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HUMAN HAND STUDY FOR ROBOTIC EXOSKELETON DELVELOPMENT

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***Abstract*—**This paper will be presenting research with application in the rehabilitation of hand motor functions by the aid of robotics. The focus will be on the dimensional parameters of the biological human hand from which the robotic system will be developed. The term used for such measurements is known as anthropometrics. The anthropometric parameters studied and presented in this paper are mainly related to the angular limitations of the finger joints of the human hand.

Keywords—Robotic Exoskeleton, Motor Function Rehabilitation, Anthropometrics

I. INTRODUCTION

TAKING a brief look at the history of technological innovation we will see that science and technology have provided us with major advancements in the industrial and economic sectors of activity. The area of robotics has brought us closer to the world where hard labor, repetitive, and difficult tasks are replaced by high-tech autonomous machinery Tarca [1]. The area of robotics has produced numerous applications such as Pasc, Tarca, Popentiu, Albeanu [2] and Pasc, Tarca, Popentiu [3]. Advancements that end some job areas and opening others, enabling us to focus on intellectual activities such as design, programming, and engineering. Although we have made significant progress in the sectors mentioned above some areas such as medical robotics are still in need of development and advancements.

It's well known that a significant part of the world's population suffers from some form of disability, be it cognitive, emotional, sensory of the motor condition, and because of poor technology and conditions the result is a reduced quality of life.

If we look at the hierarchy of needs first described by Abraham Maslow in 1943, physiological needs are of the most importance, situated at the base of our society. Basic levels of the physiological function should be a part of our human rights; every person should have the right to life without disability if they chose so Hugh [4].

The research presented in this paper is to be used for rehabilitation of the hand grasping motor function for people who have suffered a stroke or cerebrovascular accident with the aid of robotics.

The current rehabilitation techniques involve the manual exercise of the afflicted limb by specialized medical personnel. Most of the time this traditional way of rehabilitation presents inconvenience such as daily visits to the hospital or clinic and the lack of familiar environment such as a patient's own home to aid in recreating the neuronal connections used for motor functions.

The focus of this paper is merely a step in developing a device that can aid physiological rehabilitation and enhancement of the human body.

A close relation between nature's design of the human hand, the biological joints and the robotic system was vital for the project’s starting point. For this reason, the research provided in this paper was elaborated.

Factors such as bone structure, joint and ligaments, muscle actuation and degrees of freedom were researched in order to mimic the natural movement of the biological hand, in essence reverse engineering and collecting data for designing a robotic exoskeleton.

II. BIOLOGICAL HAND JOINTS AND BONES

The bone structure and joint movement must match with the structure of the exoskeleton in order for the device to be effective. Factors such as maximum angle are critical when designing a robotic exoskeleton.

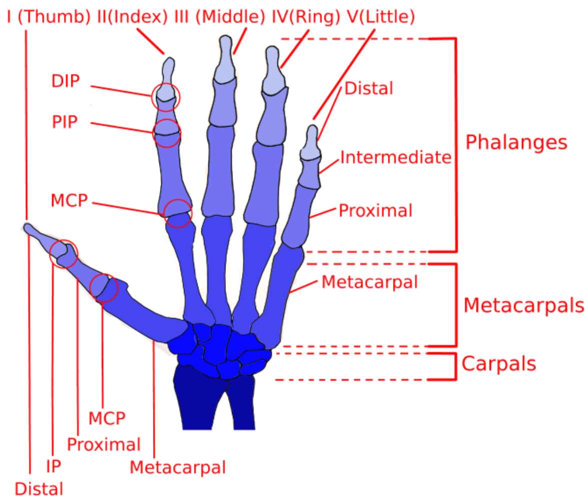

Fig. 1 Human hand bone and joint structure

That being said this section of the paper will include a general description of the human hand anatomy followed by a two-part anthropometric study, one regarding the angular limitations of the finger joints and the other regarding the phalanges length.

Starting from the root of the wrist, eight bone comprise the carpus, continued by the bones that comprise the digits, namely the metacarpals and phalange segments. The naming of each digit is as follows starting from the radial to the ulnar side: thumb, index finger, middle finger, ring finger, and little finger, the bone structure can be observed in fig. 1.

Each individual finger is composed of one metacarpal and three phalanges, the exception being the thumb which has two phalanges segments.

The joint linking the metacarpal bone to the proximal phalanx is known as the metacarpophalangeal abbreviated as the MCP joint. The MCP joints have two degrees of freedom, being classified as ellipsoidal or condylar joints. This means that MCP joints permit flexion, extension, abduction, and adduction movements. This can be seen in fig. 2 where Q_0 represents the ability or rotation on the Z_0 axis and Q_1 which represents the ability to rotate on the X_0 axis. The proximal interphalangeal abbreviated as PIP and the distal interphalangeal also abbreviated as DIP joints are found between the phalanges of the fingers. These joints permit rotation only on one axis namely X_1 for the PIP axis and X_2 for the DIP axis. A special case being the thumb, which has only one interphalangeal, also abbreviated as the IP joint Heo, Min Gu, Lee, Rhee and Kim [5].

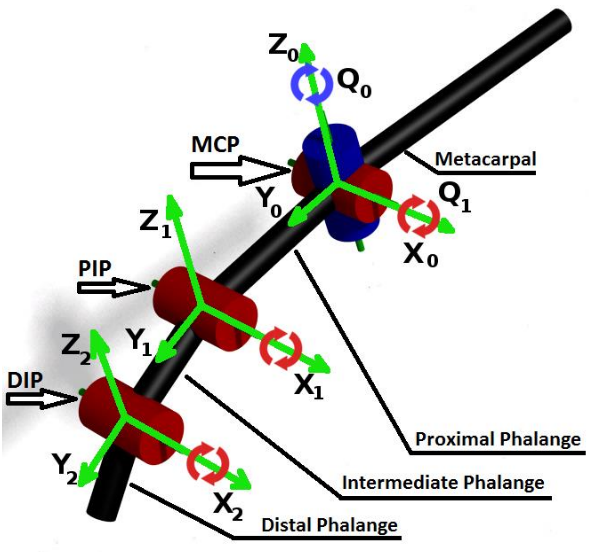

Fig. 2 Joint degrees of freedom

III. ANTHROPOMETRIC STUDIES AND DATA COLLECTING

Measuring and determining the dimensions of a human hand is important for establishing specifications for the robotic exoskeleton. In the purpose of determining these specifications, in this subchapter we will analyze and log date such as: phalanx dimensions, joint maximum angles, offsets between fingers, and also any critical dimension that would be useful later on during the mechanical design stage of the project Sandoval-Gonzalez, Jacinto-Villegas, Herrera-Aguilar, Portillo-Rodiguez, Tripicchio, Hernandez-Ramos, Flores-Cuautle, Avizzano [6].

A. Angular limitations

Each joint is capable of moving a finite and limited angle, in the following study we will consider the starting extension position of the finger as being equal to 0 degrees Yap, Lim, Nasrallah, Gohl, and Yeow [7].

An example of an extended hand is seen in fig. 3-A. In this example, all phalanges have an approximately 0-degree angle relative to one another. There are several combinations of flexion when it comes to the human hand; this varies depending on the dimensions of each person's hand, and also the task performed. In the following example seen in fig. 3-B we have a full flexion of the hand also referred to as a closed fist.

In the case of the full hand flexion, we consider the joints have reached almost their maximum bending angle. All phalanges including the metacarpals have a maximum relative angle to one another.

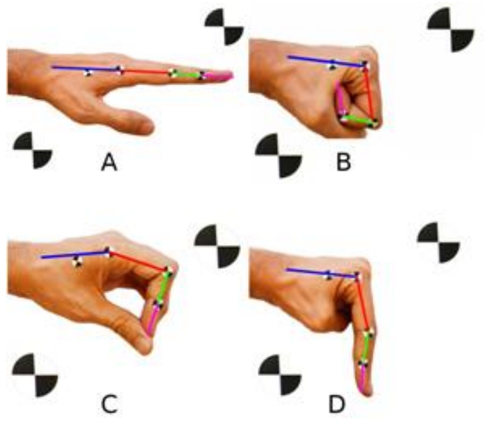

Fig. 3. Joint angular positions of the human hand

Depending on the task the hand is doing, the angles between the phalanx and metacarpals are not always all in a flexion or extension state. One such variant can be seen in fig 3-C. In this figure, we have flexion of the MCP and PIP joints and extension of the DIP joint.

Combinations like these make up most of the tasks of daily human activity, interacting with our environment, picking up object and tools would not be possible without having some degree of control over the MCP, PIP, and DIP joints. This finger position can vary, sometimes having flexion on the DIP join as well to achieve the same task of manipulation.

As mentioned earlier we consider the extension position of the finger as being 0, depending from person to person, some joint have the ability be moved by an external force under the 0-degree limit, some actually reaching as much as -45. Although this kind of movement cannot be achieved actively by one stand alone finger, this movement is done with the aid of the other finger.

Another type of movement where the DIP and PIP joints are in the extension state and the MCP joint is in a flexed state. This can be seen in fig. 3-D we can see the flexion of the MCP and extension of the PIP and DIP joints. Not used as much as the case where flexing the MCP and PIP joints and extension of the DIP joint or flexing all joints, it is still used in some task specific cases.

Using the data collected regarding the DIP, PIP and MCP joint angle play table I was generated.

TABLE I ANGULAR LIMITATIONS

Joint	Index finger		Middle finger		Ring Finger		Little Finger	
	Ext.	Flex.	Ext.	Flex.	Ext.	Flex.	Ext.	Flex.
DIP	-10°	85°	-8°	85°	53°	87°	0°	90°
PIP	-10°	110°	-8°	110°	-5°	105°	0°	100°
MCP	-50°	93°	-25°	95°	0°	92°	-10°	91°

The MCP joints can be flexed 90° and even beyond depending on the case, similar the PIP can be flexed at least 90°, usually more, and the DIP joints are flexed to a maximum of 90° but do not exceed this limit, unlike the other joints. Flexibility is at the highest at the little finger and decreases from each finger going to the index. It is observed that extension beyond the zero position depends largely on a condition named ligamentous laxity Heo, Min Gu, Lee, Rhee and Kim [5].

B. Dimensional characteristics

Besides flexibility which influences the angular limitations, dimensions of the hand differ depending on age, physique, and gender. For research purposes, the anthropometric parameters are shown in fig. 4 were considered.

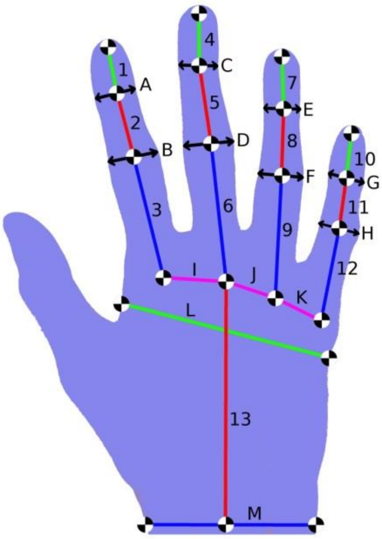

Fig. 4 Hand measurement points

Measurements carried out using the anthropometric sketch presented above in fig. 4 on a set of 10 subjects have resulted in the following sets of the date shown in table II.

TABLE II – LENGTH ANTHROPOMETRIC MEASUREMENTS

Link	Minimum	Maximum	Average
1	19.6	27.3	23.4
2	23.04	32	27.52
3	38.16	53	45.58
4	20.5	28.5	24.51
5	25.2	35	30.1
6	42.2	58.7	50.4
7	20	27.8	23.9
8	21.7	30.3	26.0
9	38.8	54	46.4
10	19.4	27	23.2
11	18.2	25.38	21.8
12	29	40.4	34.7
13	73	102.6	88.2
A	11.5	16	13.7
B	14.4	20	17.2
C	11.6	16.2	13.9
D	14.4	20	17.2
E	10.8	15.1	12.9
F	12.8	17.8	15.3
G	10.4	14.5	12..4
H	11.8	16.4	14.1
I	18.7	26	22.3
J	19.6	27.3	22.3
K	23.04	32	20.21
L	38.16	53	71.81
M	20.5	28.5	55.9

Measurements carried out on the fingers determined that the thickness of the fingers cannot be logged as a simple cylindrical diameter. In other words while measuring the diameter of the *DIP* and *IP* joints we observed that the transverse diameters of the *IP* joints are greater than the axial diameters. This is due to the fact that the shape of the human finger have variable thickness, the dimensions measured from the sides of the joints or axial to the joint usually are greater than the dimensions when measuring from the top to dorsal part of the joint, the difference can be seen in fig. 5. D1 respectively D2 are greater than d1 and d2.

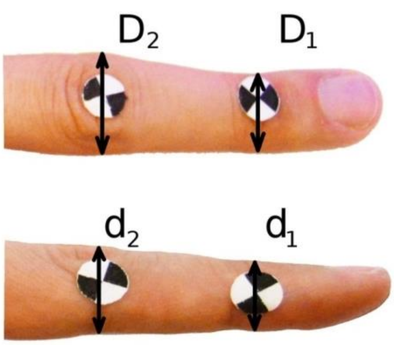

Fig. 5 Joint thickness measurement points

In table III we highlight the difference in thickness explained above.

TABLE III. JOINT THICKNESS DIMENSIONS

Joints	Index Finger		Middle finger		Ring finger		Little finger	
	D	D	D	d	D	d	D	d

DIP	16	13	16.2	13.5	15.1	12.5	14.5	11.5
PIP	20	17.5	20	17.5	17.8	16.2	16.4	15

IV. Area of application

The data collected is intended for developing a robotic hand exoskeleton. In turn, the exoskeleton main purpose and area of application is rehabilitation for people that suffered from a stroke or physical accidents that were left with motor impairment. Although the potential of the robotic exoskeleton is not limited to rehabilitation, in this paper the main focus remains rehabilitation.

Loss of dexterity and strength is a loss of motor function and is a side effect that 80% of stroke survivors have to endure. The cause of motor function loss is a result of a brain injury suffered during the stroke, but the muscular, and nervous system are still intact.

For regaining control of the motor functions repetitive motion exercise helps to create new motor connections in the brain, in essence rewiring the brain and creating new neuronal synapses much like a newborn child learning to walk.

Repetitive, controlled movements such as the occupational therapy of the paretic hand can aid in rehabilitation and gain back strength and dexterity. Tasks from the therapy that involve opening and closing the hand such as games eating, dressing, picking up objects and manipulating them help build up strength, dexterity and regain coordination. These tasks are established by the occupational therapist depending on the patient's level of functionality.

This kind of therapy usually takes place in hospitals or clinics and requires a trained specialist to effectively move the patient's hand manually and performing the exercises one at a time. Replacing the need to travel to the hospital for each session and the need for a trained specialist is a major step in hand mobility and dexterity rehabilitation. It's not only convenient, but by doing the exercises at home, it can boost the rehabilitation because it provides a sense of independence and psychological familiarity Delph, Fischer, Gauthier, Martinez Luna, Clancy, Fischer [8].

As mentioned earlier this paper is merely a small step towards a bigger purpose, namely developing robotic exoskeletons for rehabilitation purposes Iqbal and Baizid [9]. This does not mean that the data collected can not be used for similar purposes such as exoskeletons for enhancing grip force. Situations in which the human hand is placed in extreme conditions can be aided by a robotic exoskeleton are present in the industrial job sector and also space walks.

For example, an astronaut during a procedure named a spacewalk, will be equipped with a space suit in order to perform tasks outside the space station. In this situation, they are required to use their hands to grip the handles and tools on the space station for hours on end. The physical strain endured by astronauts would be drastically lessened using a robotic exoskeleton. Some research has already been done by NASA regarding an ex-glove for space exploration purposes.

V. Conclusion

Although anthropometric measurements can be done manually it can prove to be very time-consuming and susceptible to human error, for further more elaborate studies I would like to implement an automated method of determining the parameters of each subject's hand. This would drastically save time and also presumably provide results with greater accuracy. Technologies that have the potential to facilitate this are video processing and 3D scanners, preferably the first. Using video processing measurements could be done without the need of expensive hardware and most importantly it can be done almost anywhere and could be easily implemented in hospitals with minimal investments in materials Tarca [10].

For a follow-up on this paper, a new and automated way of gathering anthropometric measurements will be proposed and researched in future papers.

VI. Acknowledgment

Ph.D. School of Engineering Sciences - University of Oradea

VII. References

[1] R. C. Tarca, Introduction to Robotics (Introducere in Robotica), *Editura Universităţii din Oradea*, ISBN 973-613-456-3

[2] I. Pasc, R.C. Tarca, Fl Popentiu-Vladicescu, G Albeanu On designing virtual environments based on intelligent mechatronic systems *ISSAT International Conference on Modeling of Complex Systems and Environments*, 2007/7, pag.16-18

[3] I. Pasc, RC Tarca, Fl Popentiu-Vladicescu, Architectures for the E-Learning Mechatronic Laboratory at the University of Oradea the *3rd International Scientific Conference ELSE* 2007, Bucharest, pp.6

[4] H. Hugh. Ted - Ideas worth spreading - The new bionics that let us run, climb and dance. In *TED2014 conference*, 2014, Mar.

[5] P. Heo, G. Min Gu, S. Lee, K. Rhee and J. Kim, Current Hand Exoskeleton Technologies for Rehabilitation and Assistive Engineering in *International Journal Of Precision Engineering And Manufacturing* Vol. 13, No. 5, pp. 807-824. May 2012

[6] O. Sandoval-Gonzalez, J. Jacinto-Villegas, I. Herrera-Aguilar,O. Portillo-Rodiguez, P.Tripicchio, M. Hernandez-Ramos, A Flores-Cuautle and C Avizzano Design and Development of a Hand Exoskeleton Robot for Active and Passive Rehabilitation in *International Journal of Advanced Robotic Systems*. Feb. 2016.

[7] H. K. Yap, J. H. Lim, F. Nasrallah, J. C. H. Gohl, and R. C. H. Yeow A Soft Exoskeleton for Hand Assistive and Rehabilitation Application using Pneumatic Actuators with Variable Stiffness in *IEEE International Conference on Robotics and Automation (ICRA)* Washington State Convention Center Seattle, Washington, May 26-30, 2015.

[8] M. A Delph, S. A Fischer, P. W Gauthier, C. H. Martinez Luna, E. A. Clancy, G. S. Fischer A Soft Robotic Exomusculature Glove with Integrated sEMG Sensing for Hand Rehabilitation in *13th International Conference on Rehabilitation Robotics (ICORR)*, Seattle, WA, June 2013.

[9] J. Iqbal and K. Baizid Stroke rehabilitation using exoskeleton-based robotic exercisers: Mini Review. *In Biomed Res* - India 2015 Volume 26 Issue 1 2015; pag. 197-201.

[10] R. C. Tarca, Advanced Mechatronics, Series of Advanced Mechatronics Systems, 2012, *Publisher: University of Debrecen, Hungary*, HU ISBN 978-963-473-508-3.