



# 3D model of a satellite footprint over the Earth

ECE 445 Senior Design Project

Final Report



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# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	Problem Statement . . . . .	1
1.2	Solution Overview . . . . .	1
1.3	Visual Aid . . . . .	2
1.4	High-level requirements . . . . .	2
<b>2</b>	<b>Design</b>	<b>3</b>
2.1	Design overview . . . . .	3
2.2	Block Diagram . . . . .	3
2.2.1	System Overview . . . . .	3
2.2.2	Earth Subsystem . . . . .	3
2.2.3	Satellite Subsystem . . . . .	4
2.3	Subsystem Descriptions . . . . .	4
2.3.1	Earth Subsystem . . . . .	4
2.3.2	Voltage Regulating Subsystem . . . . .	7
2.3.3	Controlling Board Subsystem . . . . .	8
2.3.4	Satellite Subsystem . . . . .	12
2.3.5	Power Subsystem . . . . .	14
2.4	Tolerance Analysis . . . . .	15
2.4.1	Voltage Tolerance of Circuits . . . . .	15
2.4.2	Maximum weight of earth system . . . . .	16
<b>3</b>	<b>Cost</b>	<b>17</b>
3.1	Labor . . . . .	17
3.2	Parts . . . . .	17
3.3	Grand Total . . . . .	18
<b>4</b>	<b>Schedule</b>	<b>19</b>
<b>5</b>	<b>Ethics and Safety</b>	<b>21</b>
5.1	Safety . . . . .	21
5.2	Ethics . . . . .	21
	<b>References</b>	<b>23</b>

# 1 Introduction

## 1.1 Problem Statement

Educational institutions, aerospace enthusiasts, and researchers face a significant challenge in effectively visualizing and demonstrating the dynamic interactions between satellites and the Earth. While traditional models and computer simulations provide a foundational understanding, they often fall short of offering the physical interaction and direct observation components crucial for deepening engagement and comprehension. The inherent complexity of satellite dynamics requires a more immersive approach to education and demonstration.

For us adults, we can easily get access to knowledge of satellite orbitals either through formal papers or online media. However, even videos and animation, the most vivid ways of demonstration, could be too abstract for teenagers and kids, whose interest to science matters a lot.

Therefore, there is a pressing need for an accurate, hands-on representation of satellite operations in relation to the Earth. This solution should effectively illustrate critical aspects of a certain satellite orbit, such as orbit altitude adjustments, Earth rotation and the casting point from the satellite to the Earth. By bridging this educational gap, we can foster a deeper understanding of satellite technology, inspire the next generation of aerospace professionals, and support the continued innovation and growth within this vital sector.

## 1.2 Solution Overview

We propose to create a 3D hardware demonstrator that physically represents the interaction between a satellite and the Earth. This model will feature a stationary satellite with the laser attached to it pointing to the Earth, showing the area it covers. The Earth model, placed on a L-shape stand with motors controlling it, will rotate, simulating the planet's rotation. This setup aims to offer a more intuitive understanding of satellite positioning, Earth's rotation, and their interplay, enhancing educational outcomes and interest in aerospace and earth sciences.

## 1.3 Visual Aid

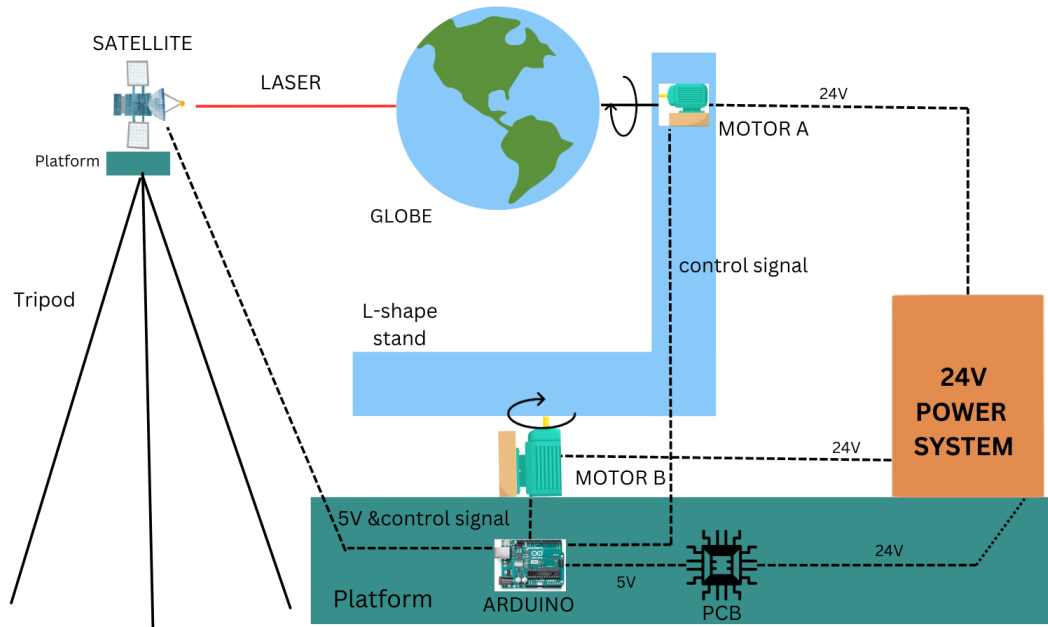


Figure 1.1: Visual Aid

## 1.4 High-level requirements

- The globe we use will be of proper size so that it will not be too large for the motors to drive or too small for poor visualization, we set the standard of the globe of 30 cm (about 11.81 in) in diameter.
- To ensure the safety and endurance of work, we will use low-power laser (3.3V-5V) and make the whole device as light as possible while keep it solid enough to avoid problems in rotation.
- Since the focus of our work is to demonstrate the satellite footprint, we must make sure that the footprint is correct. Therefore, the least accuracy of the position controlling of motors should be within 1.8 degrees, otherwise will result into a huge error in earth position.

## 2 Design

### 2.1 Design overview

In order to project a trajectory over a globe. We decide to fix the relative position of the satellite from the globe, while the globe itself can rotate in two dimensions to achieve the smooth movement of the satellite. Meanwhile, we will alter the distance between the satellite and the center of the globe to represent the change in altitude of the satellite trajectory. With an initial starting coordinate and a given trajectory, our circuit can turn it into a signal of motion to the motors to correctly represent the trajectory.

### 2.2 Block Diagram

#### 2.2.1 System Overview

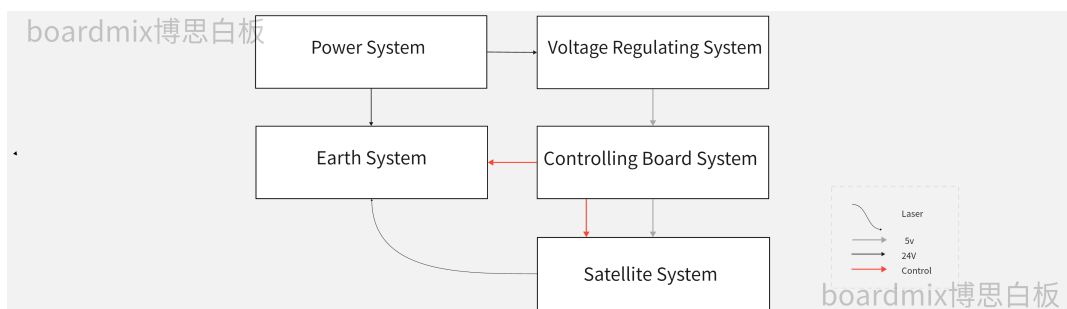


Figure 2.1: System Overview

#### 2.2.2 Earth Subsystem

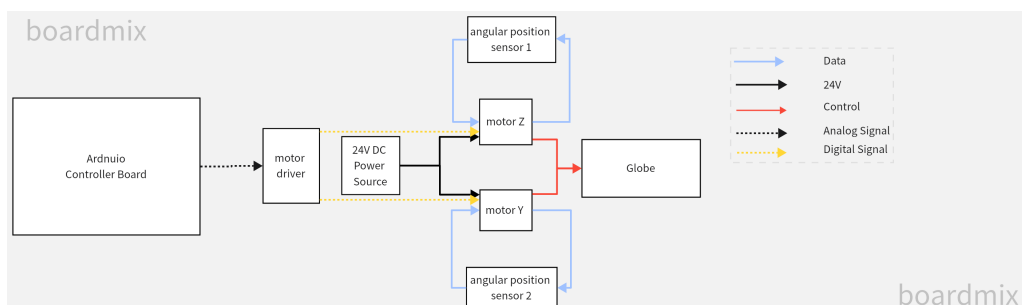


Figure 2.2: Controlling Board Subsystem

## 2.2.3 Satellite Subsystem

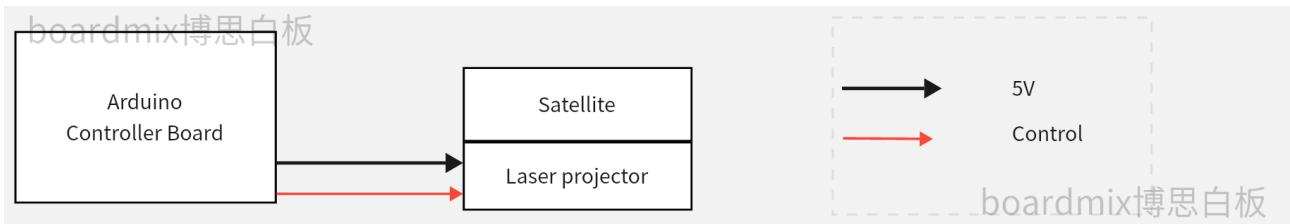


Figure 2.3: Satellite Subsystem

## 2.3 Subsystem Descriptions

### 2.3.1 Earth Subsystem

Input: driving force of motor(from Controlling Board Subsystem)

Output: Z-axis and Y- axis rotation movement of the earth model

Components: a coarse iron metal base, an 4040 V-shaped aluminum arm, two 3D printed motor connectors, two 57mm stepper motors, and a plastic hollow earth model.

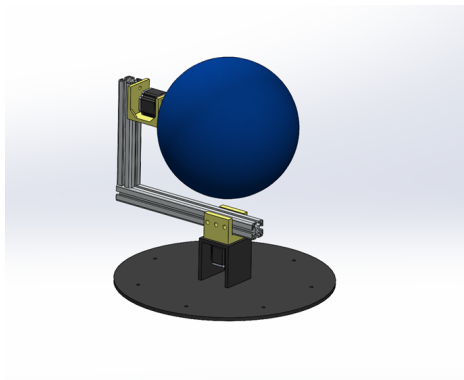


Figure 2.4: 3D-model of Earth Subsystem

### Description

The main function of this system is follows: two 57 stepper motors rotates the earth severally, the lower motor is for Z-axis movements and the upper motors is for Y-axis movements. The relative rotation posture between earth and satellite is changing, so that the laser module on the satellite can always project the satellite trajectory point to the correct position on the earth (absolute position).

## FEA analysis

Below are the lower motor connectors. Considering working conditions, we will apply very strong and heavy torque to the Z-axis motors, approximately 5 N\*M; Moreover, it's clamped to the 4040 V shaped aluminum by four M8 screws. So our main work in design procedure is to ensure no failing happens in the Z-motors connectors.

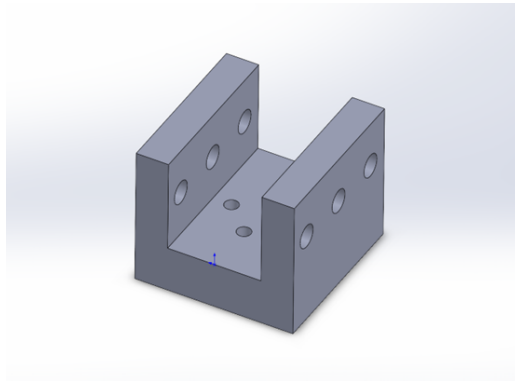


Figure 2.5: connector model

First we do some FEA analysis on this part, this part is made from photopolymer 9400A, by UV curing 3D printing, the material mechanism is as follows.

Table 2.1: 9400A material mechanism

Property	Value
HARDNESS	78-87
Bending Strength	69%-75%
Bending Modulus	2712-2791
Elongation of break	8-12%
Poisson's Ratio	0.4-0.44
Density	1.12-1.18 g/cm <sup>3</sup>

We set a vertical load of 18N to simulate the gravity of the whole structure and a torque of 1.5 NM to simulate the motor. We can see that the displacement of the structure is very small in the following figure.

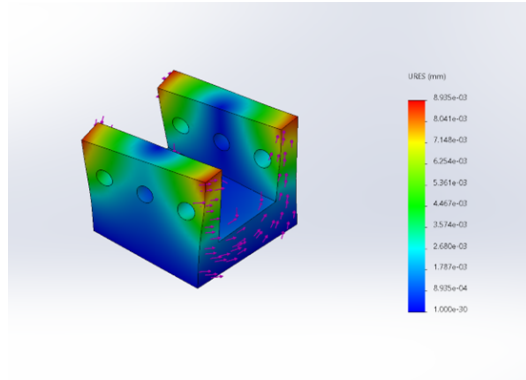


Figure 2.6: Displacement of Z axis Connector

Besides, we can see that the stress in the whole part is also acceptable, all in blue or green color.

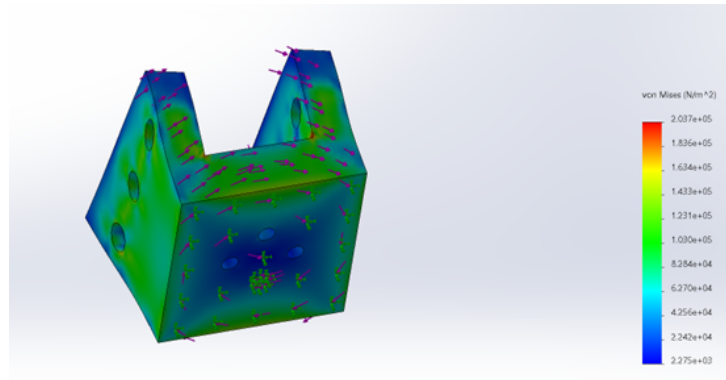


Figure 2.7: Stress axis Connector

## Requirements and Verification

Table 2.2: Requirements and Verification

Requirements	Verification
<ol style="list-style-type: none"> <li>1. The earth model should be connected with the motor y tightly without slipping. The whole 4040 aluminum arm should be connected to the motor z tightly without</li> <li>2. The two 3D-printed motor connectors should have reliable strength and factor of safety to ensure no accident happens.</li> </ol>	<ol style="list-style-type: none"> <li>1. By observing the movements of the earth system while plugging in charge of the motors, to see if the system is trembling and shaking.</li> <li>2. First we do some FEA analysis to test the design can endure 10 times the load in our projects; next we use We test the actual strength with a bench vice and 10 kg weight</li> </ol>



Table 2.2 continued from previous page

Requirements	Verification
3.The system should have two degree of freedom, one in z axis and one in y axis.	Use Arduino to drive the motors to see if the two motors can rotate freely at the full load.

### 2.3.2 Voltage Regulating Subsystem

Input: 24V DC power supply(from Power Subsystem).

Output: 5V DC power supply(to Controlling Board Subsystem)

Components: PCB board

Our DC power supply is for the stepper Motors to drive the heavy main structure, so the direct supply is too large for the Arduino Board to handle, and we need to regulate the voltage from 24V power supply to 5V power supply so that our control system can work stably and correctly. Therefore, this PCB design is to ensure that we can convert the 24V voltage supply from the power subsystem to the 5V for control system. It acts as the "bridge" the connects the subsystems together.

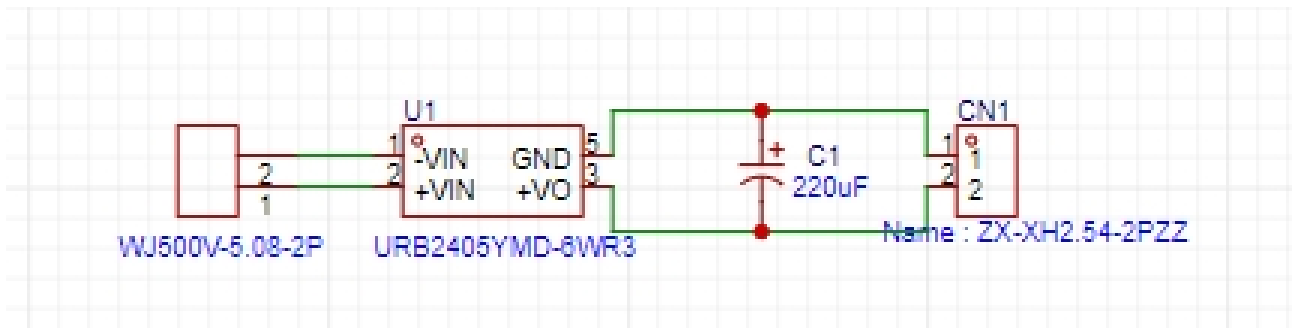


Figure 2.8: Schematic of PCB

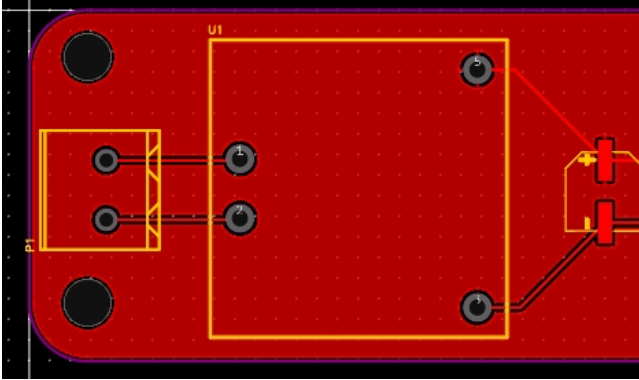


Figure 2.9: PCB design

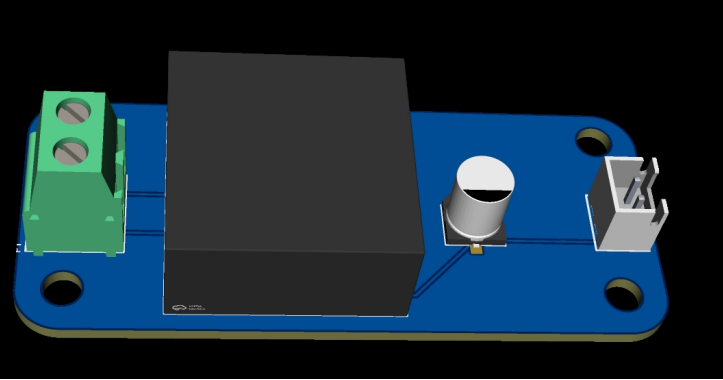


Figure 2.10: 3D PCB design

Table 2.3: Requirements and Verification

Requirements	Verification
1. The PCB can accept the 24 voltage power supply from the power system correctly.	1. We will use the Voltmeter to ensure that the voltage of the input side on PCB board is 24V.
2. The PCB can output 5 voltage to the Arduino Board.	2. We will use the Voltmeter to ensure that the voltage of the output side on PCB board is 5V.
3. The output of the PCB should be stable and constant.	3. We will measure the performance of the Arduino in a period of 30 minutes to test if our voltage regulator can work.

### 2.3.3 Controlling Board Subsystem

Input: orbital parameters (from PC) , 5V power supply(from Power Regulating Subsystem).

Output: Control signals(to Controlling Board Subsystem itself and Satellite Subsystem),5V power supply(to Satellite Subsystem)

Components: Arduino board

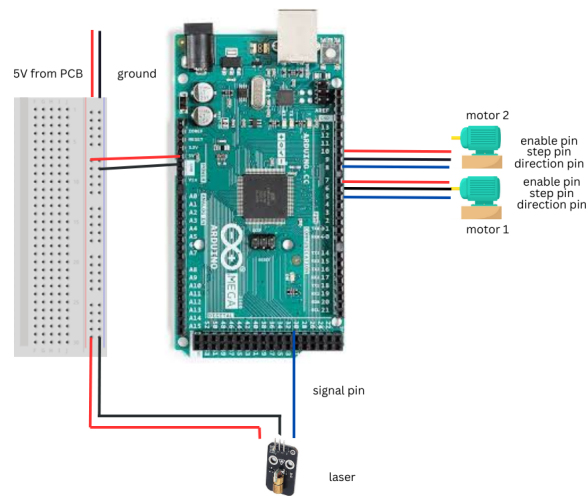


Figure 2.11: Controlling Board

The motor itself controls the two dimensions motion of the globe, rotating the globe in a perpendicular direction. Therefore, we need to complete an algorithm that turning a given orbit equation into a controlling signal that motors can accept.

The first thing to do is to turn the orbit equation, which is an equation about  $(x, y, z)$  coordinate of the satellite, into a coordinate system of  $(\Theta, \Phi, r)$ .

This coordinate system is a little bit different from the spherical coordinate system since the  $\Theta$  and  $\Phi$  here we use is different from the traditional spherical coordinate system. After finishing this, since I have to turn the motion of satellite into motion of motors, I have to calculate the relative relationship between the derivative  $\frac{d\Theta}{d\Phi}$ . With this, we can judge the speed of the motor to make the globe rotates within the trail of orbit.

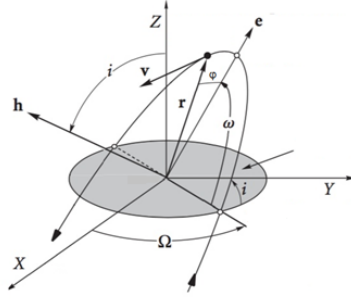


Figure 2.12: visual-aid of orbit

In this figure, the  $\Theta$  controls the rotation of Y axis while the  $\Phi$  controls the rotation of Z axis. With some angular coordinate calculations, we can derive the coordinate of previous  $(x, y, z)$  in the new coordinate system  $(\Theta, \Phi, r)$ .

They are expressed as:

$$\left( \frac{r \sin(\Theta) \sin(\Phi)}{\sqrt{1 - \cos(\Phi)^2 \cos(\Theta)^2}}, \frac{r \sin(\Theta) \cos(\Phi)}{\sqrt{1 - \cos(\Phi)^2 \cos(\Theta)^2}}, \frac{r \cos(\Theta) \sin(\Phi)}{\sqrt{1 - \cos(\Phi)^2 \cos(\Theta)^2}} \right)$$

Then we have finished the calculation of coordinates transformation. Eventually, we need to generate the orbit equation from the input parameters, which are semi-major axis  $a$ , orbit eccentricity  $e$ , argument of perigee, right ascension of ascension node. These parameters only describe the several basic features of the orbit. We need a conversion to turn them into equation. Since we are using true anomaly as the time step to represent the entire movement of the satellite. We can avoid heavy calculation required to obtain the eccentric anomaly, which required Newton-Raphson iteration for its numerical value.

The relation between eccentric anomaly  $E$  and true anomaly  $\nu$  are represented as:

$$\tan\left(\frac{\nu}{2}\right) = \sqrt{\frac{1+e}{1-e}} \tan\left(\frac{E}{2}\right) \quad (2.1)$$

Given  $\nu$ , we can calculate the altitude given semi major axis  $a$  and eccentricity  $e$ :

$$r = \frac{a(1 - e^2)}{1 + e \cos(\nu)} \quad (2.2)$$

Then, in the satellite's orbital surface, we have:

$$\begin{aligned} x' &= r \cos(\nu) \\ y' &= r \sin(\nu) \end{aligned} \quad (2.3)$$

Eventually we convert coordinates to Earth's equatorial coordinate system, using the right ascension of the ascending node  $\Omega$  and orbital inclination  $i$ :

$$\begin{aligned}x &= x' \cos(\Omega) - y' \cos(i) \sin(\Omega) \\y &= x' \sin(\Omega) + y' \cos(i) \cos(\Omega) \\z &= y' \sin(i)\end{aligned}\tag{2.4}$$

Combined with the expression of  $x'$  and  $y'$ , we get:

$$\begin{aligned}x &= r \cos(\nu) \cos(\Omega) - r \sin(\nu) \cos(i) \sin(\Omega) \\y &= r \cos(\nu) \sin(\Omega) + r \sin(\nu) \cos(i) \cos(\Omega) \\z &= r \sin(\nu) \sin(i)\end{aligned}\tag{2.5}$$

With the coordinate  $(x, y, z)$  we calculate, we can use them to get the inverse solution of  $(\Theta, \Phi, r)$ , basically, they are:

$$\begin{aligned}\Phi &= \arctan\left(\frac{x}{y}\right) \\ \Theta &= \arctan\left(\frac{x}{z}\right)\end{aligned}\tag{2.6}$$

Combined with the  $r$  we calculate before, we finally get the coordinate of  $(\Theta, \Phi, r)$ , which is:

$$\begin{aligned}\Phi &= \arctan\left(\frac{x}{y}\right) \\ \Theta &= \arctan\left(\frac{x}{z}\right) \\ r &= \frac{a(1 - e^2)}{1 + e \cos(\nu)}\end{aligned}\tag{2.7}$$

Table 2.4: Requirements and Verification

Requirements	Verification
1. Motor drivers can successfully receive the control signal from the control board and turn it into a voltage signal that powers the motors.	1. We will design a test orbit and send its parameters to the controlling board. If the motion of the orbit performs differently from our design, then we need to adjust the motor structure or correct our algorithm.

Table 2.4 continued from previous page

Requirements	Verification
2. Angular detect sensors can correctly measure the angular movement. In our design, we integrate it into the motor itself, together with the motor drive. The sensor will detect angular movement continuously and show it over the screen.	2. We will program a test signal in advance to verify the correctness of the sensor. We will run the same program for ten times to make sure that the sensor and reset function works well.
3. Motors can correctly perform the orbital movement of the satellite. This process requires the correct algorithm and the correct operation of motors.	3. We will first examine the basic structure of the motors and check whether its main structure is complete. Besides, by switching two motors and examining the difference of the shown orbit, it can reveal the potential individual differences between two motors, which can help us to adjust them.
4. The motors can correctly reset to initial state to perform next orbit. This function is integrated into the motor drive. Our motor drive can utilize the angular sensor to detect the current angular position to help it reset to initial state.	4. We will apply ten different orbits to our earth system and then send the reset signal to the motor drive. We will check the final state of the earth system whether it enforce the function correctly.
5. The error of the motors should be within 1.8 degrees.	5. We will utilize the internal self-calibrated function to calibrate the motor.

### 2.3.4 Satellite Subsystem

Input: Control signal (from Controlling Board Subsystem), 5V power supply (from Controlling Board Subsystem)

Output: Laser projection (to Earth Subsystem)

Components: Satellite model, Laser, tripod



Figure 2.13: The laser

In our design, the satellite is fixed and the laser attached to it should point at the axis of the Earth which controls the vertical rotation of the globe. We achieve this by using an independent tripod so that we can freely adjust the height and the angle of the laser.

The laser is to mark the movement of trajectory over the globe surface and we use a low-power one here, namely HS-F03A. Laser with higher power may lead to physical injury in our eyes. The laser receives both 5V DC power supply and control signal from the Arduino. Besides, the weight of satellite system should be less than 500g to ensure the platform we use can withstand that weight because a overweight structure may lead to instability in the system and cause other systemic problems such as unexpected position/angular change of the laser.

Table 2.5: Requirements and Verification

Requirements	Verification
1. The combination of the satellite model and the laser should be stable so that the position will not change due to slight environmental changes like wind.	1. Put the tripod that carries the satellite subsystem on flat ground and apply wind force (generated by electric fans) to it to see if the whole structure remains stable.
2. The laser components can project a laser point on the earth surface to indicate the real position of the satellite projection point.	2. Using Arduino commands to activate the laser and see if the red dot appears, then observe whether the projected point on the Earth's surface is clear enough to see. Also, keep the laser work for at least 2 hours to see if it can work for a period of time to ensure that its performance will not be affected by the temperature rising of itself.
3. The platform can withstand the overall weight of the satellite subsystem	3. Observe if the platform can hold the subsystem when the whole system is working.

### 2.3.5 Power Subsystem

Input: 220V AC Power

Output: 24V DC Power(to Controlling Board System)

Components: one DC24V3A power source



Figure 2.14: Power Source

We use one 24V DC power source to supply the motors and the voltage regulating subsystem. In the voltage regulation subsystem, we use PCB to convert 24V to 5V. 5V and 24V is the standard input requirement of the Arduino board and motors. Any power source providing different voltage supplies may lead to malfunction of the system.

The power requirements for all the components from the device are shown below:

Devices	Voltage/Current Requirements
Arduino MEGA2560 R3	VIN: 6-20V input to the board. MAXIMUM current per I/O: 20mA MAXIMUM current per +3.3V: 50mA
57 Stepper Motor	2.4A, 24V DC

Figure 2.15: Power Subsystem requirements



Table 2.6: Requirements and Verification

Requirements	Verification
1. The two motors should be powered by the DC24V3A power unit, which should guarantee the capability of motors to rotate the globe and the module.	1.If the globe can be driven to rotate with correct and accurate angle and speed as we want, the power supply for motors is qualified.
2. The outputs from the power supply should be stable.	2.We will use voltmeter to measure the long-time output experience of these power supplies( in 2 hours) to ensure that the supply is stable and reliable.

## 2.4 Tolerance Analysis

### 2.4.1 Voltage Tolerance of Circuits

#### Tolerance for Power supply

The required output of our DC power supply is 24V, and we use voltmeter to measure over 1000 real-time voltages over a period of 20 minutes, the average output voltage is as the following picture. Therefore, the  $\sigma_{powersupply}$  can be calculated as  $\sigma_{powersupply} = 24.0737 - 24 = 0.0737V$  and percentage of error is  $0.0737/24 \times 100\% = 0.307\%$ , which is a relatively small number. In real case performance, this error does not affect the performance of our circuit.



Figure 2.16: Average power supply voltage

#### Tolerance for voltage regulating output

The required output of our voltage regulating subsystem is 5V, and we use voltmeter to measure over 1000 real-time voltages over a period of 20 minutes, the average output voltage is as the

following picture. Therefore, the  $\sigma_{output}$  can be calculated as  $\sigma_{output} = 5.01516 - 5 = 0.01516V$  and percentage of error is  $0.01516/5 \times 100\% = 0.3032\%$ , which is also a relatively small number. In real case performance, the voltage is stable and can drive our Arduino Board correctly.



Figure 2.17: Average PCB output voltage

## 2.4.2 Maximum weight of earth system

Another problem we encountered in setting up the system is that, it's very hard to keep the 4040 V shaped aluminum arm in balance as we fix it at the end far away from the center to make the earth model and axis of motor concentric. It will cause two sever problem: firstly, due to the shaking of the whole structure, the motor can not rotates the system smoothly and stably; secondly, the earth system will very likely to fail apart due to the torque caused by the strong gravity of aluminum. The simplest and most affordable solution is to design a stable, heavy, iron metal base. We use 4 M3 screws to connects the earth system to the base, ensuring the system to be stable.

We use following equations to calculate the maximum weight the earth system can be.

$$W_{\max} \cdot l_1 = W_{\text{plate}} \cdot l_2$$

where  $l_1$  is the distance between center of gravity of the earth system and one end of the plate;  $l_2$  is the radius of the iron plate.

$$W_{\max} = 18 \text{ kg}$$

## 3 Cost

### 3.1 Labor

Table 3.1: Labor Costs

Name	Hourly Rate	Hours	Total	Total x 2.5
Zihua Gong	180 ¥	128	23040 ¥	57600 ¥
Wenhan Jiang	180 ¥	128	23040 ¥	57600 ¥
Lunan Ke	180 ¥	128	23040 ¥	57600 ¥
Kuangji Chen	180 ¥	128	23040 ¥	57600 ¥
			<b>Total</b>	230400 ¥

### 3.2 Parts

Table 3.2: Parts

Part	Vendor	Cost/unit (¥)	Quantity	Total Cost (¥)
Arduino	Taobao	295 ¥	1	295 ¥
57 stepper motor	Taobao	50 ¥	3	150 ¥
57 stepper motor driver	Taobao	70 ¥	3	210 ¥
Dupont thread	Taobao	7 ¥	2	14 ¥
9V1A power supply	Taobao	9 ¥	1	9 ¥
24V3A power supply	Taobao	25 ¥	2	50 ¥
Power cord	Taobao	3 ¥	1	3 ¥
Laser module	Taobao	7 ¥	1	7 ¥
Satellite model	Taobao	9 ¥	1	9 ¥
PCB	J@LC	58 ¥	1	58 ¥
4040 Aluminum Profile Frame	Taobao	49 ¥	1	49 ¥
3D Printing Plastic Products	Taobao	100 ¥	1	100 ¥
Stainless Steek Flanged Coupling	Taobao	40 ¥	1	40 ¥
Tellurion	Taobao	63 ¥	2	126 ¥
0.96-inch OLED Display	Taobao	19 ¥	1	19 ¥
			<b>Total</b>	1139 ¥

### 3.3 Grand Total

Table 3.3: Grand Total

Name	Cost
Labor	230,400¥
Parts	1139¥
<b>Total</b>	<b>231,539¥</b>

## 4 Schedule

Table 4.1: Project Schedule and Task Allocation

Week	Task	Responsibility
03/25/24	Design Document Due	All
	Finalize Design Document	Zhihua
	Purchase Arduino and motor	Kuangji
	Draw CAD and prepare 3D printing	Lunan
	Calculate orbital projection	Wenhan
04/01/24	Teamwork Evaluation I due	All
	PCB design	Zhihua
	Purchase Satellite model and laser adjustment	Kuangji
	Finish 3D printing	Lunan
	Program auduino and connect them to motor	Wenhan
04/08/24	Individual Progress Report Due	All
	Test PCB with satellite movement and laser	Zhihua
	Test Earth rotation and stand structure	Lunan
	Test and Fine-tune motor	Wenhan,Kuangji
04/15/24	Design Document Revision Due	All
	Finalize Design Document Revision	Zhihua
	Assemble the L-shape stand for globe and the platform	Lunan
	Connect and Test the Arduino-motor unit	Wenhan,Kuangji
04/22/24	Assemble the pole for satellite	Lunan
	Connect and Test the Arduino-motor unit	Zhihua,Wenhan,Kuangji
04/29/24	Assemble all components	Lunan
	Do whole-part test of all circuit and elements	Zhihua,Wenhan,Kuangji

**Table 4.1 continued from previous page**

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Week	Task	Responsibility
05/06/24	Mock Demo	All
	Make sure that all parts go well	All
	Prepare for final demo and presentation	All
05/13/24	Final Demo and presentation	All
	Final Individual Design Report Due	All
05/20/24	Final Report Due	All
	Teamwork Evaluation II due	All

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## 5 Ethics and Safety

In the development and implementation of our 3D hardware demonstrator for visualizing satellite-Earth interactions, ethical and safety considerations are paramount. We commit to prioritizing the safety, health, and welfare of the public in our project activities. Specifically, we will ensure that our demonstrator does not pose physical risks to users, such as electrical hazards or moving parts that could cause injury. To prevent accidental or intentional misuse, we will implement safety features like enclosed moving parts and secure electrical connections and provide comprehensive user guidelines.

### 5.1 Safety

Regarding safety and regulatory standards, our project will comply with relevant state and federal regulations, industry standards, and campus policies. This includes adhering to electrical safety standards (e.g., UL standards), mechanical safety standards (e.g., ANSI standards), and any specific regulations regarding educational tools and devices. We will review and follow the guidelines set by the Consumer Product Safety Commission (CPSC) and the Occupational Safety and Health Administration (OSHA) to ensure our project meets all required safety criteria.

Potential safety concerns include electrical safety (risk of shock or fire), mechanical safety (risk of pinching or other injuries from moving parts), and laser safety (if applicable, ensuring the laser used for satellite positioning does not pose a risk to eyesight). To mitigate these risks, our design will include protective casings for electrical components, safety guards around moving parts, and the use of low-power, eye-safe lasers, compliant with the International Electrotechnical Commission (IEC) standards for laser safety.

### 5.2 Ethics

Ethically, we recognize the importance of presenting accurate and unbiased educational content, thereby upholding the integrity and respect for intellectual property stipulated in the IEEE Code of Ethics. Our project will incorporate measures to ensure the educational materials and software used are freely and ethically sourced or developed in-house, with proper attribution and licensing where applicable.

To be more precise, we will follow the codes listed below:

- 1. to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment;

- 2. to improve the understanding by individuals and society of the capabilities and societal implications of conventional and emerging technologies, including intelligent systems;
- 3. to avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist;
- 4. to avoid unlawful conduct in professional activities, and to reject bribery in all its forms;
- 5. to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, to be honest and realistic in stating claims or estimates based on available data, and to credit properly the contributions of others;
- 6. to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations;
- 7. to treat all persons fairly and with respect, and to not engage in discrimination based on characteristics such as race, religion, gender, disability, age, national origin, sexual orientation, gender identity, or gender expression;
- 8. to not engage in harassment of any kind, including sexual harassment or bullying behavior;
- 9. to avoid injuring others, their property, reputation, or employment by false or malicious actions, rumors or any other verbal or physical abuses;
- 10. to support colleagues and co-workers in following this code of ethics, to strive to ensure the code is upheld, and to not retaliate against individuals reporting a violation.

By consciously integrating these ethical and safety considerations into our project design and execution, we aim to provide an educational tool that is not only innovative and engaging but also safe and respectful of ethical standards.



## References

1. The block diagrams in this document were created using **boardmix** online platform. Available: <https://boardmix.cn/app/editor>.
2. *IEEE Code of Ethics*. Retrieved March, 2024. Available: <https://www.ieee.org/about/corporate/governance/p7-8.html>
3. *Stepper Motor guide* [Online] <https://blog.csdn.net/zhangdatou666/article/details/132644047?spm=1001.2014.3001.5501>