulation. Unique issues found are presented, as well as adaptations to identify less highlighted particularities in previous papers.*

**Keywords:** *human hand, anatomic structure, functioning, virtual simulation*

## 1. Introduction

To evaluate the possibility to create a mechanism able to detect human hand motion, which can be then used to control an anthropomorphic gripper, the first step was considered the anatomic and functional analysis of the human hand. This initial step was necessary because the human hand represents a very advanced system. At structural level, based on 27 degrees of freedom available, it can perform various gripping operations, releasing or moving objects of various geometric shapes [Provancher, 2003]. Also, through skin and nerves, a human hand can feel vibrations between 10-100 hertz [Kyung, 2005] which greatly complicates the gripping analysis.

The paper presents a general description of the human hand, motion evaluation procedures, gripping performance, as well as analysis of the human hand command and control procedure.

## 2. Human hand anatomic structure analysis

A human hand is a complex structure made of different types of bones connected by joints. It is attached to the forearm through a group of bones called carpal complex.

From the constructive point of view, a human hand is made of five fingers, out of which, four are used for most of the tasks ; these four fingers are opposed to the fifth finger that allows object gripping.

The fingers are: **thumb**: it is the shortest finger, and from the structural point of view, it has two phalanges, and it is opposable to the other four fingers. The thumb is located parallel to the arm, the latter useful in the gripping action; **the index**: it is the first finger located after the thumb, and it is the first in the four-finger unit. It is the finger with the greatest ability and sensitivity. From the structural point of view, it is made of three phalanges; **the middle finger**: it is located between the index and the ring finger. It is the longest finger, made of three phalanges; the **ring finger**: from the structural point of view it is made of three phalanges, located between the middle finger and the pinkie; **the pinkie**: it is made of three phalanges. It is usually the thinnest finger of the human hand, opposable to the thumb. It is next to the ring finger.

Using the fingers and the palm, the human hand can perform different actions, out of which the most important is object gripping.

Gripping was intensively studied in recent years, because, after analyzing the research in the area, it was noticed its applicability in many areas like prosthetics, robotics, mechatronics and so on. Most of the studies based on gripping started with the human hand structural analysis and the way it performs the gripping operation. Therefore, this paper is not an exception and research is based on the human hand structural analysis.

After analyzing the current stage of research in the area, it was noticed that in [Taylor, 1955] exhaustive research was conducted on the anatomic and mechanical analysis of the human hand. As described in this research, the skeleton is made up of three types of bones (Fig.1), namely:

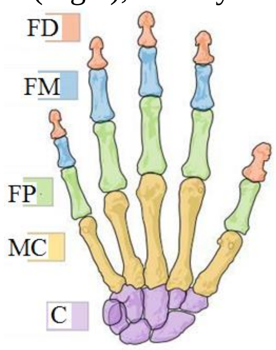


**Figure 1:** *Human hand skeleton – phalanges, carpal and metacarpal bones [Abrahams, 2011; Staretu, 2011].*

(1) **Carpal bones (C)**: 8, connected to the forearm; together they form the human hand basis, (2) **Metacarpal bones (MC)**: 5, corresponding to the medial segment and (3) **Phalanges**: 14, divided into proximal (PP), medial (MP) and distal (DP) phalanges, forming hand fingers.

Hand bones are interlinked through joints. Human hand has 36 joints divided into five types [Taylor, 1955], namely: **radial-carpal joints**: used to connect carpal bones to the forearm (3 joints); **inter-carpal joints:** used to interconnect carpal bones (8 joints); **carpal-metacarpal joints**: used to connect carpal to metacarpal bones (4 joints); **inter-metacarpal joints**: used to interconnect metacarpal bones (4 joints); **metacarpal-phalangeal joints**: used to connect the proximal phalanx to metacarpal bones (5 joints); **inter-phalangeal joints**: used to interconnect phalanges (9 joints).

Anatomically, human hand fingers are identical, except for the thumb, lacking the medial phalanx. Phalanges are interconnected through joints; human hand phalanges are divided by [Xu, 2012] into three categories, namely (Fig. 2):

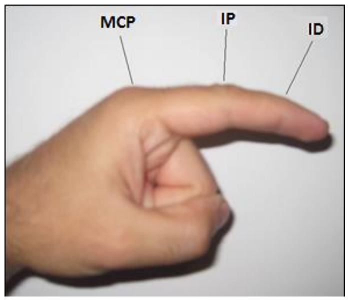


**Figure** Error! No text of specified style in document.**:** *Human hand fingers joints*.

**Metacarpal-phalangeal joints** (MCP): used to connect proximal phalanges to metacarpal bones; **inter-phalangeal distal joints** (ID): used to connect distal and medial phalanges; **inter-phalangeal proximal joints** (IP): used to connect medial and proximal phalanges.

Joints are formed connecting phalanges. It is a structure supported and stabilized by lateral ligaments. Depending on the type of the bone surface met, joints can have 1, 2 or 3 degrees of freedom that allow different movements of a finger.

## 3 Analysis of gripping and human hand motion

The 27 bones and 36 joints give the hand 27 degrees of freedom [Koura, 2003]. They are divided into 4 degrees of freedom for each finger, 5 degrees of freedom for the thumb, created through planes touching each finger joint surface center and 6 degrees of freedom for wrist rotation and translation in the carpal and carpal-metacarpal complex. Through these degrees of freedom, the human hand can interact with objects in the environment to handle and transfer an object from location A to location B.

Using the 27 degrees of freedom, the human hand can perform three types of movements (Fig.3), namely:

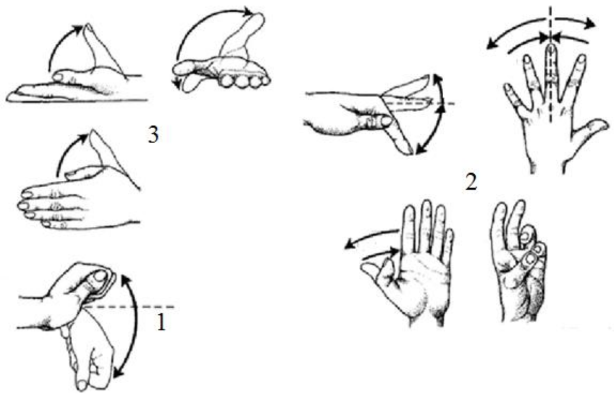


**Figure 2:** *Movements that can be performed by human hand [WWW 01].*

(1) wrist movement (flexion, extension), (2) finger movement (abduction, adduction, flexion, extension, hyper-extension, opposition to the thumb), (3) thumb movement (retro-positioning, palmar abduction, radial abduction).

Human hand has many degrees of freedom. Various movements can be performed by the human hand. Therefore, human hand detection and gesture recognition using digital image processing algorithms is complex.

Gripping has been studied intensively. It was first detailed by Schlesinger in 1919 [Schlesinger, 1919] and then classified according to object gripping procedure in a paper presented in 1955 by Taylor et all [Taylor, 1955] in: (1) cylindrical gripping, (2) hook gripping, (3) palmar gripping, (4) spherical gripping, (5) lateral gripping and (6) precision gripping.

Then, gripping was analyzed in Cutkosky's paper [Cutkosky, 1986] and classified in gripping taxonomy, divided into three levels, namely based on the force necessary to grip an object, based on the object geometry, and the last level considered gripping based on the number of fingers necessary for gripping.

Gripping classification at first level according to Cutkosky taxonomy: gripping based on force (safety and stability); gripping based on precision (dexterity and sensitivity).

Gripping classification at the second level according to Cutkosky taxonomy considers the structure of the object to grip. Thus, Cutkosky and Wrights divided objects into: prehensile, prismatic and circular, and non-prehensile.

Gripping classification at the third level according to Cutkosky taxonomy: the last classification level is represented by the number of fingers necessary to handle the object.

With the progress of virtual reality systems and human motion transfer to the virtual environment, gripping led to another dimension of research. There is research on human hand motion capture devices [He, 2012], [Nagata, 2001]; research on human hand motion detection algorithms [Kazemi, 2012]; research and analysis of virtual reality systems evolution, object generation and strategies for analyzing the impact between virtual objects [Aleotti, 2006].

In recent years, precision gripping procedures have been analyzed in detail to handle virtual objects. For example, in [Bock, 2012] research is conducted on gripping procedures taxonomy, in virtual environment (Fig.4). It is divided into a matrix, based on abduction and adduction operations and there is power gripping, intermediate or precision gripping.

They are further divided into palmar gripping (fingers grip the object against the palm), support gripping (fingertips are partially in contact with the object) and lateral gripping (the thumb works against the side of another finger).

After analyzing the current stage, the conclusion is that any gripping action first requires object stabilization, if it must be moved from location A to location B.

To grip an object, contact forces must be considered as well.

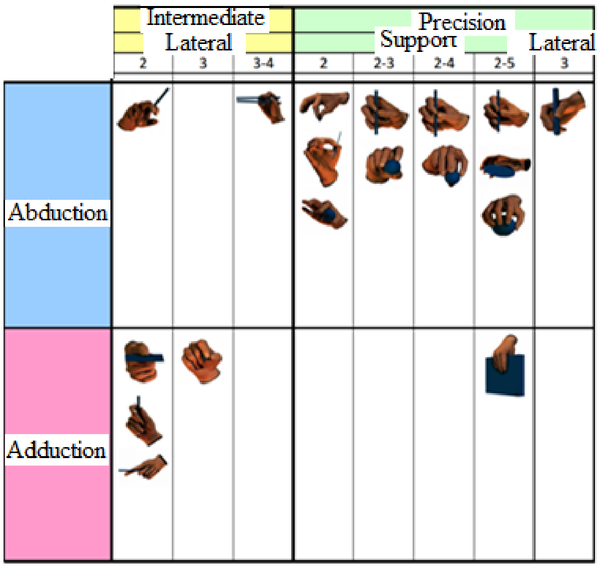


**Figure 3:** *Virtual gripping taxonomy [Bock, 2012].*

Thus, to prevent movements caused by friction, rolling or sliding, a human hand or an anthropomorphic gripper must apply appropriate force on the object surface, so that tangential forces at its surface are stabilized - cancelled (Fig. 5).

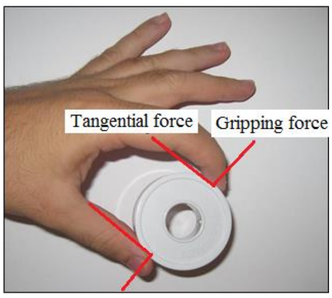


**Figure 4:** *Forces emerging at contact between two fingers gripping a cylindrical object.*

When attempting objects gripping or handling, the forces necessary to ensure gripping stability depend on the object's physical properties. Properties such as material, object weight, shape, density, impose certain conditions of fingers' arrangement on the object surface, and gripping forces must be considered when a gripping model is calculated.

To investigate human gripping and how it can be transferred to virtual environment, a first step would be its research in terms of cognitive model of human hand control.

## 4 Cognitive model analysis of human hand control

The best way to understand how human brain controls hand motion is to study natural motion through handling actions. In recent years, research in this area focused especially on hand control during precision activities. In the next section, research focuses on analysis of the current hand motion, on gripping and handling objects with different physical characteristics. From the point of view of human hand motion control at the level of the nervous system, Fig.6 presents a diagram describing the nervous impulse route from the upper cerebral level, which initiates motion, filtered by intermediate levels, reaching the top level, represented by the motor neuron [Itu, 2010].

Knowledge of human nervous system structure, controlling human hand, may be useful when attempting gripping from the artificial intelligence perspective [Contreras-Vidal, 1997]. In robotic gripping research, knowledge of nervous system functioning is useful, especially if it is approached from artificial intelligence perspective, more precisely in the area of neural networks. Thus, each processing layer in a neural network is represented by each entity in Fig.6 as it can be noticed in [Niessen, 2005].

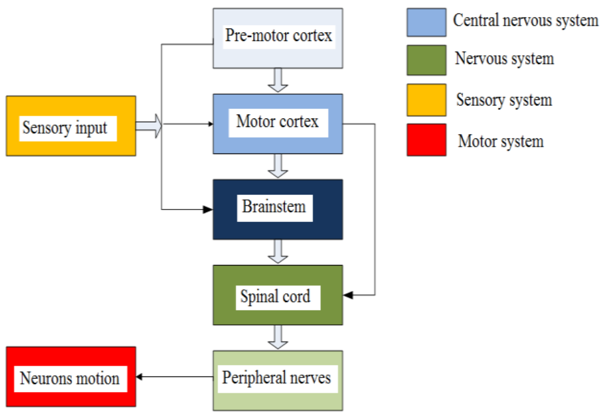


**Figure 5:** *Nervous system involved in human hand command and control [Itu, 2010].*

When the network is ready, we must learn how it can grip different objects [Rezzoung, 2006]. A way of learning the neural network is monitored learning, through which the network is provided values (gripper position, angles between phalanges) and the result (if the object is gripped or not).

Starting from the human hand functionality, this paper aims to identify elements leading to gripping, and their transfer to an anthropomorphic gripper. The result of neuropsychology studies revealed that human gripping can be divided into three main stages [Aleotti, 2006] namely: (1) visual location of the object to grip, which includes object recognition, size and physical properties estimation. The second stage (2) is represented by hand extension to the object, when the hand is pre-configured on the object shape and in the last stage (3), gripping, which represents fingers' movement to the object and application of forces at its surface to compensate weight.

In Napier's work [Napier, 1954] the concept of gripping was divided into precision gripping, intermediate gripping and power gripping. In the case of precision gripping, fingers grip the object, whereas in the case of power gripping, the hand grips it, so that each phalanx of the human finger, even the palm, come into contact with the object. Intermediate gripping is similar to both previous gripping concepts.

Using the procedures above for gripping, objects handling was divided into precision handling – when fingertips can rotate on the object surface in any direction, intermediate handling – when a finger side and the thumb perform gripping, and power handling - the whole hand is in contact with the object.

In Fig.7, we can notice gripping as precision gripping (a, e), power gripping (b, c) and lateral gripping (d, f), adapted from [Aleotti, 2006].

Based on the neuropsychological model of human gripping, adding visual analysis models, we can obtain command and control mechanisms for virtual or mechanical anthropomorphic grippers, with applicability in various areas of robotics and functional simulation.

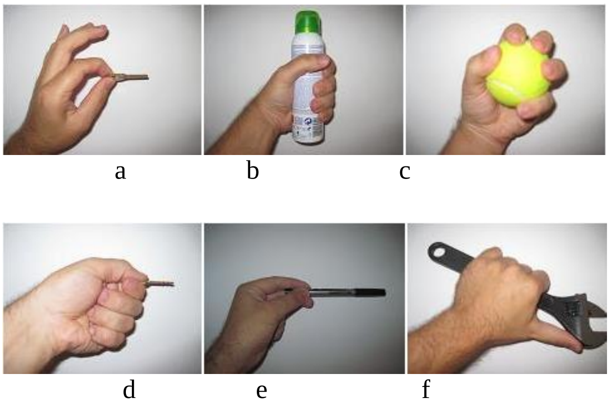


**Figure 6:** *Different ways of object gripping.*

## 5 Conclusions

Gripping is a research area of great interest, being intensively studied in time. First, it was researched from the point of view of human hand analysis, understanding anatomic structure and functioning. Then, gripping was researched in terms of motion simulation in virtual environment and automation of gripping actions that can be performed through their transfer to robotic hands. Human hand structural and functional characteristics study is still valid from the recent research perspective, based on increasing robotic grippers' capabilities to improve their flexibility to be easily used for any object gripping.

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