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PROJECT AND DESIGN OF A 1-D PROBE POSITIONER

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Abstract. *The use of semi-automatic devices has grown mainly in areas that require precision and systematization of processes, due to safety and reliability of automated processes. This work aims to design and build a device to support and motion probes, called probe positioner. With proper device moment of inertia calculations and stepper motor torque, the theoretical part of the project was built, thus ensuring the device structure to be as close as possible to the idealized. Two aluminum plates were used to support and give structure to a system composed of a trapezoidal screw and two guides. From the center of a plate to the center of the other, the spindle is the main element. A radial bearing to support the load and the rotation of this element was used. The guides follow the same spindle orientation. Coupled to the other end of the spindle, a stepper motor generates the required rotation for the vertical displacement of a mobile device, which is called nut. As the spindle rotates, the nut which is attached to the two guides and seated in a spindle nut-screw system, has a limited rotation, generating only vertical displacement. The automation of this device was made using Arduino, which is responsible for systematizing the stepper motor rotation, allowing accurate positioning of the probe. The calculations of motor torque and moment of inertia of positioner indicated a normal operation of the device, as designed, which certainly will be very important and useful for the study and development of mechanical devices.*

Keywords: *positioner, probe, automation, time, Arduino.*

1. INTRODUCTION

The search for new devices that aim to reduce costs and increase productivity has been the main reason for the adoption of automated systems. According to Groover (2011), automation can be defined as "a technology by which a process or procedure is performed without the use of direct human assistance. It is implemented using an instruction program combined with a control system that performs these instructions ".

The use of sensors in several industrial processes has expanded the application of automation in this sector. This is explained by the fact that some conditions hamper the manual movement of the device in the environment that is being studied. A sensor is a transducer that converts a physical variable from the space in which it is inserted into a logic signal. The purpose of this conversion is to measure the stimulus and quantify it from numerical analysis.

In this way, the construction of a prototype of an automated system that allows movement on an axis corroborates in the accomplishment of measurements of specific parameters. It is possible, with the aid of instruction software, to process and read collected data to aid in a more detailed study of the information. The numerical control used in this research is a type of programmable automation, that is, the equipment is designed with the flexibility to allow the sequence of operations of the manufacturing process to be modified. In these systems, positioner control and accuracy are of great importance, as these aspects have a direct influence on the dimensional accuracy of the final product and on the productivity of the equipment (Lasmar, 2011). In this sense, the structural analysis of the system was performed by means of 3D modeling in AutoCAD for the development of the drive system, as well as specific calculations for the stepper motor torque and moment of inertia of the device.

The machining and assembly of the materials were carried out in such a way as to facilitate the smooth operation of the positioner, as well as to simplify the motor-Arduino integration in order to increase the speed with which the parameters are measured and to optimize the industrial process.

2. MATERIALS AND METHODS

The device presented here is simple to understand, and so are its basic theories. The positioner is nothing more than a force converter, having as the generating source the stepper motor and, at the end of the chain of transmission, the displacement of the probe.

Firstly, the stepper motor receives an electric current and, with proper programming, it turns its axis at a certain frequency. This axis is coupled to the spindle by a component of the device called Flexible Coupling and it transmits the rotational movement. This rotational movement generates a torsional tension in the spindle, making it rotate (Halliday, 2012). The nut, the keystone of the device, has an internal thread and is fitted to the spindle in a nut-screw system. The tendency of this part is to rotate along with the entire motor-coupling-spindle system, but this does not occur, since it is fixed to the lateral guides to the spindle by a component of the device which we call T-Plate. The angular momentum of the rotating system is transmitted to the nut, generating a driving force on it; with the interrupted rotation of this part and by obeying the preservation of the energy generated by the amount of angular momentum, the nut is forced to move vertically in the axial direction of the motor-coupling-spindle axis system.

With the control of the spindle rotation, provided by the automation of the stepper motor, one can easily position the nut at a certain height, with high precision. The probe is fixed to the T-Plate, and as it accompanies the movement of the nut, we conclude that the rotation of the spindle, in fact, positions the probe at the desired height. This is the main goal of the positioner.

In order to carry out the project successfully, some calculations were necessary to validate all this theoretical part and indicate the best specifications of the materials and parts to be purchased. The estimated weight of the positioner, its moment of inertia (to avoid, even if very little, an imbalance of the structure) and the necessary torque of the stepper motor were calculated; calculations which will be presented later.

The positioner is composed of 12 main elements (not counting fixing screws, nuts and washers). These are:

- Spindle: main element, responsible for transmitting driving force to the nut, generating its vertical movement.
- Guides: ensure the effectiveness of the theory behind the positioner, preventing the nut’s rotation, forcing it to move in the axial direction.
- Nut: mobile component responsible for moving the T-Plate, therefore, the probe, vertically.
- Base plates: provide the design architecture and ensure the balance of the device.
- Stepper Motor: generating source of the work to be carried out by the nut; is responsible for turning the spindle as much as desired.
- Flexible Coupling: a vital component for the transfer of forces between the motor and the spindle. This element ensures that the fit between the two shafts is not so rigid, which could lead to problems in the operation of the device by generating unnecessary stresses.
- T-Plate: it is responsible, as said before, for fixing the nut on the guides and preventing their rotation when the spindle rotates, which generates axial forces, resulting in the desired displacement.
- Arduino Board: microcontroller responsible for all the device automation.
- Rolling Bearing: responsible for holding the spindle and ensuring a free spin.
- Linear Bearings: responsible for ensuring smooth movement along the guides accompanying the displacement of the nut. The T-Plate is fixed to these bearings.
- Fasteners: elements that will fixate various components (e.g., guides on structural plates, T-Plate on linear bearings).
- Stepper motor stand: will sustain motor weight so as not to produce axial forces in the coupling.

2.1 Calculation of the estimated weight

The estimated weight of the device was the first factor to be calculated. It was not observed in other literatures the obedience of a weight standard of the positioners, nor the relation of the weight with the functionality of the device. Therefore, it was decided to choose the parts in order to minimize the final weight of the project, making the selection of materials lighter and equally effective. Thus, the estimated weight is the sum of the weights of each component of the device. The heaviest components are the base plates of the device, weighing about 625g each. Table 1 presents the average of three weight measurements of each component on a precision scale:

Table 1. Mean and total weights for each element.

Element	**Mean Weight (g)**	**Quantity**	**Total weight for each element (g)**
Spindle	300,58	1	300,58
Guide	308,54	2	617,08
Base plate	625,53	2	1251,06
Nut	17,54	1	17,54
Fastener 10mm	16,80	4	67,20
Fastener 20mm	48,03	2	96,06
Rolling bearing	54,76	1	54,76
Linear bearing	24,97	2	49,94
Stepper motor	550,35	1	550,35
Flexible coupling	15,59	1	15,59
T-Plate	46,02	1	46,02
Stepper motor stand	250	1	250

Thus, the estimated total weight of the device is approximately 3,316.18g. Adding 50g for bolts, nuts and washers, we have the fine weight equal to 3,366.18g or 3.366618kg.

2.2 Calculation of structural balance

In order to perform these calculations, we used the computational tool Working Model 2D version 9.0, a software made by the company Design Simulation Technologies. It was easy to manipulate and able to perform complex simulations. This is a paid software, but the supplier made available the free version for this study, after due explanations. This free version is valid for 8 days and is available at the company's website. For the calculation of the tipping of the device, it was supposed:

- All the components are homogeneous.
- The T-Plate to be at its highest possible position (450mm from the inferior base).
- The probe to be at the tip of the T-Plate.
- The total mass of the guides and spindle to be distributed along a single central axis, in the same position as the spindle.

The described considerations represent the situations when the stress caused by the weight of the probe to cause the structural imbalance is minimum, that is, the position in which there is more possibility of the device to fall over (Hibbeler, 2010). The design in the software was the lateral view of the device, since it is the only one that does not show symmetry, therefore, has risks of imbalance. As in this view the guides and the spindle are aligned, and, taking into account that these 3 elements interact in a similar way with the T-Plate (only when referring to structural balance) can be replaced by a single element which has the mass of the 3 components and equal orientation.

Therefore, identifying the maximum weight value of the probe in the specified situation will guarantee the structural balance of the whole project, regardless of the positioning of the probe-T- Plate system. Fig. 1 shows the simulation of the device in Working Model 2D version 9.0:

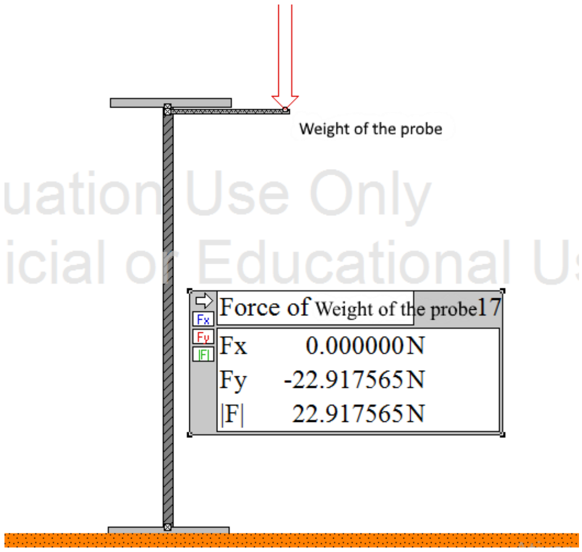

Figure 1. Drawing of the positioner in the software.

The program indicated a limit for the force of the probe weight of approximately 22.86 N; which implies that the probe must have a maximum of 2.33 kilograms in order to guarantee the balance of the structure.

The normally used probes are lightweight devices and do not exceed 500g, which is certainly not enough to tip the positioner. This indicator allows us to work with a good margin of safety, removing the possible problem of structural imbalance.

2.3 Calculation of the torque of the stepper motor

The necessary torque of the stepper motor is defined by the equation (1): (Silveira apud Norton, 2004)

$$Mt = \frac{P \cdot Dp}{2} \cdot \frac{(\mu \cdot \pi \cdot Dp + L)}{(\pi \cdot Dp - \mu \cdot L)} \qquad (1)$$

Where Mt is the torque [N.cm], P is the weight of the structure of the axis [N], Dp is the primitive diameter of the spindle [cm], μ is the coefficient of friction between the materials of the nut and the spindle, L is the step of the spindle [cm]. The values used in this calculation were: P = 9.81 N, Dp = 1.1 cm, μ = 0.12 and L = 0.2 cm. The P value was obtained by adding the spindle masses, the T-Plate, the linear bearings, the 20mm fasteners and the probes (a mean of the most common probes). As the sum of the masses approached 1kg and there are several types of probes, the value of 1kg was adopted for the mass of the structure, and the weight is defined by equation (2): (Halliday, 2012)

$$P = m \cdot g \qquad (2)$$

Where P is the weight [N], m is the mass [kg] and g is the acceleration of gravity [m/s^2]. The values used were: m = 1 kg and g = 9.81 m/s^2. Thus, we have that P = 9.81 N. Applying this result in the equation (1), we have that:

$$M\,t = \frac{9{,}81 \cdot 1{,}1}{2} \cdot \frac{(0{,}12 \cdot \pi \cdot 1{,}1 + 0{,}2)}{(1{,}1 \cdot \pi - 0{,}12 \cdot 0{,}2)}$$

This results in an approximate value of Mt = 0.966434 N.cm. Converting from N.cm to kgf.cm, knowing that 1 kgf.cm = 9.80665 N.cm, we obtain Mt = 0.09854884186 kgf.cm. As the chosen motor has an effective torque of 4.6 kgf.cm, it will be more than enough for the positioner. With this torque, the engine would be capable of erecting a probe with a mass of 46kg, approximately. Nonetheless, a probe of this magnitude would ruin the moment calculations of the device, which would certainly make the positioner tip over.

3. DIMENSIONING

As mentioned before, the consulted literature does not present a standard for the structural dimensioning of a positioner.

The size of the spindle and guides has been specified to cover as many applications as possible for future use of the device. As a free course of 45cm was determined for the probe, and the probe would not weigh more than 3kg, the diameters of these components were chosen for these situations. The spindle has a larger diameter because it is the main element and will be in charge of transmitting all the force that will result in the displacement of the probe.

The base plates were designed according to the length of the spindle and the guides, the respective diameters, and the moment calculation of the device. They have a thickness slightly larger than that of a sheet, since it is necessary to ensure that the structure of the project is firm.

The stepper motor was specified according to the calculated torque. However, considering the possibility of future applications and taking advantage of the situations at the time of the purchase, we selected a motor with greater torque, after all, it will meet the needs of the device and allow other applications, such as the movement of heavier probes, as long as it respects, of course, the weight limit established by the moment calculation.

The T-Plate was dimensioned by cutting a square plate of 18cm of side and 0.7cm of thickness. The cutting was performed with the aid of a saw.

All other components have been specified according to these 4 others, since they are only complements and agents responsible for connecting the main elements to each other.

4. AUTOMATION

All automation was performed on Arduino, as previously said, with the aid of a specific driver for stepper motors, the Easy Driver.

4.1 Arduino

Arduino is an open source development and prototyping platform designed to promote easy communication between user and hardware. It has several functions and can be used together with the most varied types of sensors, motors, servos, digital circuits and other applications. This microcontroller is programmed using a language very similar to C and the Arduino development environment. It is very accessible, and can be used even by those who do not know much about programming. Arduino can be run from any operating system.

With the aid of the Arduino development environment, it was implemented the code that controls the stability of the multirotor. The PWM signal that controls the motors and sensors will also be provided by the board. An important factor of Arduino is that it can be used with 3.3 V and 5.5 V outputs, which is extremely important because some components work on different voltage ranges.

The model used in the design is "Uno", its microcontroller is the ATMega328, it has 14 digital inputs/outputs (6 PWM), 6 analog inputs, 32Kb of flash memory, 2Kb of RAM and 16 MHz of "Clock Speed".

Figure 2. Arduino board.

4.2 Easy Driver

This driver was chosen due to its easy use and ability to support 4, 6 and 8-way step motors, as well as providing a secure connection with the Arduino, because it does not withstand direct contact with the stepper motor due to its larger voltage that would result in the burning of some Arduino ports. Based on this driver we can control the speed and torque used in the motor, thus facilitating programming. The module requires a source of 7 to 30V to power the motor, its current is adjustable between 150 to 750mA per way. With the control of these parameters it is possible to rotate the system Axis of the motor-Coupling-Spindle as much as we want; as the code allows us to move the probe by a minimum of 1mm. The direction of rotation defines whether the displacement of the nut-T-Plate-probe will be upwards or downwards.

4.3 Sketch of the automation

Finally, the integration between controllers was carried out correctly, which ensured the final result: the automated probe positioner in Arduino. Next, Fig. 3 shows the final sketch of the automation of this project, made using the software Fritzing.

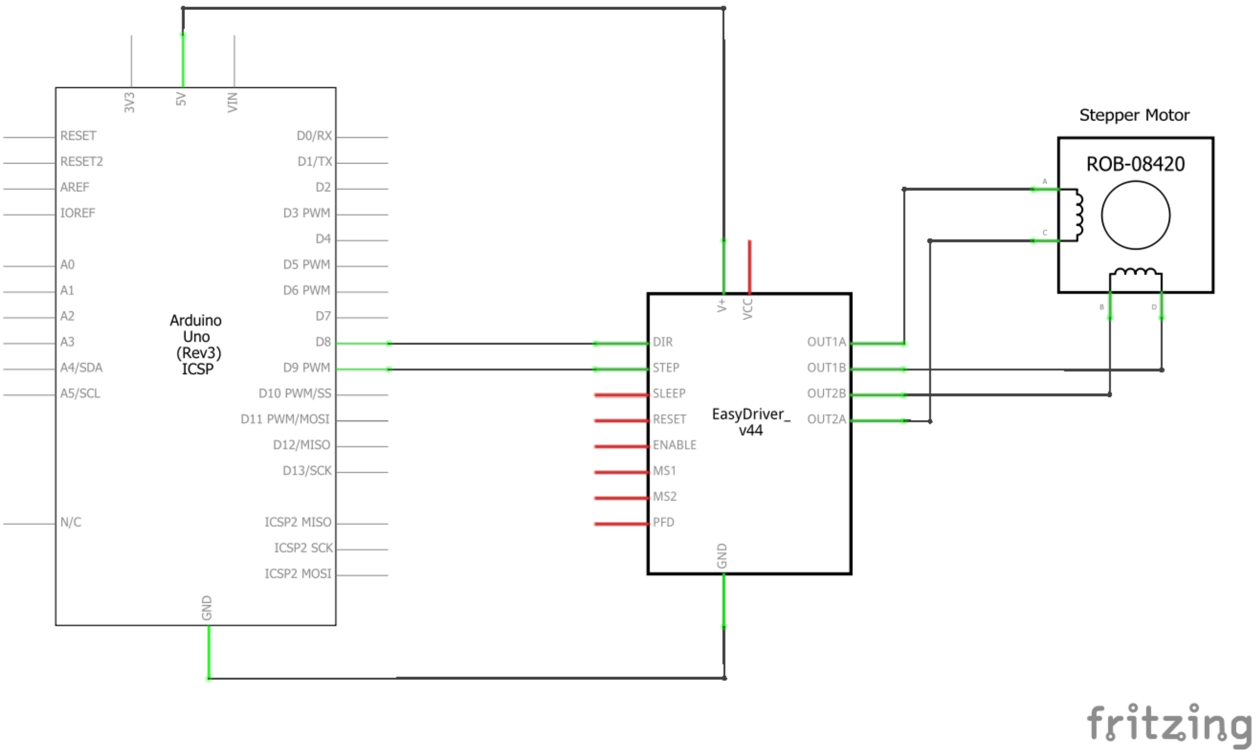

Figure 3. Sketchof the integration of the components.

5. RESULTS

As a result of the study of this positioner the final design obeyed what was estimated by the theoretical calculations and hypothesis. The project remained stable and steady, without tending to tip over to either side. The estimated weight was extremely accurate, deviating from the actual weight by a few grams. Finally, as expected, the motor torque was more than enough to generate the necessary displacement, presenting no difficulty at all. From the analysis of the calculations and the dimensioning, it was possible to obtain the necessary information to stipulate the complete specification of the components to be purchased, which is presented in the topic below.

5.1 Specifications of the components

Because it is a mobile device, the need for low weight and equal efficiency appears as an important factor. It was concluded that most of the elements had to be made of aluminum (with some exceptions that will be mentioned below), because it is a light and sufficiently resistant metal (Callister, 2008). Tables 2 and 3 show the components and their specifications:

Table 2. Specifications of circular components.

Component	**Market Name**	**Diameter (mm)**	**Length (mm)**	**Step (mm)**	**Material**
Spindle	Trapezoidal Spindle	11	500	2	SAE 1045 Steel
Guide	Eixo CNC	10	500	X	Retificated H7 Steel
Nut	Castanha com Flange	11	29	2	Polyamide
Stepper motor	Stepper motor	6.35	50x57	X	Aluminum
Flexible coupling	Flexible coupling	10x6.35	25	X	Aluminum
Rolling bearing	Bearing for spindle pillow block linear	10	60	X	Aluminum
Linear bearing	Linear bearing Lm10uu	10	30	X	Aluminum
Fastener	Support parts for linear axle CNC	10	43	X	Aluminum
Fastener	Support parts for linear axle CNC	20	60	X	Aluminum

Table 3. Specification of rectangular components.

Component	**Market Name**	**Length (mm)**	**Width (mm)**	**Thickness (mm)**	**Material**
Base plates	Chapa	200	130	10	Aluminum
T-Plate	X	180/50*	50/130*	7	Aluminum
Stepper Motor Stand	Stepper Motor Stand U Type	96	83	X	SAE 1020 Steel

*The dimensions of the T-Plate will be further specified in the following drawings.

Note: The spindle has the tips machined to the 10mm diameter, ensuring fit in the coupling and the bearing. On the side of the coupling, the spindle has 4cm machined, while on the bearing side, only 1cm.

5.2 Drawings

With the aid of AutoCAD Student software, the drawings required for a first view of the positioner were made. Next, the T-Plate is shown in top and isometric view, in order to guarantee the understanding of its dimensioning.

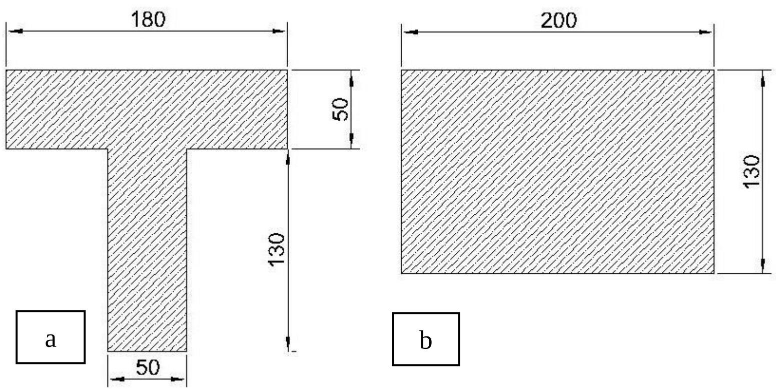

Figure 4. Dimensions of the T-Plate (a) and base plates (b) in superior view.

Finally, the design of the positioner is shown below:

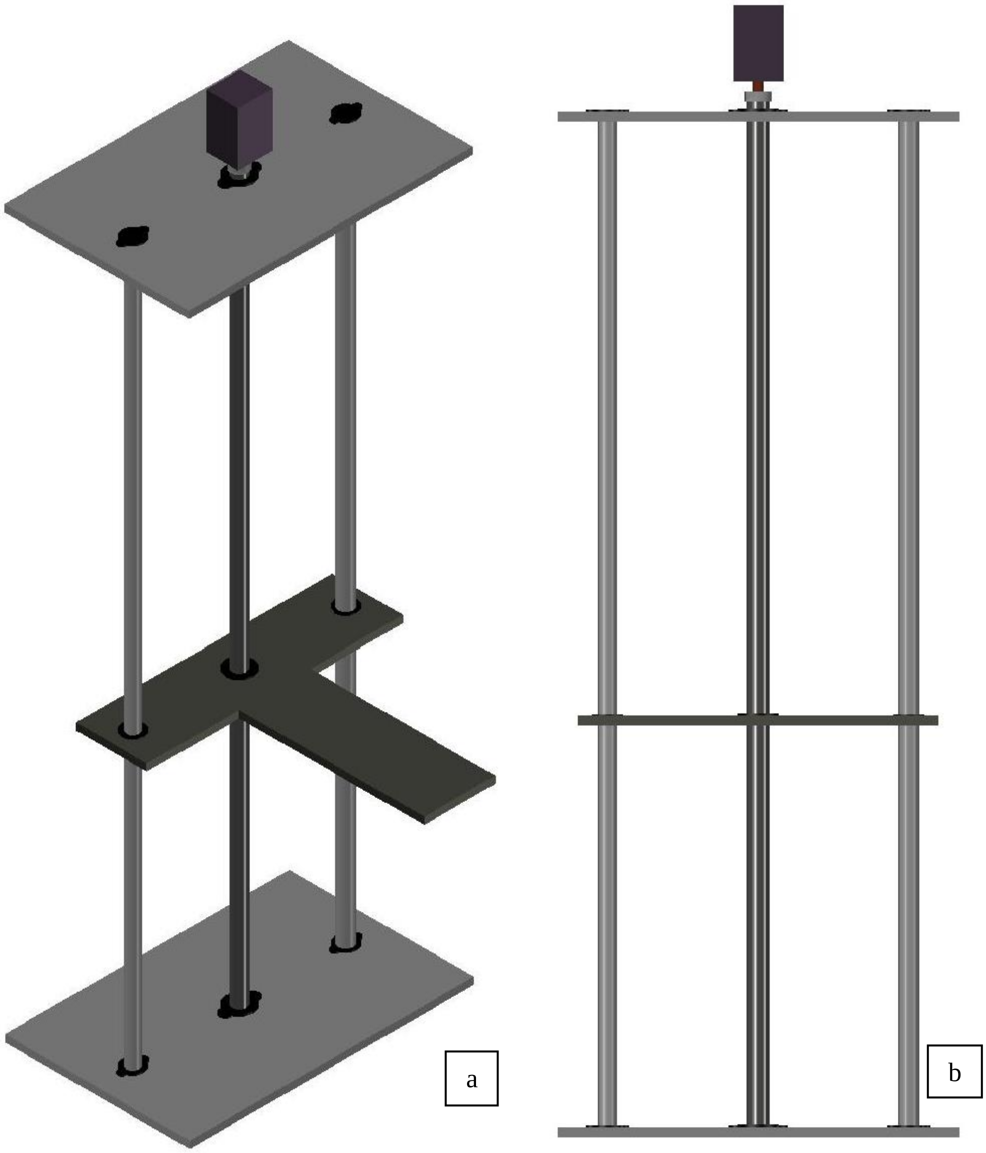

Figure 5. Probe positioner in isometric (a) and frontal (b) views.

5.3 Probe positioner

The expected end result is the mentioned device. In this way, the following is the Probe Positioner developed and presented in this scientific work.

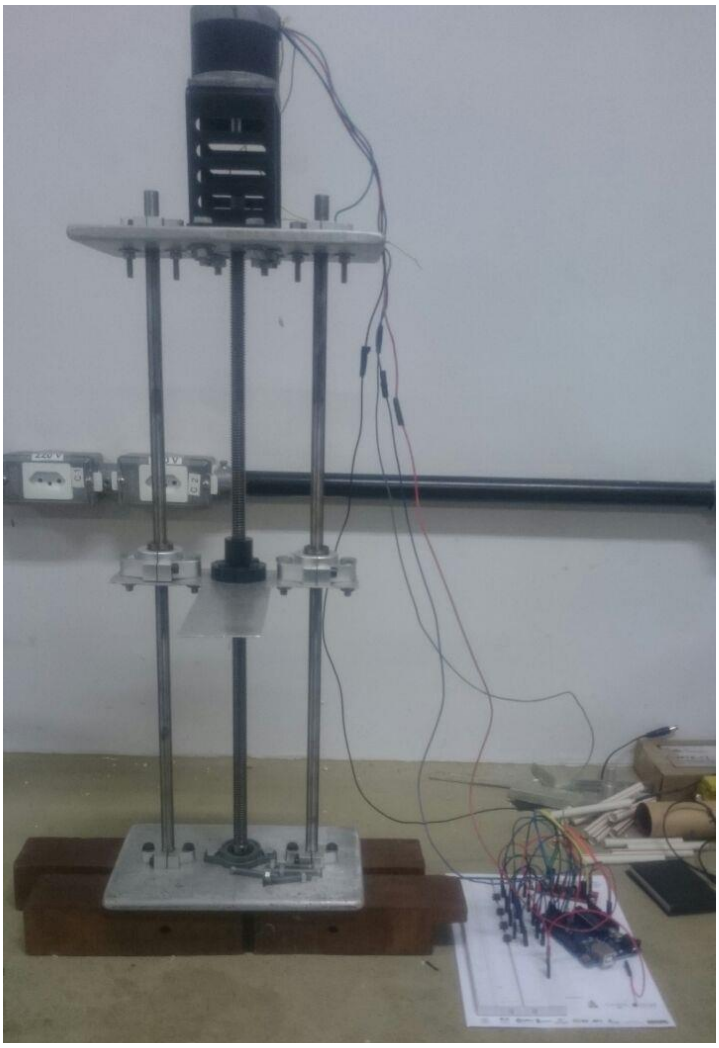

Figure 6. Finalized probe positioner.

6. CONCLUSION

The results of this work were in agreement with the objectives outlined. The values obtained in the equilibrium, motor torque and estimated weight calculations were satisfactory, which resulted in the normal operation of the actual device. It did not present structural flaws, miscalculations or erroneous theoretical grounds. Finally, the automation in Arduino was equally effective, being the selected driver apt for the accomplishment of the objective. The stepper motor responded correctly to the signals of the board, performing the requested task in the desired way and in real time. All these previously predicted results were achieved, which allowed a final result as idealized. The device will certainly be of great importance and useful for the study and development of new mechanical technologies.

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