Integration and programming of delta-type parallel robot prototype

Integración y programación de prototipo de robot paralelo tipo delta

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Abstract

The development of the present study focuses on the exploration of the parallel robot in delta configuration, highly applied in the industrial environment, in order to integrate a prototype that concentrates the basic characteristics of its function. The constitution of the exposed implement implied the use of materials and devices of easy acquisition and low cost. Likewise, a detailed analysis of the respective mechanical structure and its operation was necessary, in reference to both the way and the medium through which the movement generated by the actuators is managed, to be transmitted to the end effector. The incorporation of the Arduino electronic board as the robot controller is reported, which contains the established programming to ensure its correct operation, given the instructions entered by the user from a computer. The results observed during the performance tests confirm the effective adoption of the joint values assigned by the user, within the mobility limits imposed; even at the level of a prototype.

Parallel robot in delta configuration, Prototype integration and programming, Joint position

Resumen

El desarrollo del presente estudio se enfoca en la exploración del robot paralelo en configuración delta, altamente difundo en el medio industrial, con la finalidad de integrar un prototipo que concentre las características básicas de su función. La constitución del implemento expuesto implicó el uso de materiales y dispositivos de fácil adquisición y bajo costo. Asimismo, fue necesario el análisis minucioso de la estructura mecánica respectiva, y de su operación, en referencia tanto al modo como al medio a través del cual es gestionado el movimiento generado por los actuadores, para ser trasmitido hacia el efector final. Se reporta la incorporación de la tarjeta electrónica Arduino como controlador del robot, la cual contiene la programación establecida para asegurar la correcta operación del mismo, dadas las consignas ingresadas por el usuario, desde una computadora. Los resultados observados durante las pruebas de desempeño, constatan la adopción efectiva de los valores articulares asignados por el usuario, dentro de los límites de movilidad impuestos; aun al nivel de un prototipo.

Robot paralelo en configuración delta, Integración y programación de prototipo, Posición articular

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Introduction

The integration of robotic mechanisms within multiple industrial systems has allowed the manipulation of materials in environments where the direct intervention of the human being used to be limited, implying a risk for their integrity (Bilyea, Seth, Nesathurai, & Abdullah, 2017). Thus, the incorporation of such equipment provides efficiency in the execution of operations with high repeatability, in long periods of time, increasing the productivity and profitability of production processes (Fong, Deb, & Chaudhary, 2015) (Valente, 2016). For more than half a century, industrial robotics focused its interest on the development of manipulators based on open kinematic chains (Szűcs & Galambos, 2020). These are implements made up of a set of links joined, one to another, from their ends; and in whose final portion a tool is located, which enables the execution of a specific task (Mann, Damti, Tirosh, & Zarrouk, 2018). Originally, the function of these articulated mechanisms was limited to parts handling, positioning or welding operations (Birglen & Schlicht, 2018).

However, the reduction of maneuvering spaces in the plant and the need to reach higher speeds, ensuring high precision in the movements described, would soon lead academics and, later, manufacturers to consider other design options (Gasparetto & Scalera, 2019) . Research fields were constituted around the conceptualization, analysis and design of other types of robotic configurations that differed from the conventional ones, which did not take long to become a reality (Borchert, Battistelli, Runge, & Raatz, 2015) (Wu , Bai, & Hjørnet, 2016).

One option to solve the emerging challenges of industrial robotics was the proposal of parallel robots; implements made up of closed kinematic chains or extremities (Altuzarra, Şandru, Pinto, & Petuya, 2011). In this type of mechanism, each end is assembled at one end to a fixed base, while the end effector is supported at the opposite end (Brinker, Funk, Ingenlath, Takeda, & Corves, 2017). Some of the notable attributes in this configuration are the rigidity of its mechanical structure and the stability in the transmission of movement from the actuators to the end effector (Bellakehal, Andreff, Mezouar, & Tadjine, 2011).

Among an infinity of proposals generated from the 1980s to the present day, the parallel robot in delta configuration constitutes the most representative and widely disseminated unconventional variant in the industry (Avizzano, Filippeschi, Villegas, & Ruffaldi, 2015).

Motivation

From the academic aspect with a technological orientation, owning and putting into operation a delta-type parallel robot would imply access to an analysis and programming model based on a highly dynamic and highly useful unconventional robotic configuration today. It is worth mentioning that the application of this type of robot in the industrial environment has determined a positive impact on the performance of selection and positioning processes of parts at high speeds, with excellent levels of precision; which encourages its growing implementation.

However, owning such equipment means a strong investment for any institution of higher education, particularly if it is public. Therefore, a valid option to have a mechanism with the characteristics described is the integration of a prototype based on low-cost technology and devices. Thus, the mechanical structure to be used could be manufactured by printing by adhesion of material or 3D, in addition to acquiring the commercial elements necessary for its assembly, which do not imply a considerable expense.

On the other hand, the electronic system required for the manipulation of the prototype could be formed from a board with adequate performance features, and economically accessible. In addition, to resort to a specialized, high-level, open source programming language. As well as being used other multiple devices of easy acquisition, that make possible the communication and interaction between the integrated delta parallel robot and a computer interface, through which its manipulation is carried out. In this way, once the proposed parallel robot in delta configuration has been formed, and through the variation of parameters that establish its operation, initially position, behaviors can be established that lead to the understanding of its use in the industry and the optimality of its operation.

Also promoting, having a test equipement that provides another perspective of the application of Industrial Robotics to students of the Engineering areas of the Universidad Tecnológica del Norte de Aguascalientes, through the subjects related to this field.

Delta robot characterization

The delta configuration was proposed in the 1980s by Professor Reymond Clavel from the École Polytechnique Fédérale de Lausanne, in Switzerland. Originally, this robot had three translational degrees of freedom, one per limb, and one rotational in its end effector (Clavel, 1991). Figure 1 show how, in each extremity, the input links are arranged as rotating levers, actuated by electric motors at a first end; while at their opposite end, they are joined to the respective output links, using joints of revolution. The latter transmit the movement from the base to the mobile platform, where the end effector is located (Huang, Chiba, Arai, Ueyama, & Ota, 2015).

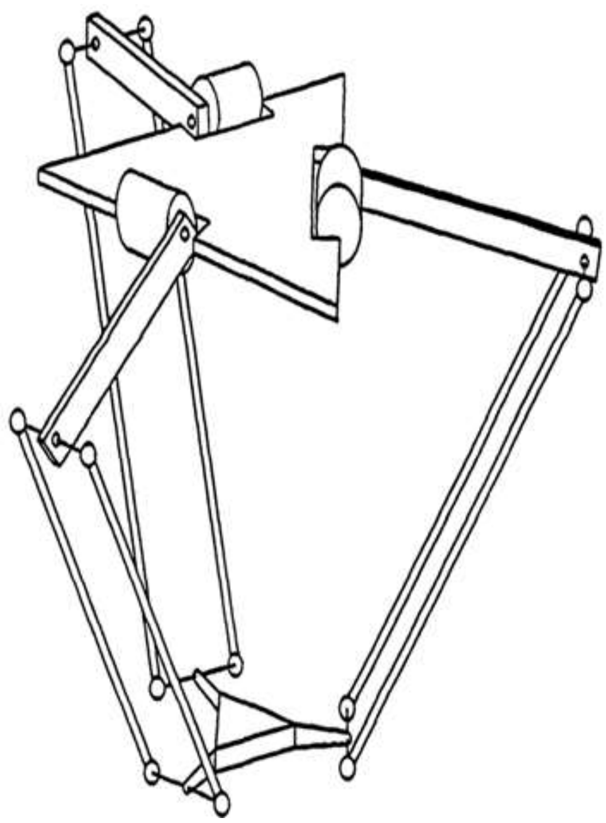

Figure 1 Delta parallel robot proposed by Clavel
Source: Clavel, 1991

The organization of the elements that make up the delta-type robot, allow the execution of tasks in which the performance of the serial robots would be limited.

However, on the contrary, its workspace is usually limited (Bellakehal, Andreff, Mezouar, & Tadjine, 2011). For its part, the arrangement of the actuators on the base and the use of low-weight links, allow the mobile platform to reach high accelerations (Staicu & Carp-Ciocardia, 2003), making the delta robot the ideal elementpick and place tasks of light objects, in consumer goods, food and electronics industries (Pedraza, Cárdenas, Rodríguez, & Yime, 2015).

Thus, the geometric parameters of the parallel delta robot, shown in Figure 2, are: the length of the actuated link (L_A), the length of the driven link (L_B), the radius of the fixed platform or base (R), the radius of the mobile platform or end effector (r), as well as the angles of the radii of the fixed platform q_i (i = 1, 2, 3), which affect the active and passive joint angles that determine the configuration of each limb (Laribi, Romdhane, & Zeghloul, 2007) (Sánchez-Alonso, Castillo-Castañeda, González-Barbosa, & Balmaceda-Santamaría, 2015).

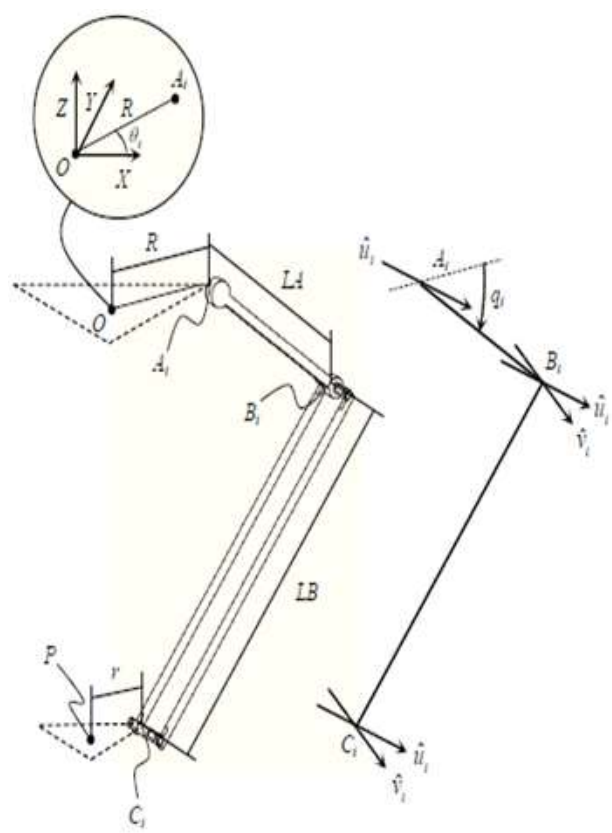

Figure 2 Geometric parameters of Delta parallel robot
Source: Sánchez-Alonso, Castillo-Castañeda, González-Barbosa, & Balmaceda-Santamaría, 2015

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Description of the prototype used

The prototype of a parallel robot in delta configuration implemented, consists of three limbs in a closed mechanical chain configuration. Such chains are joined at their upper end by means of the fixed platform, which contains the motors that provide the movement for each one.

In its lower portion, the junction of the extremities is defined by the mobile platform, smaller than the previous one, and which supports the end effector, a pair of pliers that will hold the pieces. It should be noted that the design used for the development of the prototype is for public use, under a Creative Commons license (Franciscone, 2016).

The fixed platform is made up of three folds screwed together, with an upper hexagonal finish, which support the motors used. Both the pleats and the finish were manufactured using 3D printing.

In turn, the hexagonal element allows the insertion of three PVC half inch diameter plastic pipes diameter, to provide support to the physical structure of the robot itself from the union, at its other end, with directly coupled vertical supports on the mounting surface.

Each of the robot's limbs is made up of two links (Figure 3). The actuated link, also made by 3D printing, is coupled at one of its ends to the shaft of the respective motor, by means of screws. At its opposite end, such arm is attached to the driven link by means of copper joints, also screwed; which provide freedom for the axial and semi-torsional positioning of one element with respect to the other.

The driven link was manufactured from stainless steel threaded rod. The mobile platform, also printed, is attached to the opposite end of the driven link, in the same way that both arms are joined.

Figure 3 Delta parallel robot prototype used
Source: Own elaboration, 2021

It is worth mentioning that the copper joints used both for the assembly of both links, which integrate each extremity, and for the union between the driven link and the mobile platform, provide freedom so that the latter can vary not only its position but also also its orientation, with a certain limit. In this way, each chain can adopt a different angle, established by the independent movement of each motor. Whereas, if such joints are not used, a movement of equal magnitude could only be promoted for each motor, given the impossibility of modifying the orientation of the mobile platform.

Selection of actuators

In order to ensure the movement of each extremity of the robot, in order to fulfill the proposed function, it was necessary to select actuators that could support not only the weight of their own mechanical structure, but also the load that the part will add by handle. On the other hand, it was also a priority to guarantee the execution of a simple process by varying the position that the same actuators can acquire during the request, by the user or the system that manages the robot, of some specific joint movement; or, of the location of an assigned point, given certain coordinates in a Cartesian reference space.

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Thus, both the motors used to transmit movement to each of the robot's chains, as well as to drive the gripper used, are servomotors. Such type of electric motor provides an angular movement in integer values, which vary in a range between 0 and 180 °; In addition, they can be controlled by pulse width modulation (PWM). Usually, the operating frequency of the servomotors is 50 Hz, which implies an activation time or presence of an electrical signal of 0.5 ms to reach the 0 ° position and 2.5 ms to achieve 180 °; this during each cycle of the supplied control signal.

The servomotor used for the movement of each limb of the implemented parallel delta robot is of the Tower Pro brand, model MG995, high speed, shown in Figure 4. This actuator has a load capacity of 15 kilograms force per centimeter and a mechanical transmission made up of steel gears. Other operating specifications of this servomotor are presented in table 1.

Figure 4 Tower Pro MG995 servomotor
Source: https://www.alldatasheet.com, 2021

Characteristic	Specification
Input voltage	3.5 to 8.4 V (Recommended 5 V)
Dimensions	40 x 20 x 36.5 mm
Weight	48 to 55 gr
Operating speed (4.8V no load)	0.17 seconds / 60 degrees
Operating speed (6.0V no load)	0.13 seconds / 60 degrees
Stopping torque (4.8V no load)	13 kg / cm
Stopping torque (6.0V no load)	15 kg / cm
Operating temperature	-30 a 60°C

Table 1 Tower Pro MG995 servomotor technical data
Source: https://www.alldatasheet.com, 2021

It is worth mentioning that a Tower Pro brand servomotor is also used to drive the gripper, only in this case it corresponds to the MG90S model; same that is visualized in Figure 5. Unlike the previous servomotor, this one has a load capacity of up to 2.2 kilograms force per centimeter and a mechanical transmission made up of plastic gears; among other characteristics specified in Table 2.

Figure 5 Tower Pro MG90S servomoto
Source: https://www.alldatasheet.com, 2021

Characteristic	Specification
Input voltage	4.8 to 6.0 V (Recommended 5 V)
Dimensions	22.5 x 12 x 35.5 mm
Weight	13.4 gr
Operating speed (4.8V no load)	0.1 sec / 60 degrees
Operating speed (6.0V no load)	0.08 sec / 60 degrees
Stopping torque (4.8V no load)	1.8 kg / cm
Stopping torque (6.0V no load)	2.2 kg / cm
Operating temperature	-30 a 60°C

Table 2 Tower Pro MG995 servomotor technical data
Source: https://www.alldatasheet.com, 2021

Given the commercial variety of servomotors, the selection of the proposed elements was made from the material with which their transmission is manufactured. In this way, it was determined that for the execution of the movement of each limb of the robot, the transmission made of steel would provide greater durability, unlike its simile in plastic. Thus, even operating under the specification recommended by the manufacturer, the resistance of the steel transmission is considerably higher than the corresponding one made of plastic, whose teeth tend to present fatigue and premature wear in load applications.

On the other hand, for the gripper, it was decided to use a lower capacity servomotor than those that mobilize the robot's extremities. This decision is based on the fact that the actuator, arranged in the end effector, does not directly support the weight of the transported part, but only opens or closes the pair of pliers to hold it; ensuring such condition during its transfer between the designated points. Therefore, the weight of the piece is supported by the aforementioned servomotors, this being part of the set that is attached in its lower portion to each arm of the robot.

Analysis of geometric parameters

The geometric parameters of the parallel robot in delta configuration prescribe particular characteristics that allow the physical differentiation of its mechanical structure with respect to other existing arrangements. Thus, for the establishment of the geometric parameters of the robot used, it was initially required to identify each of the main mechanical components that constitute it, as well as to establish the associated function within the robot mechanism, as a whole. Such elements are shown in Figure 6 and their respective characteristics are shown below:

1. *Fixed platform or base.* Provides support to the robot actuators and an equal arrangement of 120 ° to each other, with respect to the center of the robot. Each actuator will allow the direct conduction of the rotational movement generated, towards the first link of the respective limb, as they are both joined, through the axis of the first.

2. *Actuated link.* This element transmits the movement generated by each actuator, towards the end effector of the robot, through its mechanical connection with a second link. Together, these two elements make up each limb of the robot.

3. *Driven link.* This implement is attached to the respective actuated link, by means of a type of universal joint, to transmit the movement directly affected by itself, and direct it to the end effector.

4. *Mobile platform or end effector.* It is the device that contains the tool to be used by the robot. Therefore, this element will have to acquire a specified position through the movement executed by each of the actuators used, which will be transmitted up to this point, through the respective joints at each extremity.

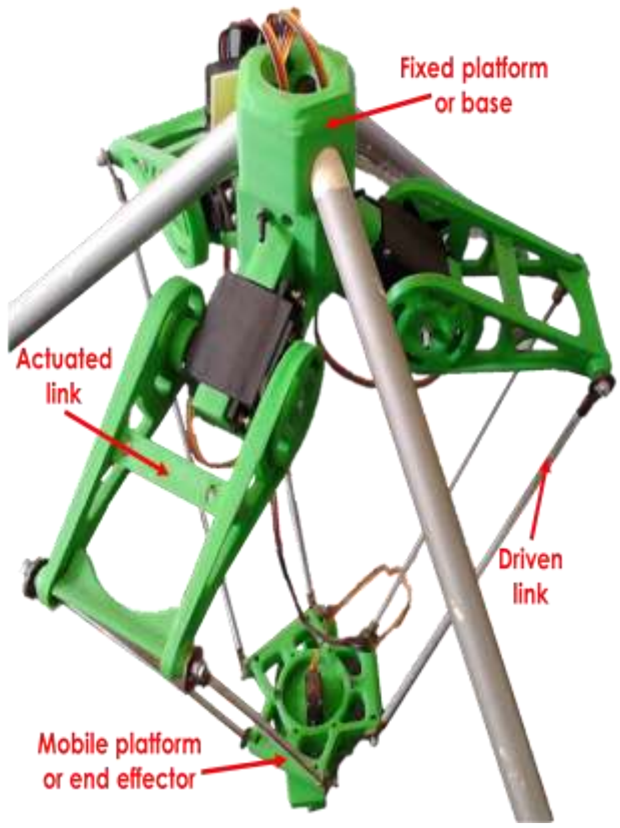

Figure 6 Mechanical elements of the parallel robot in delta configuration used
Source: Own Elaboration, 2021

Thus, from the identification of each of the elements described, it was possible to establish the value associated with the geometric parameters of the parallel robot in delta configuration used, and concentrate such information in Table 3.

Geometric parameter	Specification
Base radius (R)	7.5 cm
End effector radius (r)	4.5 cm
Actuated link length (L_A)	9.5 cm
Driven Link Length (L_B)	32 cm

Table 3 Definition of geometric parameters of the robot used
Source: Own Elaboration, 2021

Controller programming

A controller determines the energy required for the execution of a specified task, by the user, on a given system. Therefore, for the present study, it was necessary to select a device capable of adequately managing the energy that would be required by each robot servomotor, while ensuring the correct positioning of its shaft, as required. The function of the controller used is set out in the joint control and data communication scheme in Figure 7; in which, given the designation of a positional value by the user, through a computer application, it is translated into the respective electrical signal and destined for the corresponding actuator.

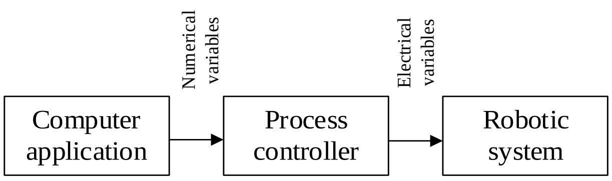

Figure 7 Relationship between application, controller and robot
Source: Own Elaboration, 2021

Thus, given the need to relate the numerical values emitted from the computer with the electrical signals that would directly and independently manipulate each limb of the implemented robot, the use of a programmable controller was considered that would allow transcription between both representations, in a simple, agile and reliable way. Therefore, after the validation of the characteristics provided by various control devices, it was decided to incorporate the Arduino UNO electronic board, shown in Figure 8 and whose specifications are shown in Table 4, as the controller of the delta robot available.

Figure 8 Arduino UNO board
Source: https://arduino.cl, 2021

Characteristic	Specification
Microcontroller	ATmega328
Supply voltage (recommended)	7 a 12 V
Supply voltage (limit)	6 a 20 V
Digital input / output pins	14
PWM output pins	6
Analog input pins	6
Current demanded by digital terminal	40 mA
Flash memory	32 kb
SRAM	2 kb
EEPROM	1kb
Clock frequency	16 MHz

Table 4 Arduino UNO board technical data
Source: https://arduino.cl, 2021

For its part, for the development of the algorithm in charge of managing each limb of the robot used, a proposal was made of an operation sequence triggered by the communication between the respective cybernetic and physical systems. In this way, the control instructions were exchanged from the computer to the robot or, by default, the feedback of the values acquired from each joint system and their presentation in the computer application used. Such functions, in the proposed order of execution, can be seen in the flow diagram of Figure 9; while a more detailed description of the interaction between the computer, the process controller and the robot is presented below.

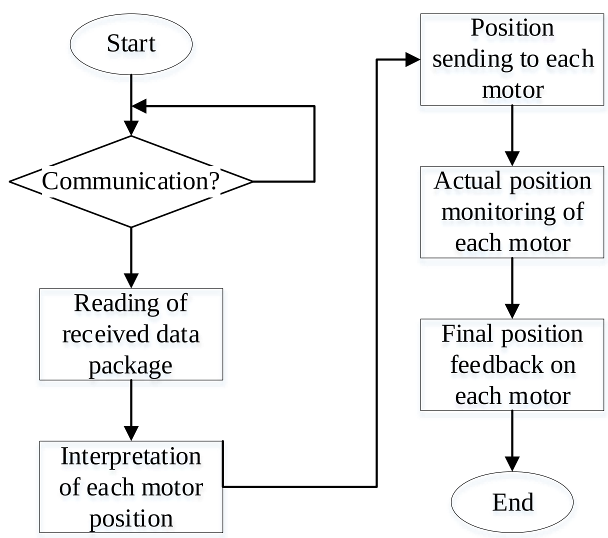

Figure 9 Algorithm for the process controller
Source: Own Elaboration, 2021

1. Through serial communication via USB, the respective data is transmitted to the movement to be executed by each of the servomotors integrated to the robot, according to the values emitted from the computer to the Arduino board used as the implement controller.

2. The controller receives the data packet, interprets it and separates it, and then effectively allocates it to the corresponding actuator.

3. After a specified period of time has elapsed, the controller monitors the actual position adopted by each servomotor under management.

4. Via serial communication, the controller feeds back the data that allow the user to know the position of each robot actuator, during the execution of a movement and at the end of such action.

After finishing the edition of the respective programming code, it was downloaded into the microcontroller of the Arduino board used, through the COM port to which it was connected. Subsequently, it was needed to validate the effectiveness of such code, once applied to the motion control of each limb of the implemented robot.

Robot operation results

By enabling the Monitor Serial utility, integrated into the Arduino development software, it was possible to interact with the electronic system that executes the manipulation of the robot used. Thus, through the tool described, it is possible to manage communication, through a specific USB port on the computer, to another device that supports the serial standard, in this case the Arduino board used, both for reading and for write data to it.

To verify the adequate performance of the algorithm programmed in the controller board, the three servomotors that enable each robot arm were connected to it. However, given the need to handle a variable voltage, to ensure the operation of each actuator, the use of PWM outputs from the board itself was established, which were designated in the respective code. Thus, starting from the sending of a data packet, from the computer, with the angular position for each servomotor, the board manages on these the value requested by the user, by means of the serial monitor; at the same time that it emits the positional value reached by each actuator.

Before proceeding with the transfer of data to the servomotors, it was necessary to perform the physical calibration of the zero joint position, relative to each of these. Such position is defined by the fully horizontal alignment of the actuated link, by assigning a zero value to the respective joint. Figure 10 shows the arrangement of the actuated links, by assigning a zero joint value to the three joints of the robot used. In this way, a coherent relationship is established between the value proposed by the user towards each joint of the robot and the real position that both the servomotor and the respective actuated link must adopt.

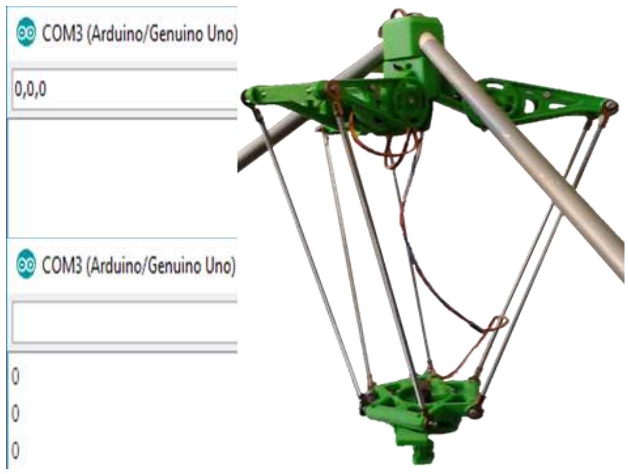

Figure 10 Zero position at the robot joints
Source: Own Elaboration, 2021

In the previous Figure, it can be seen that by assigning the same value to the three joints of the robot, the movement made by the end effector is described on a central vertical line, with respect to the fixed platform, establishing the specific height as a function of the value proposed. However, given the nature of the joint variables qi of the delta-type parallel robot, as the value assigned is higher, the end effector will tend to go down, or by default, it will go up. Therefore, it was essential to impose both the maximum and minimum value that each joint could adopt, without the mechanical structure itself adopting a seizure condition.

Likewise, since it was necessary to adopt both positive and negative joint values, to increase the range of positions to be reached by the end effector of the robot, the freedom of rotation of the servomotor was modified, from 0 ° to 180 °, to values between -90 ° and 90 °.

In this way, the description of joint values, required by the user, was enabled, without their polarity with respect to the horizontal affecting the process. Figure 11 shows the assignment and adoption of three different joint values, one for each limb, thereby restricting the specific location of the mobile platform, outside of the previously analyzed vertical arrangement, thereby increasing the space of robot task.

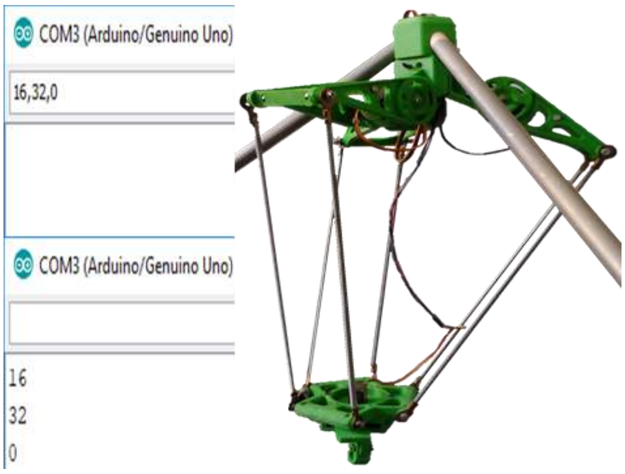

Figure 11 Emission of different joint values to the robot
Source: Own Elaboration, 2021

Conclusions

The integration of a test prototype from the use of a parallel robot in delta configuration, implied a precise analysis of the respective mechanical structure and the transmission of the movement provided by each actuator, through the pertinent limb, so that the effector final was set in a specific location. Although the Cartesian position of the point reached is not yet reported, the proper operation of each servomotor is guaranteed, based on the joint value entered by the user, from the computer. A detailed study to determine the specific location of the end effector may imply the continuity of the present work.

The analysis of two ways to influence movement towards the extremities of the robot used is highlighted: the assignment of the same joint value to its actuators and the sending of different values to each of them. The adequate performance of the robot is reported, by fully describing the behavior requested by the user, during the execution of the tests for both cases.

Likewise, both the calibration carried out on the operation of the actuators, as well as the interpretation that the programming of the controller exerted on the designated values, to emit the respective electrical signal to each actuator, as appropriate, were essential.

The use of the Arduino board for the implementation of the exposed prototype is exhibited, given its easy acquisition and low cost; highly valued qualities for its replacement, when causing a mishap that damages it. The performance of this board is acceptable and comparable to that offered by specialized and higher-cost controllers; in addition to being feasible its application in didactic projects. Emphasis is placed on simplicity to communicate the board used with a computer, program it and connect it to peripherals that are managed by the same.

References

Altuzarra, O., Şandru, B., Pinto, C., & Petuya, V. (2011). A symmetric parallel Schönflies-motion manipulator for pick-and-place operations. *Robotica*, 853-862.

Avizzano, C. A., Filippeschi, A., Villegas, J. M., & Ruffaldi, E. (2015). An optimal geometric model for Clavels delta robot. *2015 IEEE European Modelling Symposium*, 232-237.

Bellakehal, S., Andreff, N., Mezouar, Y., & Tadjine, M. (2011). Vision/force control of parallel robots. *Mechanism and Machine Theory*, 1376-1395.

Bilyea, A., Seth, N., Nesathurai, S., & Abdullah, H. A. (2017). Robotic assistants in personal care: A scoping review. *Medical Engineering & Physics*, 1-6.

Birglen, L., & Schlicht, T. (2018). A statistical review of industrial robotic grippers. *Robotics and Computer-Integrated Manufacturing*, 88-97.

Borchert, G., Battistelli, M., Runge, G., & Raatz, A. (2015). Analysis of the mass distribution of a functionally extended delta robot. *Robotics and Computer-Integrated Manufacturing*, 111-120.

ISSN 2414-4924

Brinker, J., Funk, N., Ingenlath, P., Takeda, Y., & Corves, B. (2017). Comparative study of serial parallel delta robots with full orientation capabilities. *IEEE Robotics and Automation Letters*, 920-926.

Clavel, R. (1991). *Conception d'un robot parallèle rapide à 4 degrés de liberté (Tesis Doctoral).* Lausanne: Ecole Polytechnique Federale de Lausanne.

Fong, S., Deb, S., & Chaudhary, A. (2015). A review of metaheuristics in robotics. *Computers & Electrical Engineering*, 278-291.

Franciscone, C. (10 de Enero de 2016). *EEZYbotDELTA*. Obtenido de MakerBot Thingiverse: https://www.thingiverse.com/thing:1249297

Gasparetto, A., & Scalera, L. (2019). From the unimate to the delta robot: The early decades of industrial robotics. *Explorations in the History and Heritage of Machines and Mechanisms*, 284-295.

Huang, Y., Chiba, R., Arai, T., Ueyama, T., & Ota, J. (2015). Robust multi-robot coordination in pick-and-place tasks based on part-dispatching rules. *Robotics and Autonomous Systems*, 70-83.

Laribi, M. A., Romdhane, L., & Zeghloul, S. (2007). Analysis and dimensional synthesis of the delta robot for a prescribed workspace. *Mechanism and Machine Theory*, 859-870.

Mann, M. P., Damti, L., Tirosh, G., & Zarrouk, D. (2018). Minimally actuated serial robot. *Robotica*, 408-426.

Pedraza, M. F., Cárdenas, P. F., Rodríguez, F. J., & Yime, E. (2015). Aproximación al diseño de robots paralelos, análisis de caso del robot delta. *Memorias IV Congreso Internacional de Ingeniería Mecatrónica y Automatización*, 216-224.

Sánchez-Alonso, R. E., Castillo-Castañeda, E., González-Barbosa, J. J., & Balmaceda-Santamaría, A. L. (2015). Análisis del desempeño cinetostático de un robot paralelo tipo delta reconfigurable. *Ingeniería Investigación y Tecnología*, 213-224.

Staicu, S., & Carp-Ciocardia, D.-C. (2003). Dynamic analysis of Clavel's delta parallel. *2003 IEEE International Conference on Robotics & Automation*, 4116-4121.

Szűcs, L., & Galambos, P. (2020). A workspace mapping software tool for generalized triangle parallel robots. *2020 IEEE 14th International Symposium on Applied Computational Intelligence and Informatics (SACI)*, 235-240.

Valente, A. (2016). Reconfigurable industrial robots: A stochastic programming approach for designing and assembling robotic arms. *Robotics and Computer-Integrated Manufacturing*, 115-126.

Wu, G., Bai, S., & Hjørnet, P. (2016). Architecture optimization of a parallel Schönflies-motion robot for pick-and-place applications in a predefined workspace. *Mechanism and Machine Theory*, 148-165.