Student Highlights:

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Student Experiences With a Clinostat for Microgravity Simulation

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INTRODUCTION

With the advent of human space travel, understanding microgravity's effects on various aspects of life has become essential. Studying these effects directly in space is costly and impractical, so simulating microgravity on Earth using a clinostat is proposed. The primary objective is to develop a clinostat with two rotational axes and speed regulation to simulate microgravity conditions and capture study images. This development is part of the INCA program at the Universidad de Ciencias y Humanidades [1].

A clinostat can equalize the gravity vector across different axes through constant rotations [2]. Various studies have explored microgravity's effects on biological samples [3], [4], [5], [6], [7], [8]. For example, Choi et al. [4] investigated skin effects using a 3D clinostat, and Oluwafemi et al. [5] compared plant growth under normal and microgravity conditions. Clinostats, such as the 3D clinostat, developed in Japan and The Netherlands, use two independent rotational frames to better simulate microgravity [9]. Kiss et al. [10] noted that random positioning machines (RPMs) with two axes are sufficient to mimic microgravity, especially for plant studies.

Several designs of these devices exist. For instance, Przystupski et al. [11] used aluminum for the frames and incorporated motors offering speeds from 0.1 to 60 r/min. Yotov et al. [12] developed an RPM for studying rats, using aluminum structures and regulating parameters, such as angular speed and rotation period.

The rest of this article is organized as follows. It continues with the methodology for implementing the clinostat in the "Methodology" section and findings and results in the "Results" section. Finally, the "Discussion and Conclusion" section concludes this article.

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METHODOLOGY

A clinostat with two rotation axes was constructed using V-slot aluminum bars, designed to house a central box for the study object. Two 12 V dc motors control the frames, with slip rings ensuring communication between the exterior and interior. 3D-printed parts were used to attach frames and adapt motor rotation. An Arduino Nano manages control, displaying motor r/min on an LCD. The box includes a surveillance camera and LED strip for lighting, with real-time video viewing available via the Little Stars app and a Wi-Fi connection.

DESIGN OF THE CLINOSTAT STRUCTURE

The 3D design of the clinostat structure underwent several modifications to address design considerations (clinostat's functionality and stability under operating conditions, optimizing the structure's balance, ensuring compatibility with rotational motors, and maintaining durability while minimizing weight), ultimately resulting in a final design that suited the clinostat's structure, as shown in Figure 1.

Figure 2 presents the flowchart of the clinostat. It begins with "leveling the variables," where the dimensions and operating values for the clinostat are defined. The "system process" section addresses the control system's behavior. Lastly, in the "acquisition of results," a motor power controller adjusts speed variation, and the speed values for each motor are displayed on an LCD.

The materials required for implementing the random movement machine are listed in Table 1. These components were chosen based on the design requirements.

To simulate microgravity and handle payloads with dimensions between 15 × 15 × 15 cm^3 and 20 × 20 × 20 cm^3, the CHW-GW4058-3162 geared motor, which provides a torque greater than 25 kg/cm, was used. A V-Slot 2040 profile support with a 20 × 40 mm^2 cross section supported this torque. The Arduino Nano acted as the main microcontroller.

To control the motors, the L298N H-bridge driver was utilized, capable of managing dc motors up to 2 A, with two full H-bridges for controlling two motors. A 20 × 4 LCD display, equipped with the HD44780 controller, was used for showing results. Slip rings

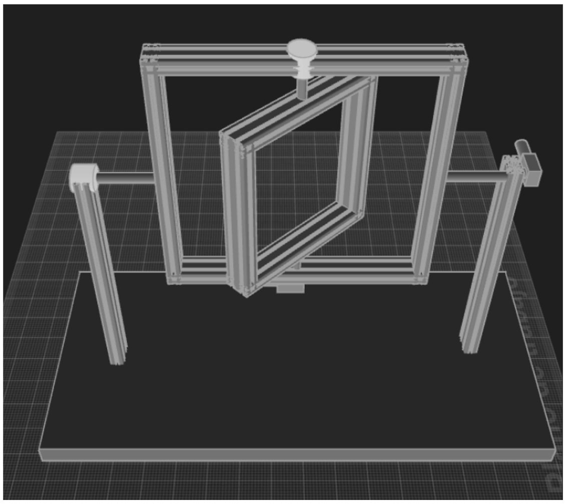

Figure 1.
3D clinostat visualization.

Table 1.

Materials

Item	Description	Quantity
1	Mini surveillance camera Full HD magnetic base	1
2	Bridge H L298	2
3	Profile V-SLOT 2040 L3.2M	1
4	Switching power supply ac/ dc 60W 12V 5A	1
5	Angle for aluminum profiles	25
6	Low profile screw M5*8	100
7	Insert T-nut M5	100
8	Motor CHW-GW4058-3162 12 V 111RPM with Bracket	2
9	Slip ring 6 wires	1
10	Slip ring 12 wires	1
11	Module MPU6050: Accelerometer, gyroscope I2C	1
12	LCD 20x4	1

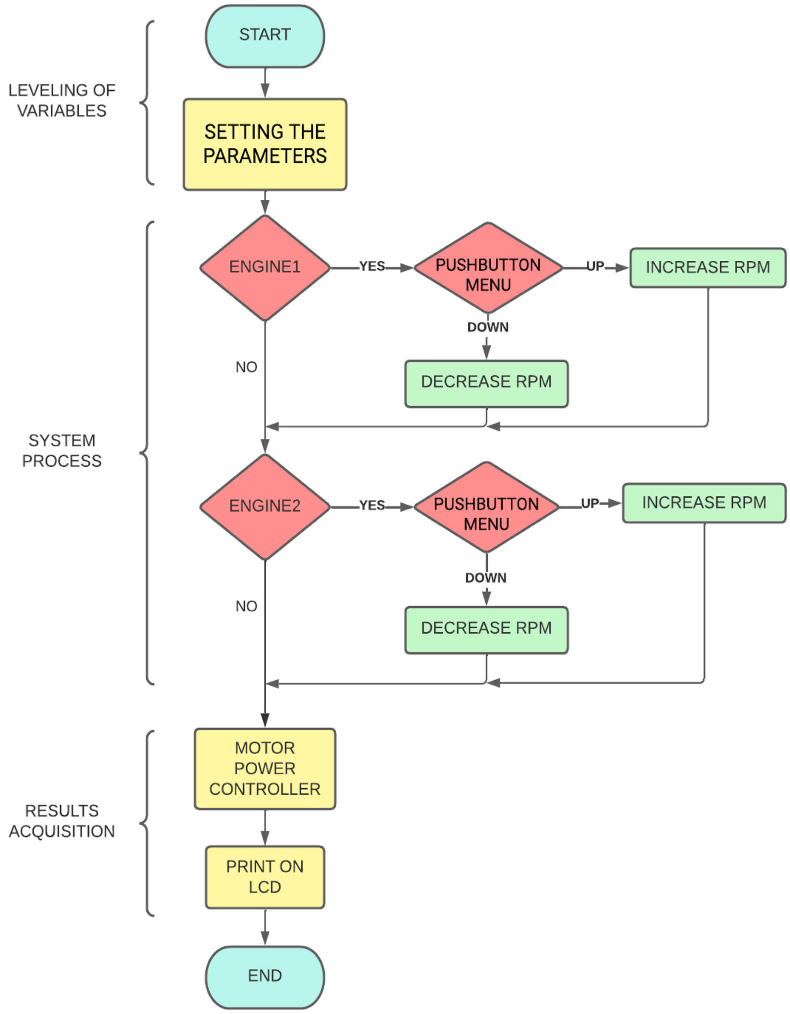

Figure 2.
Clinostat flowchart.

enabled communication between the stationary and rotating sections of the clinostat.

SIMULATION OF CLINOSTAT OPERATION

The design and simulation of the device connections for the clinostat's operation were completed. To control the revolutions, a configuration of pushbuttons and resistors was arranged in a voltage divider setup, allowing the microcontroller's analog ports to read the input. The design can be seen in Figure 3.

DEVELOPMENT OF THE SYSTEM ALGORITHM

The system algorithm was developed by implementing code using the Arduino Integrated Development Environment, which facilitated programming and troubleshooting. The algorithm was developed with a focus on efficient communication between components, particularly through the use of interintegrated circuit (I2C) libraries. These I2C libraries enabled seamless communication between multiple sensors and controllers, allowing the system to manage data inputs and outputs effectively. It is important to mention that the algorithm controls the speed of the motors based on the commands entered manually since the flow shown in Figure 2 must be respected.

IMPLEMENTATION OF THE CLINOSTAT

For the construction of the clinostat structure, aluminum bars were cut for the internal and external frames, as well as for the lateral supports. Printed parts were used to fix the motors, considering the shape of the motor and the bars. Slip rings were placed on the opposite side of the motors, requiring a printed part for proper fitting. The motor axes were attached to bolts for correct movement transfer, with cylindrical pieces designed to fit the required shapes. The pieces were painted black, joined

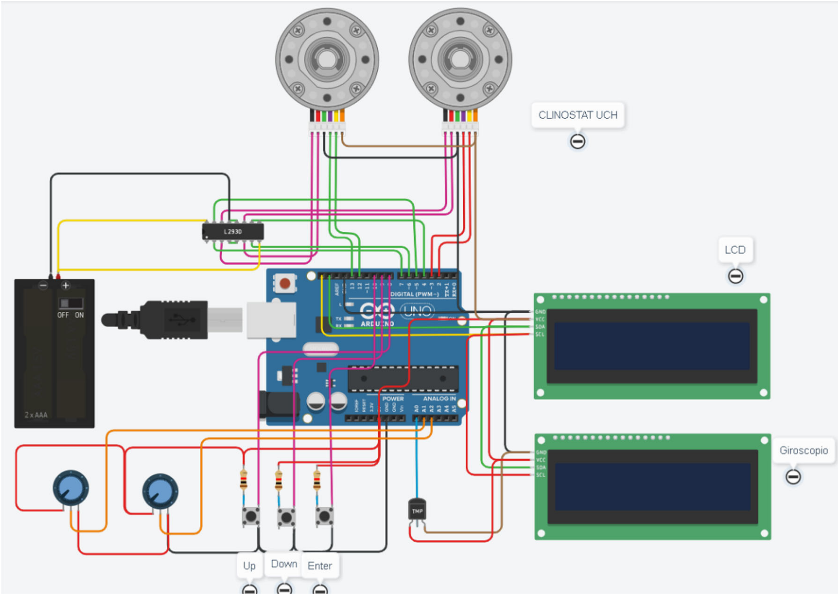

Figure 3.
Connection design.

into a single structure, and fixed to a melamine base. A box was printed to integrate the control board, LCD, and buttons, allowing power cables to enter from the ac/dc source and exit to power the motors and the internal clinostat components. Inside the clinostat, a box with a surveillance camera and LED strip was placed for interior viewing and lighting, and both the power supply and control system box were fixed to the melamine base.

The container was also printed in PLA material with a 3D printer. The implementation is shown in Figures 4 and 5.

RESULTS

Functional tests were conducted on the clinostat, allowing independent control of each motor's rotation via buttons, with speeds displayed on the LCD ranging from 0 to 35 r/min. However, practical motor rotation values start at 10 r/min due to weight considerations. Real-time images can be viewed by installing the Little Stars application and connecting to the camera's Wi-Fi network.

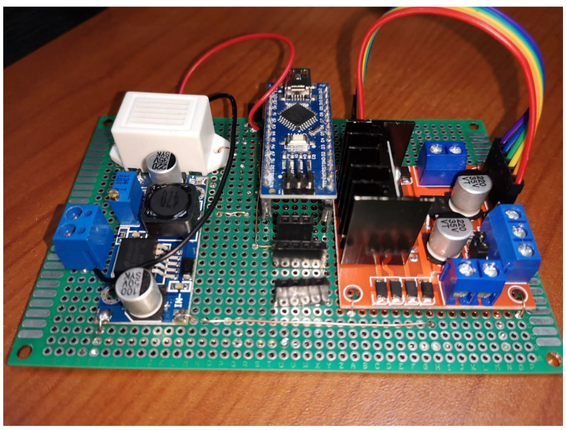

Figure 4.
Control board.

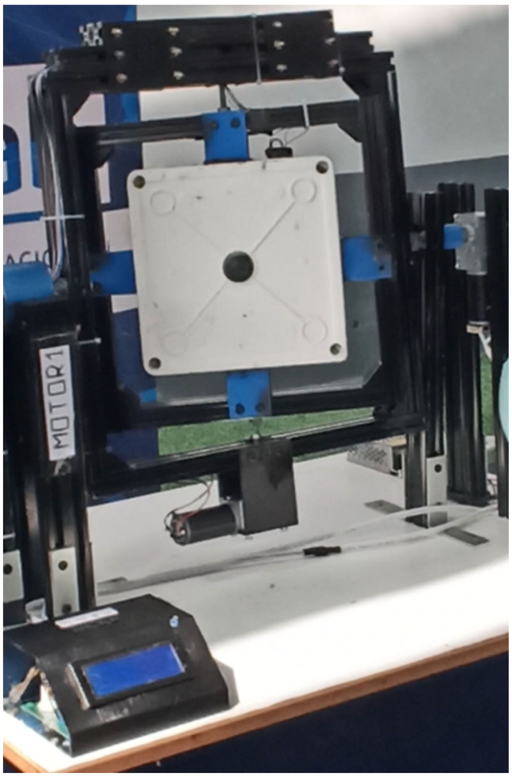

Figure 5.
Fully built clinostat.

Figure 6.
Presentation of the clinostat at a vocational fair.

The clinostat successfully simulates microgravity conditions using the Arduino platform and specified materials. The random motion machine supports a $20^{*}20^{*}20$ cm^3 payload, with speed variation controlled through its interface, and real-time images are accessible on Android or Windows devices via a 2.4-GHz network.

DISCUSSION AND CONCLUSION

The implemented random motion machine reached a maximum speed of 35 r/min for both motors, which, although lower than the initially targeted 20–90 r/min, is sufficient for the intended applications. It also exceeded expectations in load capacity (approximately 500 g), providing an ideal workspace for various load sizes. The machine's broad base effectively supports the rotational movements of each dimension. This project is significant in promoting interest in space technology, particularly in developing countries with limited resources. In addition, it has been showcased at science and technology fairs (see Figure 6) to inspire interest in STEM fields, making a notable societal impact.

The distinction between the presented work and existing studies is the hands-on educational experience it provides to students. It allows them to implement and build their own clinostat rather than purchasing a premade one. Developing the clinostat within the laboratory also achieves a more cost-effective solution, making it significantly cheaper than commercially available alternatives.

REFERENCES

[1] A. Roman-Gonzalez and N. I. Vargas-Cuentas, "INCA program for developing a nanosatellite at the UCH," in *Proc. 67th Int. Astronautical Congr.*, 2016, Paper hal-01403828.

[2] A. Rojas-Moreno and F. Santos-Rodríguez, "Design of a novel 3DOF clinostat to produce microgravity for bioengineering applications," in *Proc. IEEE 25th Int. Conf. Electron., Elect. Eng. Comput.*, 2018, pp. 1–4.

[3] R. Herranz et al., "Use of reduced gravity simulators for plant biological studies," *Plant Gravitropism: Methods Protoc.*, vol. 2368, pp. 241–265, 2022.

[4] D. H. Choi et al., "3D cell culture using a clinostat reproduces microgravity-induced skin changes," *NPJ Microgr.*, vol. 7, no. 1, Jun. 2021, Art. no. 20.

[5] F. A. Oluwafemi, O. M. Ibraheem, and T. H. Fatoki, "Clinostat microgravity impact on shoot morphology of selected nutritional and economic crops," *Plant Cell Biotechnol. Mol. Biol.*, vol. 21, pp. 92–104, Oct. 2020.

[6] S. L. Wuest et al., "A novel microgravity simulator applicable for three-dimensional cell culturing," *Microgr. Sci. Technol.*, vol. 26, pp. 77–88, Oct. 2014.

[7] S. M. Kim et al., "An experimental and theoretical approach to optimize a three-dimensional clinostat for life science experiments," *Microgr. Sci. Technol.*, vol. 29, pp. 97–106, Feb. 2017.

[8] J. J. Van Loon, "Some history and use of the random positioning machine, RPM, in gravity related research," *Adv. Space Res.*, vol. 39, no. 7, pp. 1161–1165, Jan. 2007.

[9] R. Herranz et al., "Ground-based facilities for simulation of microgravity: Organism-specific recommendations for their use, and recommended terminology," *Astrobiology*, vol. 13, no. 1, pp. 1–7, Jan. 2013.

[10] J. Z. Kiss, C. Wolverton, S. E. Wyatt, K. H. Hasenstein, and J. J. van Loon, "Comparison of microgravity analogs to spaceflight in studies of plant growth and development," *Front. Plant Sci.*, vol. 10, Dec. 2019, Art. no. 1577.

[11] D. Przystupski et al., "Testing lab-on-a-chip technology for culturing human melanoma cells under simulated microgravity," *Cancers*, vol. 13, no. 3, Jan. 2021, Art. no. 402.

[12] V. V. Yotov, J. Marovska, V. Turiyski, and S. I. Ivanov, "A new random positioning machine modification applied for microgravity simulation in laboratory experiments with rats," *Inventions*, vol. 7, no. 3, Sep. 2022, Art. no. 85.