VOL. 16, NO. 4, FEBRUARY 2021 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

DESIGN AND IMPLEMENTATION OF A ROBOTIC HAND PROSTHESIS UNDER THE TENSEGRITY APPROACH FOR TRANSRADIAL AMPUTEES

Miguel Ángel Tovar Cardozo[1], Ruthber Rodriguez Serrezuela[2], Jorge Luis Aroca Trujillo[2], Roberto Sagaro Zamora[3] and Enrique Marañón Reyes[4]
[1]Faculty of Business Administration, Corporación Universitaria Minuto de Dios UNIMINUTO, Colombia
[2]Industrial Engineer, University Corporation of Huila - Corhuila, Neiva, Republic of Colombia
[3]Facultad de Ingenieria Mecánica e Industrial, Universidad de Oriente, Santiago de Cuba, Cuba
[4]Facultad de Ingenieria en Telecomunicaciones Informática y Biomedica, Universidad de Oriente, Santiago de Cuba, Cuba
E-Mail: ruthber.rodriguez@corhuila.edu.co

ABSTRACT

The prosthesis of hands in some of the cases allow to reach the same functionality that has a real hand. For this reason, in the development of this document we present a functional hand and forearm prosthesis, which allows providing a replacement option to those who, due to lack of development of this part of the body or an amputation, do not have this limb. To design this prototype, first some calculations of forces and torques that the proposed system can support are made. Then, with the support of a model designed in the software of Autodesk, simulations are found in which the design is subjected to external forces, giving as results the forces, deformations, tensions, among others, to which the prototype can operate.

Keywords: prosthesis, hands, tensions, forces, model.

1. INTRODUCTION

The use of prosthesis aims at replacing the lack of an organ or a member either total or partial. In other words, the prosthesis has to accomplish a similar function, which the missing part should develop. This is the reason why, for years, humans have sought how to solve the limitations caused by the amputations, the problems that bring different diseases or the non-development of the part of the body. Such is the case of the hands of steel that were used by Götz Von Berlichingen (1504 A.D.), Capua's (300 B.C.) bronze leg, the toe found in an Egyptian mummy (between 1069 B.C. to 664 B.C.), and the prosthesis used after War World I and II, the conflict in Vietnam, Iraq, among others [1]. In the case of Colombia, the total or partial loss or absenceso fan upper limb can be caused not only by diseases, accidents or an incorrect development of the body, but also by problems of armed conflict.

This research is one solution to the need for replacing the missing hand, using the forearm for the assembly of the engines and the part of the treatment of the bioseñeles for the patient, i.e. transradial amputations.

To this end, this document is divided into the following parts: the first will be an introduction of the basic required information, such as mechanisms, degrees of freedom, functions of the hand, prosthesis, amputation and anatomy of the hand.

Once some concepts have been defined, some mathematical analysis of forces and torques that can occur in the cinematic of the limb movement will be carried out. Along with this, a prototype of the system with computational tools as CAD/CAE is designed. It will define the elements that should make up the fingers, the palm, and the forearm.

Finally, simulations of the proposed model are developed, and the results, analysis and conclusions of the research are shown.

2. THEORETICAL BASES

The set of elements that make up a hand are the bones divided into phalanges, metacarpal and carpal bones constituting in all twenty-seven (27). Likewise, thirty-two (32) muscles that act as actuators of the same constitute it. The hand is also irrigated by a number of blood vessels in which the blood is exchanged from the veins to the arteries collecting innumerable signals from the millions of nanoreceptors that it possesses.

A machine is defined as the set of various bodies that are interwoven in some way allowing the transmission or production of work "Its purpose is the study of the laws that regulate the movements of the various parts, members and organs of machines and the forces that these elements transmit"[2]. Currently, the concept of mechanism refers to the ability to transmit different forces or moments as a combustion engine, as an example.

A. Prosthesis Structure

The structure of the proposed prosthesis is composed by mechanical parts and an electronic system where the electronic system has as a function, to control the movements of the mechanical parts. Some basic components that make up the structure are:

Mechanical structure: the under-robotic prosthesis is composed of links that represent the phalanges of the hand, interconnected by rotational joints. The number of movements that each joint can make related to the immediately preceding link is known as degrees of freedom (DOF). For the case of the hand, each joint has a degree of freedom and the sum of these represents the total amount of degrees of freedom that the hand has.

Actuators: They are devices in charge of transforming electrical energy into force or torque, in order to generate movements in the prosthesis of the hand.

Hands functions: Some of the functions that the hands possess are those of holding or grasping objects, endowing the brain with information of the environment through the touch and generating a language of communication. Among the main types of grip that have been implemented for hand prostheses are: pliers grip, cylindrical grip, hook grip.

Types of prosthesis: There are mechanical, electrical, pneumatic, hybrid and cosmetic prostheses, where the latter one only does a function that would be the esthetic aspect. When a prosthesis is constructed with moving parts, it requires a source of energy to generate the force or torque, a transmission system, a control system and a fastening device.

Levels of amputation: The levels of amputation of upper extremities are presented as follow:

- Intercross-thoracic or clavicle amputation.
- Disarticulation of the shoulder.
- Transhumeral amputation or above the elbow.
- Elbow disarticulation.
- Transradial or below-elbow amputation.
- Disarticulation of the hand and wrist.
- Transcarpal or partial hand amputation.
- Amputation of fingers.

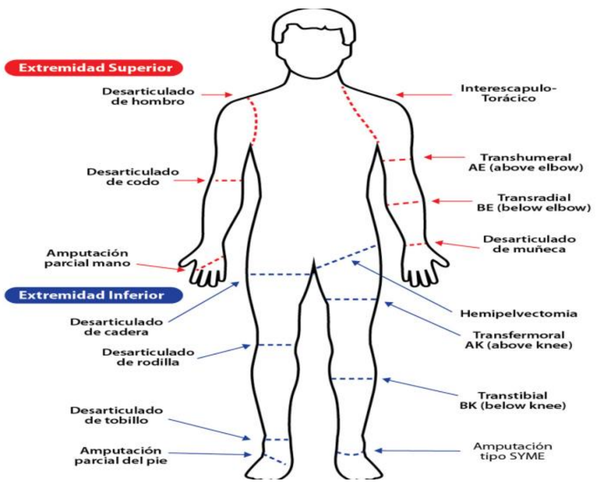

Figure-1. Levels of upper limb amputation [3].

Kinematics of the hand: For the development of the prosthesis, the degrees of freedom that make up the human hand must be analyzed. The wrist has 2 DOF. The rotational joints between middle and distal is 1 DOF, as well as the proximal and middle joints. In the phalangeal metacarpal joints, there are 2 DOF that perform the flexion-extension and abductor-adductor movements. The latter has a low rotation, compared to the other joints.

For the correct functioning, a human hand must have around 32 muscles in charge of making movements that imply pressure, flexion, and extension, among others. Considering that most contraction and extension movements are generated through tendons, the Tensegrity mechanism is implemented. This refers to the use of cables (tendons) that are joined together through a network of tensioners and can generate a movement. This mechanism has characteristics such as lightness and precision [4].

3. RESEARCH DEVELOPMENT

We start from the analysis of forces that can be present. For this, we analyse the force exerted by the combination of the muscles present in the hand.

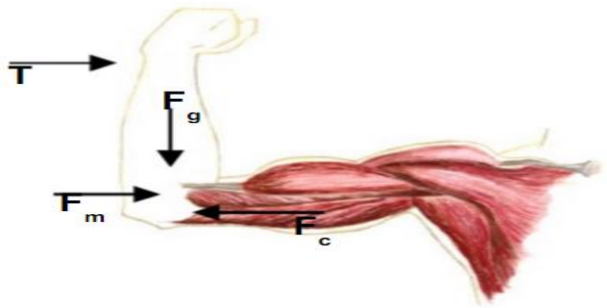

Figure-2. Behavior of the forces in combination of the biceps and forearm.

It is required to know the value of the tension (T). The value of the variables of the muscular Force (F_m) and Contact Force (F_c). These were found from the average of the forces given by Álvarez Diego et al. [4], which takes the values F_m = 116,540 kgf and F_c = 100,120kgf.

$$T = F_m - F_c \quad (1)$$

Thus, T = 116,540 kgf-100,120kgf T = 16,420kgf

Represented in the SI, you have the following: T = 161.020N

The strength of the biceps and forearm must be transmitted to a sheet, which in turn is distributed on each finger of the prosthesis. This is related to the distance, the difference in length that is had when extending or contracting the hand. According to studies by Camilo Rodríguez *et al*. [5] the maximum variation of the length in most prostheses is 50mm.

Therefore,

$$F\_t = T * \Delta x \quad (2)$$

ARPN Journal of Engineering and Applied Sciences

Where; Δx = Longitudinal change

Ft = Transmitted force

T = Stress $\Delta x = (50mm * 1m)/(1000mm) = 0.050m$

$F_t = 161.020N * 0.05m$

$F_t = 8{,}051Nm$

With the previous result, it can be assumed that this is the pair transmitted to the sheet, which will be distributed equally by the five (5) nylon threads, based on the Tensegrity approach. In order to have: $F_d = F_t / N$ (3)

Where;
Fd = Strength of the fingers
N = Distribution number
Ft = transmitted force

$F_d = F_t / N = (8{,}051\ Nm) / 5 = 1{,}61Nm$

In this way, it is possible to find the torque-load that must at least support each phalanx of the prosthesis when contracting or compressing.

4. CALCULATION OF THE CONSTANT K

To determine the K value of the spring, the Hooke equation will be used:

$$K = F / (\Delta x) \quad (4)$$

Where,
K = spring elasticity constant
F = Force applied to the spring
Δx = Maximum spring elongation

The system will be designed with a maximum elongation of 5cm to ensure the correct operation of the hand. Because of this, a spring that has a maximum elongation of 15cm (0.150m) is chosen so that it is able to ensure that the spring will not reach the maximum elastic area in which, it is ensured that the spring will never present a permanent deformation. Thus,

$$K = F / (\Delta x) = (161{,}020\ N) / 0{,}150m = 1073{,}460\ N / m$$

Then, it is needed to calculate the displacement of the spring, with the weights provided by the design in the Inventor software. Given as a result that the weight of the prototype is 0.176Kg and that of a Teflon cylinder is 0.200Kg. That is, the weight of the object plus the weight of the prototype (total weight) is equal to 0.376 kg.

The given force is found in Newton:
$0.376kg * 9.8m / s ^ 2 = 3.691N$
With this information supplied and by means of equation 4, we have that the spring will extend:

$\Delta x = F / (K) = 3{,}691N / (1{,}073{,}460\ N / m)$
$\Delta x = 0.00343841m$

In short, if a force of 3.691N is applied, the spring will have an elongation of 3.430mm.

5. LEVEL CALCULATION OF FIRST ORDER

To determine the force that the arm must exert on the prosthesis, when you have a grabbed object, it must be assumed that the system is in equilibrium:

$$F * B_f = F_r * B_{fr} \quad (5)$$

Where;

F: Applied force.
Bf = 0.070m: Strength arm length.
Fr = 3,691 N: Strength that exerts resistance.
Bfr = 0.177m: Length resistance arm.

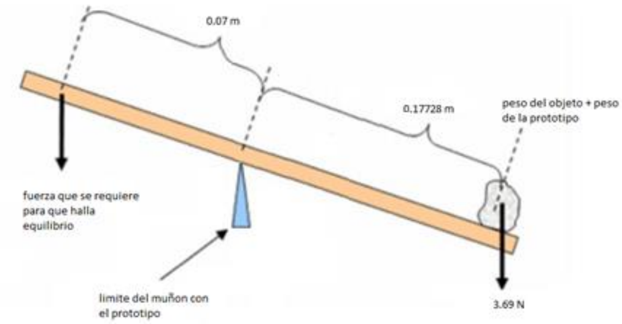

Figure-3. Lever of 1st order of the prototype [Author´s source].

It is cleared and the values are replaced:

$F = (F_r * B_{fr}) / B_f = (3.69N * 0.177m) / 0.07m$
$F = 9.35N$

In order to have the system in equilibrium, the force that the arm must generate is 9.35 N.

6. MECHANICAL DESIGN IN CAD

A model was developed with tools such as CAD / CAE, allowing designing each of the elements that make up the prosthesis of the hand. The ABS material is used because it has the mechanical characteristics required in the project and the resistance to the torque-load that was previously established. Resulting in the design presented in Figures 4, 5 and 6.

Although a human hand has three phalanges, this prototype is designed with a hand with only two phalanges, the distal and the middle [6].

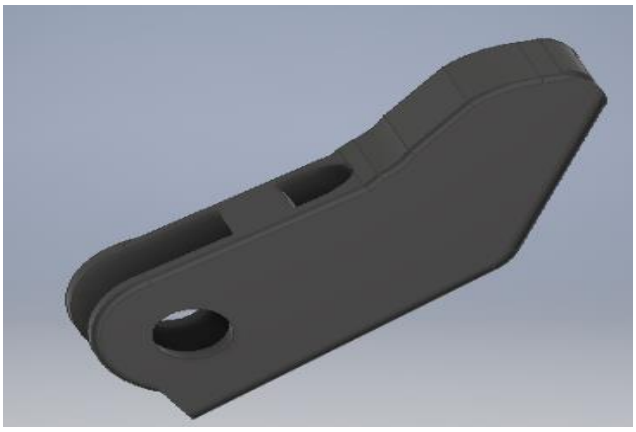

Figure-4. Distal phalanx [Author´s source].

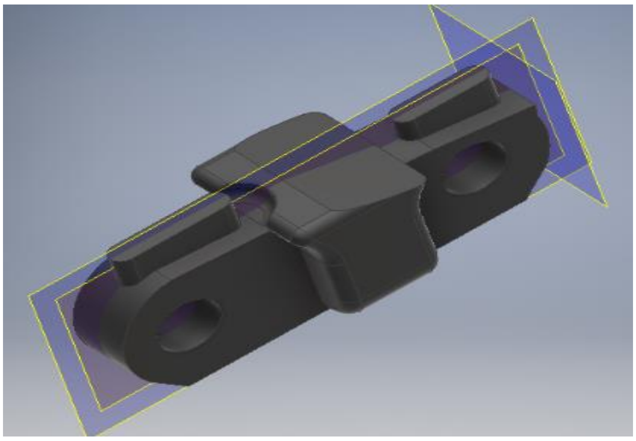

Figure-5. Middle phalanx [Author´s source].

Due to the complexity of designing a palm of the hand that molds to the objects to be gripped, a rigid model will be made. This has five holes, through which the Carbon Nylon thread passes, are responsible for performing the movements of the phalanges.

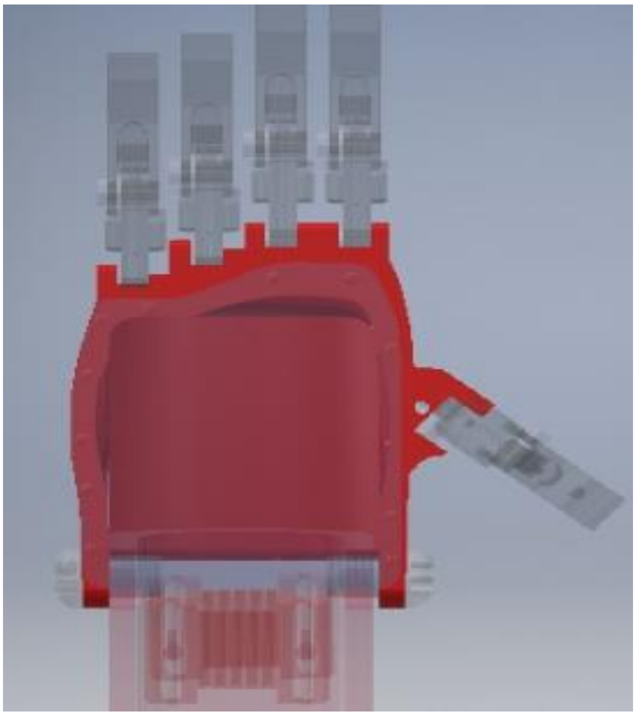

Figure-6. Prototype of the hand [Author´s source].

For the design of the forearm, the shape of coupling with the stump must be taken into account, together with the space occupied by the mechanical and electronic systems.

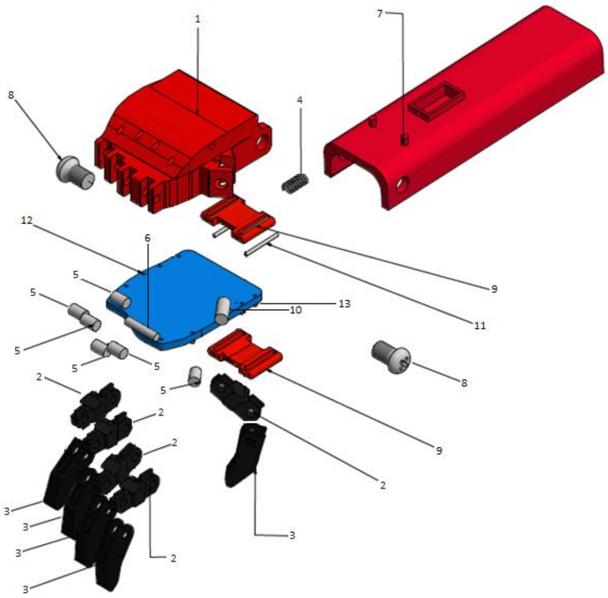

Figure-7. Forearm of the prototype [Author´s source].

First, a modeling of the phalanges has to be done, as the fingers have three phalanges, this prototype will have two, of which will be the distal and the bottom. Then, the modeling of the palm of the hand is made which will be hollow with a lid so that the prototype can be improved later. A forearm is designed, which was decided to be U-shaped because the prosthesis has a drawback and is has to

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

have the measures of the affected person or at least where the stump is going to be placed. After having these pieces, the sheets are made, where the Carbon Nylon threads are distributed to the phalanges. Next, the spring to be used is designed. Afterwards, the required screws are designed as well as the bolts to carry out the assembling and test them in simulations [7], [8].

7. RESULTS OF SIMULATION OF THE PROTOTYPE

With the help of several simulations of Autodesk's 3D Max software you will find the directions of the forces that are applied when holding an object, as shown in figure 8.

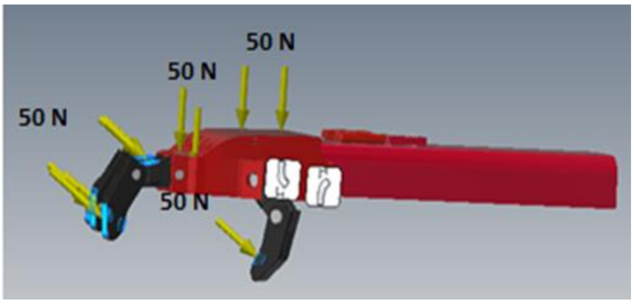

Figure-8. Application of force on the prototype [Author's source].

Additionally, Von-mises voltages are found and they determine stress and deformations in multiple directions (three-dimensional).

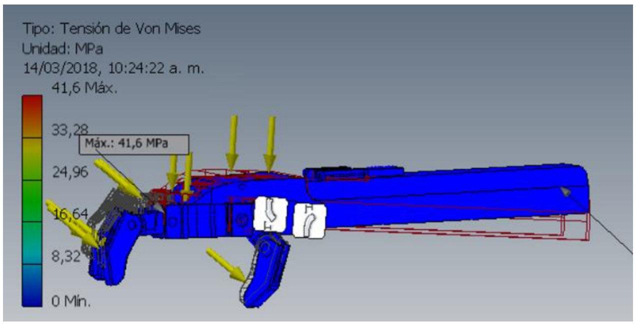

Figure-9. Tensions exerted on the prototype [Author's source].

According to Figure-9, there are no anomalies of stresses and deformations. Figure-10 shows the displacement of the prosthesis by an external force.

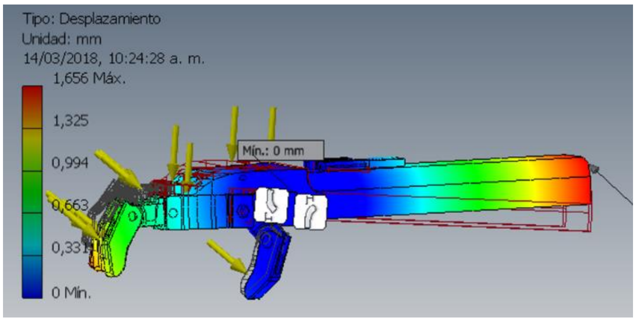

Figure-10. Displacement presented in the prototype due to an external force [Author's source].

There is a critical displacement in the lower part of the forearm, this is understandable if considering that this is not subject to the stump, and therefore it moves a considerable distance.

Finally, Figure-11 shows the deformation that may occur, which shows non-representative values and, on the contrary, are negligible values.

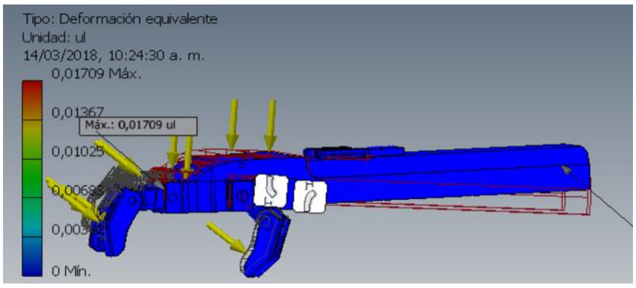

Figure-11. Deformation presented in the prototype due to an external force [Author's source].

8. CONCLUSIONS

A functional prototype of prosthesis of the hand and forearm with Tensegrity mechanism is presented. Good simulated results are obtained through the computational tool of Autodesk Inventor 2017.

The results of gripping tensions, deformations and displacements to grasp an object of 200 grams provide sufficient information to determine the viability of the product with the ABS material, used for the design, as well as the possible forces to which the carbon Nylon cables will be subjected.

It is found that the proposed system of the Tensegrity mechanism is feasible because, once the simulations are acquired; it is found that the prosthesis will not present any failure, as long as the parameters in the present simulation are used.

REFERENCES

[1] L. Puglisi and H. Moreno. 2006. Prótesis robóticas. Rev. del Dep. Automática e Informática Ind. pp. 1-10.

[2] P. E. Harold A., Realpe Judy C., Jojoa. 2004. Avances en sistemas e informática., vol. 4, no. 1. Escuela de

Ingeniería de Sistemas de la Facultad de Minas, Universidad Nacional de Colombia Sede-Medellín.

[3] J. L. Aroca Trujillo, A. Pérez-Ruiz and R. Rodriguez Serrezuela. 2017. Generation and Control of Basic Geometric Trajectories for a Robot Manipulator Using CompactRIO®. J. Robot. Vol. 2017.

[4] B. Sospedra Griñó. 2015. Diseño mecánico de prótesis de mano multidedo antropomórfica infractuada.

[5] D. Alonso-Álvarez *et al*. 2008. Carrier recombination effects in strain compensated quantum dot stacks embedded in solar cells. Appl. Phys. Lett. 93(12): 123114.

[6] C. A. Rodríguez Pachón, R. L. César Augusto, L. V. David Fernando and C. Q. Rodrigo Esteban. Diseño Y Construcción De Una Mano Electromecánica Controlada Por Mandos De Voz.

[7] C. A. Quinayás-Burgos, M. Muñoz-Añasco, Ó. A. Vivas-Albán, and C. A. Gaviria-López. 2010. Diseño y construcción de la prótesis robótica de mano UC-1 Design and Construction of the Robotic Hand Prosthesis UC-1 2 Desenho e construção da prótese robótica de mão UC-1 3. 14(2): 223-237.

[8] A. A. Alonso, H. R. Sánchez, E. P. Hurtado, D. R. la Rosa Steinz and de R. la Rosa Steinz. 2002. Entrenador mioeléctrico de prótesis para amputados de brazo y mano. Mapfre Med. 13(13): 11-19.

[9] Trujillo J. L. A., Zarta J. B. R. & Serrezuela R. R. 2018. Embedded system generating trajectories of a robot manipulator of five degrees of freedom (DOF). KnE Engineering. 3(1): 512-522.

[10] Trujillo, J. L. A., Serrezuela, R. R., Zarta, J. B. R., & Ramos, A. M. N. (2018). Direct and Inverse Kinematics of a Manipulator Robot of Five Degrees of Freedom Implemented in Embedded System-CompactRIO. Advanced Engineering Research and Applications, B. S. Ajaykumar and D. Sarkar Eds., Nueva Deli, India, Research India Publication, 405-419.

[11] Serrezuela R. R., Cardozo M. Á. T., Ardila D. L. & Perdomo C. A. C. 2018. A consistent methodology for the development of inverse and direct kinematics of robust industrial robots. ARPN Journal of Engineering and Applied Sciences. 13(01): 293-301.

[12] Serrezuela R. R., Chavarro A. F. C., Cardozo M. A. T., Toquica A. L. & Martinez L. F. O. 2017. Kinematic modelling of a robotic arm manipulator using Matlab. Journal of engineering and applied sciences. 12(7): 2037-2045.

[13] Rojas J. H. C., Serrezuela R. R., López J. A. Q. & Perdomo K. L. R. 2016. LQR hybrid approach control of a robotic arm two degrees of freedom. International Journal of Applied Engineering Research. 11(17): 9221-9228.

[14] Zarta J. B. R., Villar F. O., Serrezuela R. R. & Trujillo J. L. A. 2018. R-Deformed Mathematics. International Journal of Mathematical Analysis. 12(3): 121-135.