DESIGN, DEVELOPMENT, AND CREATION OF A TEST BENCH AND USER INTERFACE FOR NANOSATELLITES

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ABSTRACT

This work introduces a single-axis rotating test bench, also known as a "Single-Axis Rate Table," commonly utilized in the aerospace and engineering industries to subject objects, such as nanosatellites, to precise and controlled rotational movements. This platform is employed for conducting simulation tests that assess how the system will respond to specific conditions in space. These tests are crucial to ensure that space equipment and systems function correctly and can withstand the stresses and forces they will encounter in actual missions.

At the core of this platform is the Stepper Motor (PaP), chosen for its suitability in high-precision applications, allowing the division of rotation into discrete steps. This feature facilitates precise control of angular position, a necessity for the test table. The motor necessitates integration with a specific Stepper Motor driver, such as the A4988 model. An Arduino Nano will serve as the microcontroller due to its compact design and straightforward implementation. The program will be controlled by a Graphical User Interface (GUI) designed and developed in Visual Studio.

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INTRODUCTION

It is a fact that Paraguay has taken its initial steps into the aerospace industry, demonstrated by the successful launch of its first nanosatellite, 'GuaraniSat-1,' in February 2021. This significant achievement resulted from the collaborative efforts of Paraguayan engineers and members of the Birds-4 project [1] at the Kyutech Institute of Technology in Kyushu, Japan, where simulations and necessary tests were conducted for project approval. To further advance the development of space systems and satellite technology in Paraguay, it is essential to transfer the knowledge and technology used for such tests and simulations to Paraguayan territory.

This work presents a single-axis rotating test bench designed for positioning and constant rotation tests on nanosatellites, with a special focus on 'GuaraniSat-2.' The system comprises a NEMA17 stepper motor, an Arduino Nano, and other electronic components, along with rigid ball bearings, 3D-printed parts, and wood. This platform allows for the simulation of precise rotational movements to assess the response of the nanosatellite and its components, contributing to the development and quality of satellite missions in Paraguay.

The Attitude Determination and Control System are among the subsystems that benefit significantly, utilizing this platform to verify the proper functioning of sensors such as gyroscopes, accelerometers, and magnetometers by integrating them with a Helmholtz cage. Additionally, the Telecommunications System can leverage the precise positioning of the test bench to conduct Antenna Radiation Pattern Tests, as well as ensure that deployable "Patch" antennas do not undergo premature deployment due to the stresses and forces caused by constant rotation in space.

METHODOLOGY

Specifications

Firstly, we must define the dimensions and the load to which our test bench will be subjected. For a standard 3-unit (3U) nanosatellite, the dimensions are 10 cm x 10 cm x 34 cm, with an estimated weight ranging from 3.0 to 3.9 kg [2].

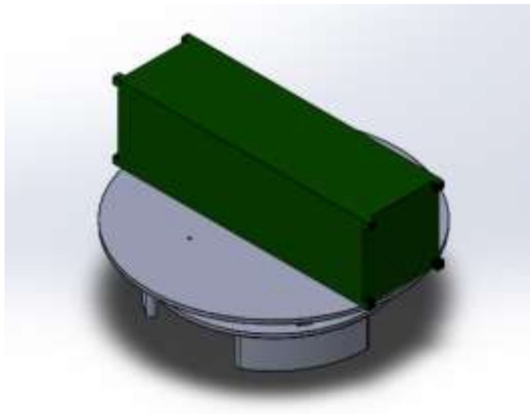


Figure 1. 3U CubeSat on the Test Bench.

The selected stepper motor for this application is the NEMA 17HS2408-s. This motor performs 200 steps per revolution (1.8º per step) and is capable of exerting a torque of 1200 g/cm. Both the dimensions and detailed specifications can be found in the manufacturer's datasheet in the folder "Single-Axis Rate Table → Annexes → Nema17 – datasheet.pdf," shared in the following GitHub link along with the rest of the project: https://github.com/mcristaldo17/Single-Axis-Rate-Table. It is also necessary to complement the motor with a Stepper Motor Driver, which supplies the current when instructed by the microcontroller. The driver used in this project is the A4988 model, paired with the Arduino microcontroller. Below is a very similar example of the circuit schematic using an Arduino UNO:

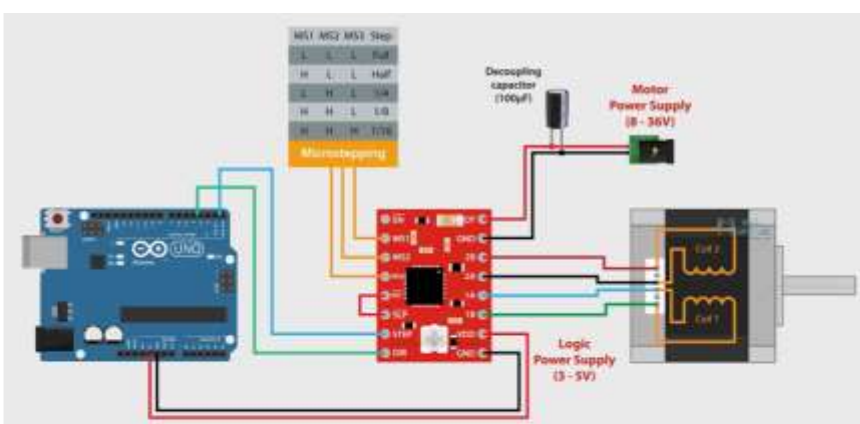


Figure 2. Circuit Example with an Arduino UNO and A4988 Driver. **Source:** HowToMechatronics (YouTube).

Due to certain manufacturing differences from the manufacturer, the stepper motor in possession has coil connections arranged alternately, forming one coil between the first and third cables and the other between the second and fourth cables. This is detailed in the following image with the colors Blue (1st cable), Green (2nd cable), Yellow (3rd cable), Red (4th cable). Incorrect connections may prevent the motor from rotating, causing it to vibrate when supplied with current.

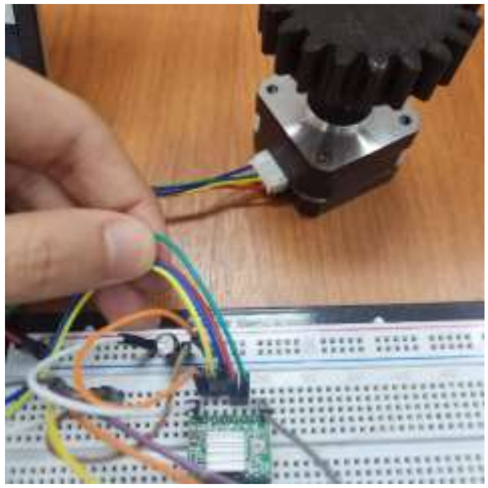
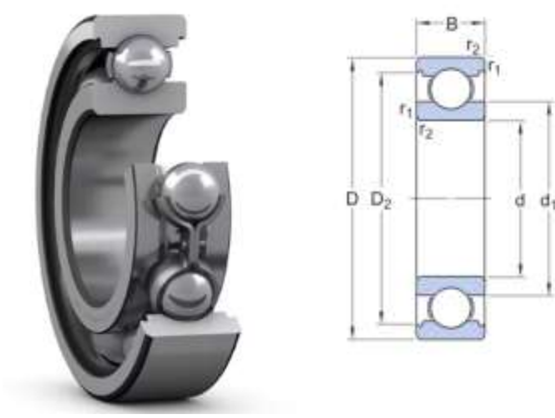


Figure 3. Coil 1: Yellow and Blue cables. Coil 2: Red and Green cables.

To achieve a reduction in friction on the platform, rigid ball bearings, or "Ball Bearings," are incorporated into the structure. These bearings enable smooth and efficient rotation by providing support with minimal resistance to movement, thereby helping to maintain platform stability. These mechanisms were recycled from the SpaceLab laboratory and donated by project collaborators. They come in different dimensions, with two of them being model 608 with an outer diameter of 22mm and three of them being model 608 with an outer diameter of 24mm. Both models have an internal diameter of 8mm, allowing them to be integrated with M8 screws, nuts, and custom 3D-printed parts.



Dimensiones

d	8 mm	Diámetro interno
D	22 mm	Diámetro exterior
B	7 mm	Ancho
d_1	≈ 12.15 mm	Diámetro del resalte
D_2	≈ 19.2 mm	Diámetro del rebaje
$r_{1,2}$	min. 0.3 mm	Dimensión del chaflán

Figure 4. Dimensions of the 608 Ball Bearing.

Software

The code provided in the folder "Single-Axis Rate Table → Rate Table Codes → StepperControl_ArduinoCode → StepperControl_ArduinoCode.ino," created in the Arduino IDE, must be compiled and loaded onto the microcontroller to be used. It is responsible for receiving commands through the Graphical User Interface and communicates serially with the COM port to which it must remain connected during operation.

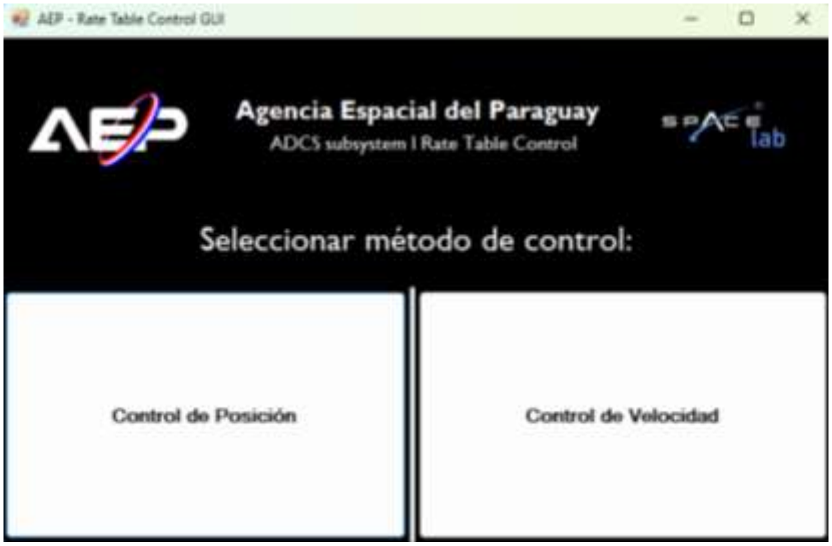


Figure 5. Graphical User Interface, Home. (Spanish Version)

Once the program is started, the user should select the control method according to their needs. Afterward, the communication with the COM port where the Arduino is connected must be configured. The available port options can be viewed at the time the program was started. If the Arduino is connected after running the program, it is necessary to click the "Update" button to be able to select it. The default BaudRate will be "115200," with the option to change it to "9600" if also adjusted in the Arduino code. If the serial communication connection is successful, text boxes for sending commands will be enabled.

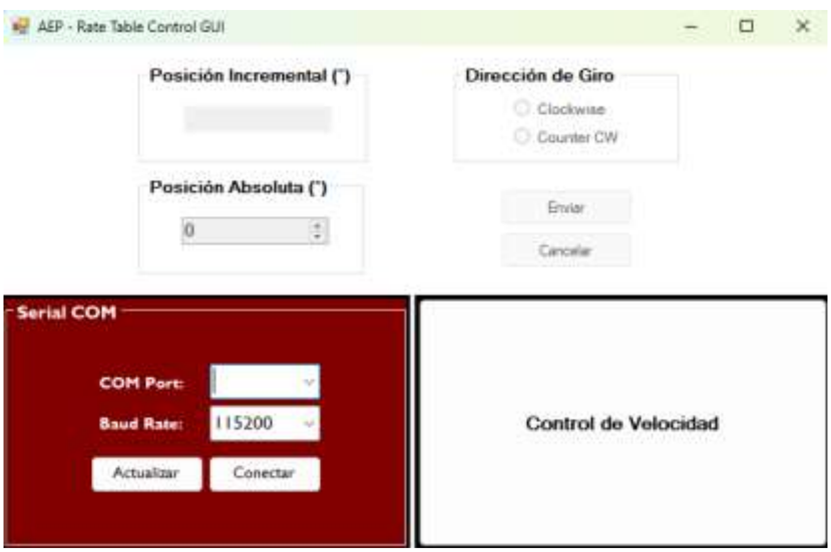


Figure 6. GUI, Position Control Menu. (Spanish Version)

In the position control, we will have the option for incremental positional rotations relative to the last location, and another option for absolute positional rotation relative to the origin (set as 0 in the position where the program was executed and the Arduino was powered). With this option, the object to be tested can be positioned in the desired orientation, rotating at a speed predetermined by the microcontroller program.

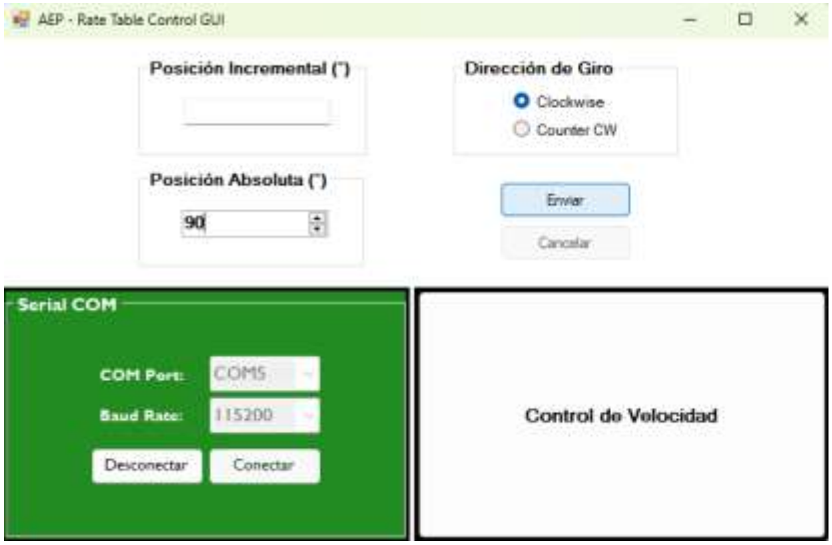


Figure 7. Position Control, successfully connected.

On the other hand, if you desire continuous rotation for a certain period and at a specific speed, you should select the "Speed Control" option, which is available at all times on the right-hand button.

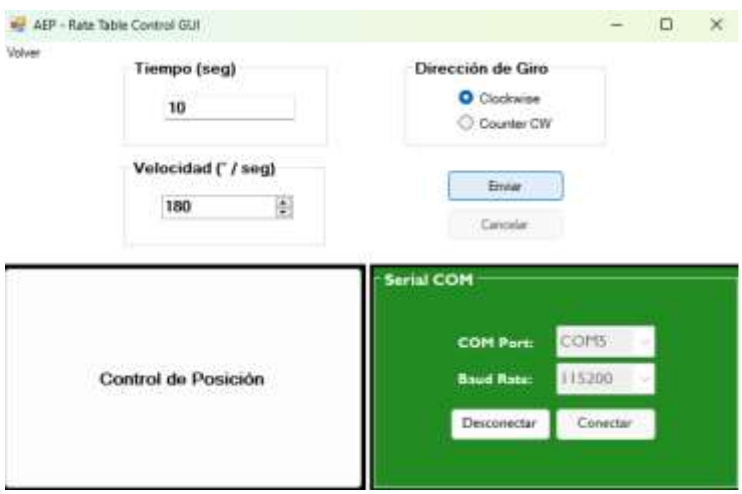


Figure 8. Velocity Control, successfully connected.

Structure

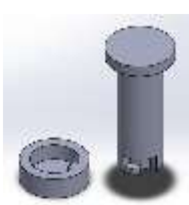
Table 1 presents the list of components for assembly. The models for 3D printing and laser cutting can be found in the folder "Single-Axis Rate Table → Rate Table Design."

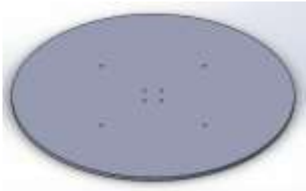
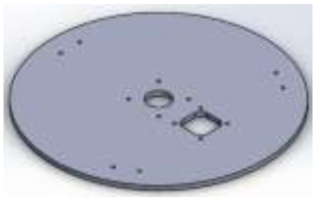
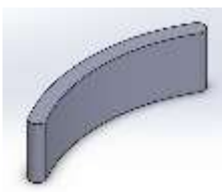
Table 1. List of Test Bench Components.

Component	Quantity	Manufacturing	Cost
 Nema 17 HS2408-s	x1	Prefabricated	Gs. 200.000
 Driver A4988	x1	Prefabricated	Gs. 35.000
 Arduino Nano	x1	Prefabricated	SpaceLab property
 Jumpers M-M	x15	Prefabricated	-

 Protoboard	x1	Prefabricated	SpaceLab property
 Fuente de Alimentación	x1	Prefabricated	SpaceLab property
 Capacitor 100uF	x1	Prefabricated	-
 Rodamientos	x5	Prefabricated	Donation (Gs. 15.000 c/u)
 Tornillo M8 x50mm	x1	Prefabricated	Gs. 1.500

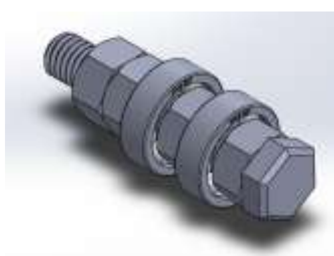
 Tuercas M8	X5	Prefabricated	Gs. 5.000
 Tornillos M3 x10mm	X24	Prefabricated	Gs. 24.000
 Arandelas M3	X8	Prefabricated	Donation
 Tuercas M3	X14	Prefabricated	Gs. 14.000
 Engranaje externo	x1	3D printing	-

 Engranaje interno	x1	3D printing	-
 Soporte Central	x1	3D printing	-
 Centralizador	x1	3D printing	-
 Soportes p/ Rodamientos	x3	3D printing	-
 Pin de Rodamientos	x3	3D printing	-

 Base Superior	x1	Laser cut	Donation
 Base Principal	x1	Laser cut	Donation
 Soportes	x3	Laser cut or 3D printing	Donation

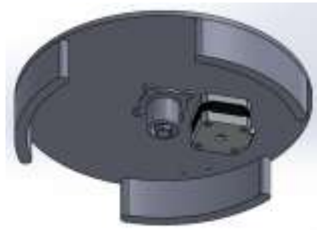
Assembly Procedure

First, assemble the M8 screw with 4 M8 nuts and 2 Bearings 608 with a 22mm outer diameter alternately. Then, insert this assembly into the Central Support.

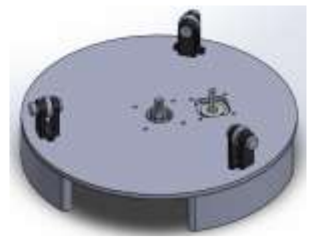



Next, use 8 M3 screws, 8 washers, and 4 M3 nuts to secure the Motor and the Central Support to the Main Base.

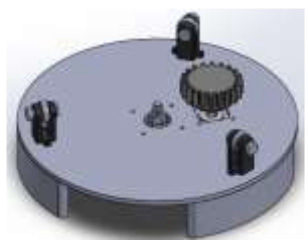
The supports of the Main Base will be attached with wood glue (in case they are made of this material). They should be fixed equidistantly from each other.



The supports for the bearings will be assembled together with the pins and the 608 bearings with a 24 mm outer diameter. They will then be secured with 6 screws and 6 M3 nuts to the Main Base.



To finish with the Main Base, secure the internal gear to the Nema17 motor with 2 M3 screws.



To conclude the assembly, secure the External Gear and the Centralizer to the Upper Base using 8 screws and 4 M3 nuts. *Note: Hardware glue was used to secure the external gear.

Finally, place the Upper Base on the bearings and insert the Centralizer onto the screw of the Central Support. In this step, ensure the gears are correctly engaged.

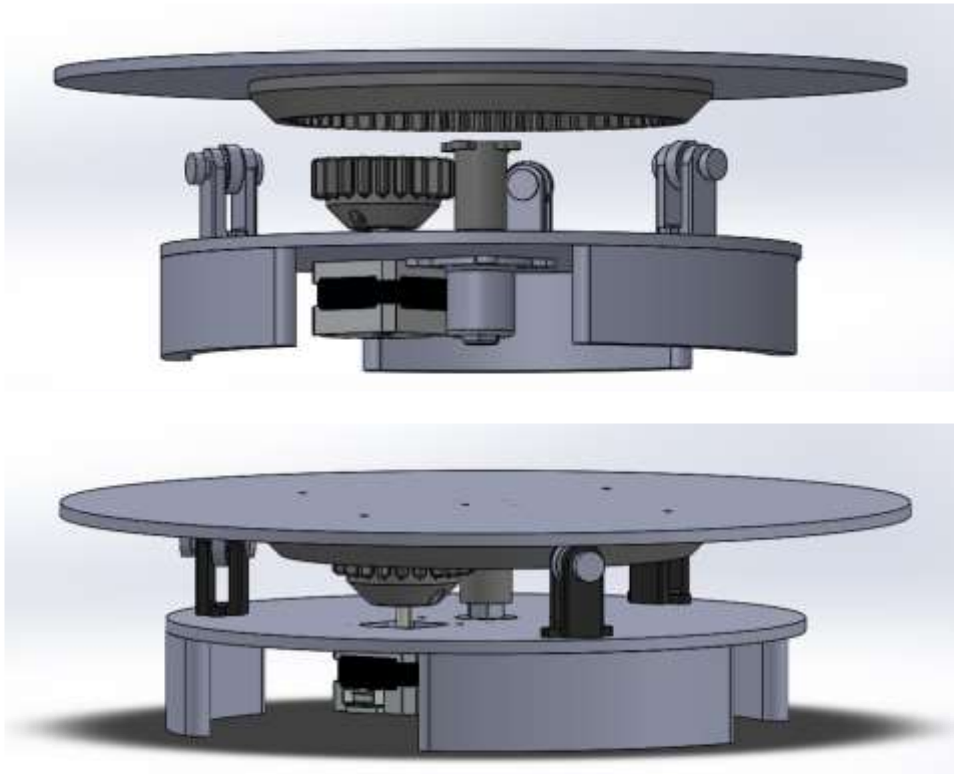


Figure 9. Final assembled design.

FUTURE CONSIDERATIONS

There are opportunities for improvement that could enhance the efficiency and quality of the tests. In particular, the implementation of spherical air bearings [3] would be ideal to reduce friction instead of using traditional bearings. This could optimize the platform's operation, ensuring a simulation much closer to real orbital conditions.

Even if traditional bearings are still used, another potential improvement would be replacing the A4988 driver with drivers from the TMC family (such as the TMC2209). Although more expensive, these drivers would provide much quieter motor operation with less vibration, highly valued characteristics in applications like ours that require precision in measurements.

The User Interface could receive real-time data from Arduino, such as angular position, enabling the creation of graphs showing position and speed over elapsed time. These graphs could then be compared with data obtained from tested gyro and acceleration sensors. For this application, a time meter and a memory card should be integrated into the system, storing time and position data using the "Stepper.currentposition();" function from the library used in the Arduino code, "AccelStepper."

CONCLUSION

In summary, the presented single-axis rotary test bench in this work is a valuable asset for the aerospace industry and engineering in Paraguay. As mentioned earlier, it particularly benefits the Attitude Determination and Control System and the Telecommunications System. It enables essential simulation tests, laying the groundwork for future research and improvements in the country's space systems technology, paving the way for a promising future in this field.

References

[1] Adolfo Javier Jara Cespedes, *An Overview of the BIRDS-4 Satellite Project and the First Satellite of Paraguay.*

[2] NASA, CubeSat101: Basic Concepts and Processes for First-Time CubeSat Developers, 2017.

[3] E. Fretes, DEVELOPMENT OF TEST BENCH AND USER INTERFACE FOR ADCS TESTING OF MICRO AND NANOSATELLITES, 2022.