Prospectus
Rudimentary Spacecraft Guidance System

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1 Introduction

1.1 Background Information

A gyroscope is a device that consists of a disc or wheel spinning about a rotating axis, which is free to alter its own direction. The orientation of this spin axis is unaffected by the nature of the mounting contraption, due to conservation of angular momentum, and thus can be used to compute a change in orientation and maintain stability.

In a mechanical gyroscope, a rotor is mounted onto a set of pivoted supports, or gimbals. Each gimbal allows the rotation of the rotor along a single axis, while allowing the spin axis to remain independent and keep its orientation in space. In a gyroscope with two gimbals, the outer gimbal acts as the gyroscope frame and possesses one degree of rotational freedom, while its axis is held still. The inner gimbal pivots on the plane that is perpendicular to the outer gimbal and possesses two degrees of freedom. Finally, the spin axis is always perpendicular to the inner gimbal, thus allowing for two degrees of rotational freedom and three degrees for the rotor.

Regardless of position, the angular momentum of the spinning disc allows for the conservation of the original orientation. With this property, gyroscopes have found various applications in navigation. In modern aircraft, a set of gyroscopes form the inertial guidance system to monitor and control the orientation of flight. Steadicams, heading indicators, gyrocompasses, and accelerometers are other contemporary uses for gyroscopes.

1.2 Project Description

The purpose of this project is to design a device based on motorized gyroscopes that will sense the orientation of a “spacecraft” relative to an initial stationary position. Then, the spacecraft will be moved manually and correction inputs will be sent to control fins to adjust and maintain the original orientation of the motionless situation. These inputs as well as data of the status of the system during its operation will be displayed in a graphical and digital manner and collected for post “flight” analysis.

According to guidelines set pursuant to van Bemmel (2019), the device must be able to control powered flight for a minimum of 120 seconds (2 minutes) while operating autonomously with no user input except prior to the operation. Furthermore, the device must be powered with a DC battery not exceeding a potential of 12V and the power must be less than 1Ah. No purpose-built gyroscope or internal sensors are allowed either. This prospectus will describe the design for a one-axis guidance system. The structure of the one-axis guidance system will be extrapolated and constructed to be able to operate in three dimensions.

2 Design

2.1 Gyroscope and Light Source

The gyroscope apparatus will consist of a vertical axle supporting an extended axle. A spinning disc will be mounted upon the extended axle, given a high angular velocity. The gimbal will thus have two degrees of freedom, upon the vertical axle and the extended arm, allowing it the rotor axis to point in any direction. A source of light via LEDs will be attached to the supporting axle holding the gyroscope, keeping the light in line with the gyroscope's orientation relative to external space at all times. This is possible due to the conservation of angular momentum, assuring the gyroscope will maintain the same orientation regardless of the spacecraft's actual orientation.

The spinning disc will be rotated independently of the supporting axle, and will be lubricated to prevent friction from hindering its speed. A DC motor will assure the gyroscope spins at a high, constant angular velocity throughout the run.

2.2 Photosensors and Orientation Mechanics

For a one-axis system, the gyroscope would only be given one axis of freedom (through its vertical axle, having the supporting beam fixed), thus limiting light to only be able to shine along a ring. To account for this shape, a minimum of two photoresistors will be placed non-symmetrically at different points on the ring. The non-symmetrical placement will prevent ambiguous cases of gyroscope angular position, where all sensors would have equal light readings as if the gyroscope faced another direction. When the device rotates upon the designated axis, the gyroscope and light source will maintain its orientation, based on the external environment (e.g. reference stars in space), however it will then have a different placement relative to the photoresistors fixed to the internals. While the gyroscope does the equivalent of rotating along the full circumference of its ring, the combined perceived light values calculated by the photoresistors will be unique at every angle, allowing for the orientation to be calculated at all angles of the spacecraft's tilt.

The method for calculating the angular position of the gyroscope relative to the internal frame relies on the fact that, when the gyroscope and light source face a photosensor, that sensor will yield a greater reading. Likewise, it will be pointed away from other sensors, causing them to transmit lower readings. During runtime, the ratio of the photoresistors' intensities will be used to compute the direction the gyroscope is facing relative to the internals. The algorithm to achieve adequate accuracy in this manner will be finetuned during construction. This method will be implemented for each sensor recording the gyroscope, and will be used during runtime.

2.3 Implementation of Additional Axes

This single-axis system can be implemented to 3D space. Given the two degrees of freedom as initially described, the gyroscope and light source would be able to project to all points of a sphere. Four photoresistors would be placed in a tetrahedral shape, able to sense the light source and distinguish the orientation of the gimbal relative to each cardinal axis. The minimum, analogous to the two sensors for the ring, would be three photoresistors placed non-symmetrically. Once again, ambiguity may be removed by having a slightly asymmetrical placement of sensors. Two of these sphere-projecting gyroscopes would be required in order to distinguish rotation in all three axes at all times, thus requiring two separate compartments. Each will have its own photoresistors, however, the gyroscope's vertical axle will be fixed differently in order to detect rotation in different axes.

A similar methodology will be used to calculate angular position, now using the additional sensors. In this case, the sensor with the highest light reading will be used as the "base" sensor, while the remaining sensors are used to pinpoint the precise angle at which the gyroscope is pointing to the "base" sensor. From there, the angular position in all three axes can be found, translating to the entire spacecraft's orientation relative to an external frame.

2.4 Arduino Setup

An Arduino Mega 2560 and an Arduino Uno will be used for computation of orientation and communication to the external environment, respectively. If time and budgeting permits, a Liquid Crystal Display (LCD) will be mounted on the outside of the spacecraft, permitting for observers to view calculated orientations on the device, as well as on a computer receiving values via bluetooth from the Arduino Uno. The Arduino Mega used for computation will be connected to each photoresistor in order to track light intensities for angle calculations. The software as detailed will be uploaded to this processor, and any data will be transferred to the Arduino Uno for wireless data transmission to the computer. The Arduino used for communications will use an HC-05 Bluetooth Module in order to permit serial communication to the logging external computer. At each time increment (most likely every whole second), the module will send the current calculated orientation to the computer, as well as the visible LCD. These sources will be used for calibrating software and testing.

2.5 Steering Mechanism

Upon detecting changes in orientation, a fin-throttling system will be used to correct for rotations, according to the angles computed. Servo step motors will control the angle of the mechanism relative to the spacecraft, "steering" the ship in the correct direction in each axis.

This will be done by sending an appropriate PWM signal through the Arduino Mega, controlling the angular position of the stepper and the direction the spacecraft is corrected towards.

2.6 Setup Variations and Optimization

A similar configuration, for example for a one-axis system, is to place a colour hue in a ring shape and install a colour sensor on the gyroscope. Thus, the gyroscope and the sensor would discern the RGB values of the hue it is pointed at, which could be used to determine the angular position and orientation. This method was not used, however, in considering implementations for a three-axis system; this would require a sphere of hues for the sensor to discern from. Other logistics such as ensuring adequate and uniform internal brightness and printing a colour hue ring/sphere within the contraption rendered this method inferior.

3 Blueprint

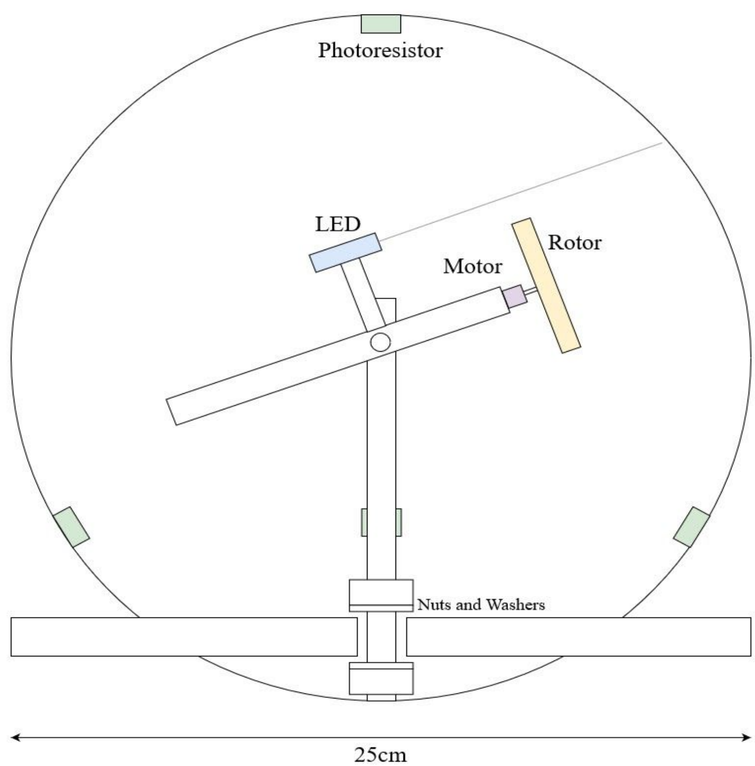

Fig 1. Photoresistor and Gyroscope Diagram. Above outlines the build for the internal gyroscope, light source, and sensor placement for a three-axis system. The gyroscope is able to map out a sphere, and thus four sensors at minimum form a tetrahedron to collect light intensities for angular position calculations. Nuts and washers will secure the axles.

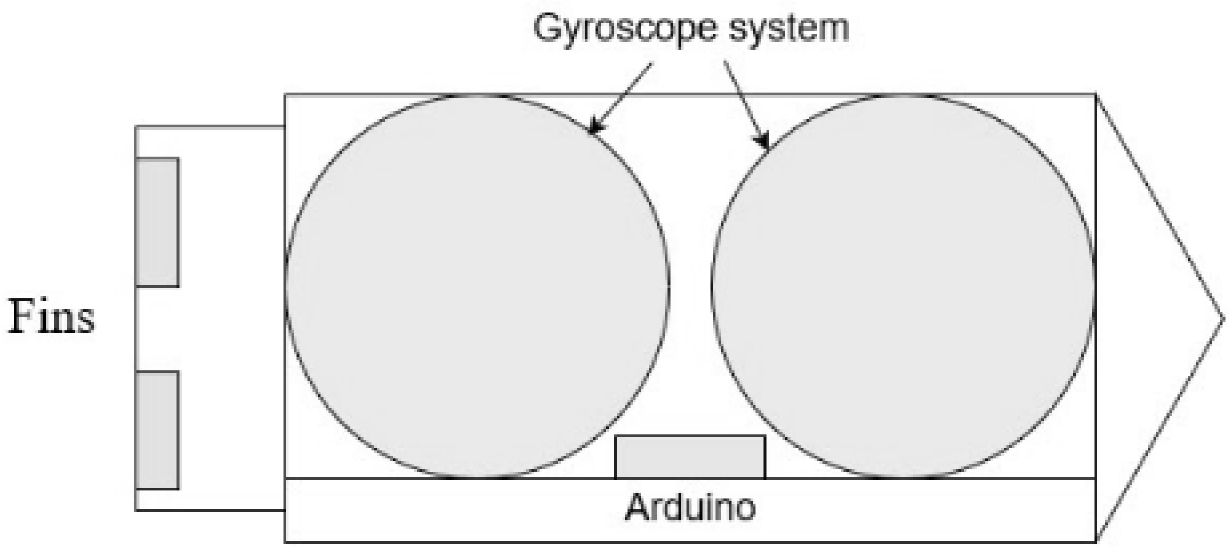

Fig 2. Fin Diagram. Above details the construction of the fin-throttling mechanism, used to correct orientation after sensed deviations during runtime. The Arduino Mega will send appropriate signals to the stepper motors controlling fins, which act as an according correction based off of calculated orientations. The two gyroscope compartments are shown for scale.

4 Schematic Diagrams

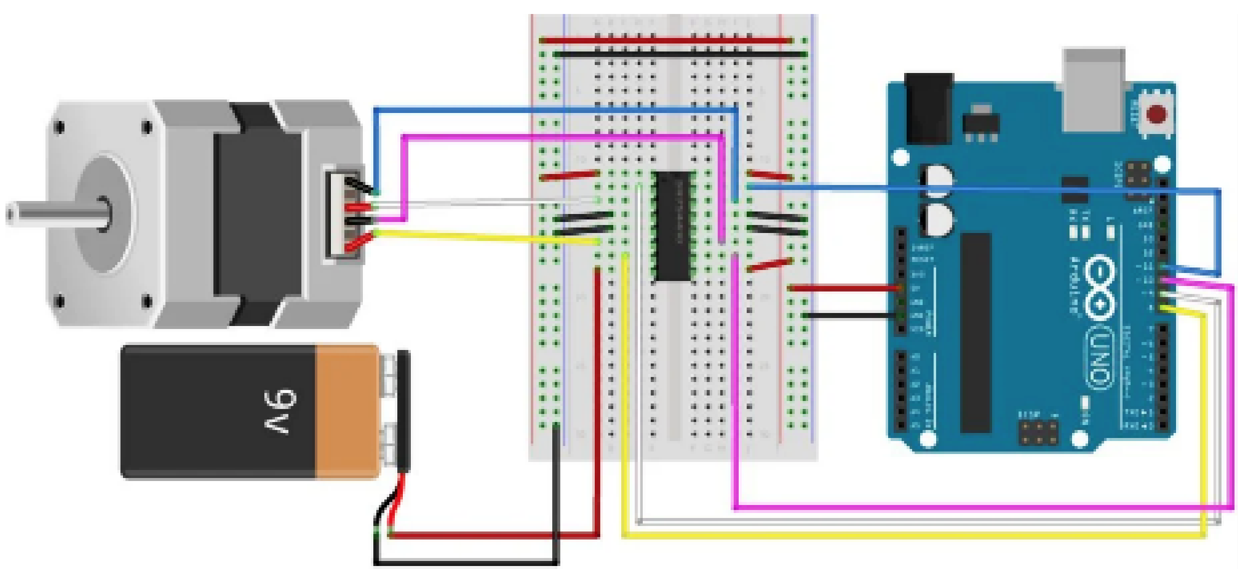

Fig 3. Stepper Motor Schematic. Above outlines the circuitry for the stepper motor used in the steering mechanism, pursuant to Maximous (2014). Although the diagram showcases its implementation to an Arduino Uno, an Arduino Mega will handle the movement in runtime. The middle H-Bridge is used to control motor angular position. An external power source is required. Several of this configuration may be implemented for additional steering control.

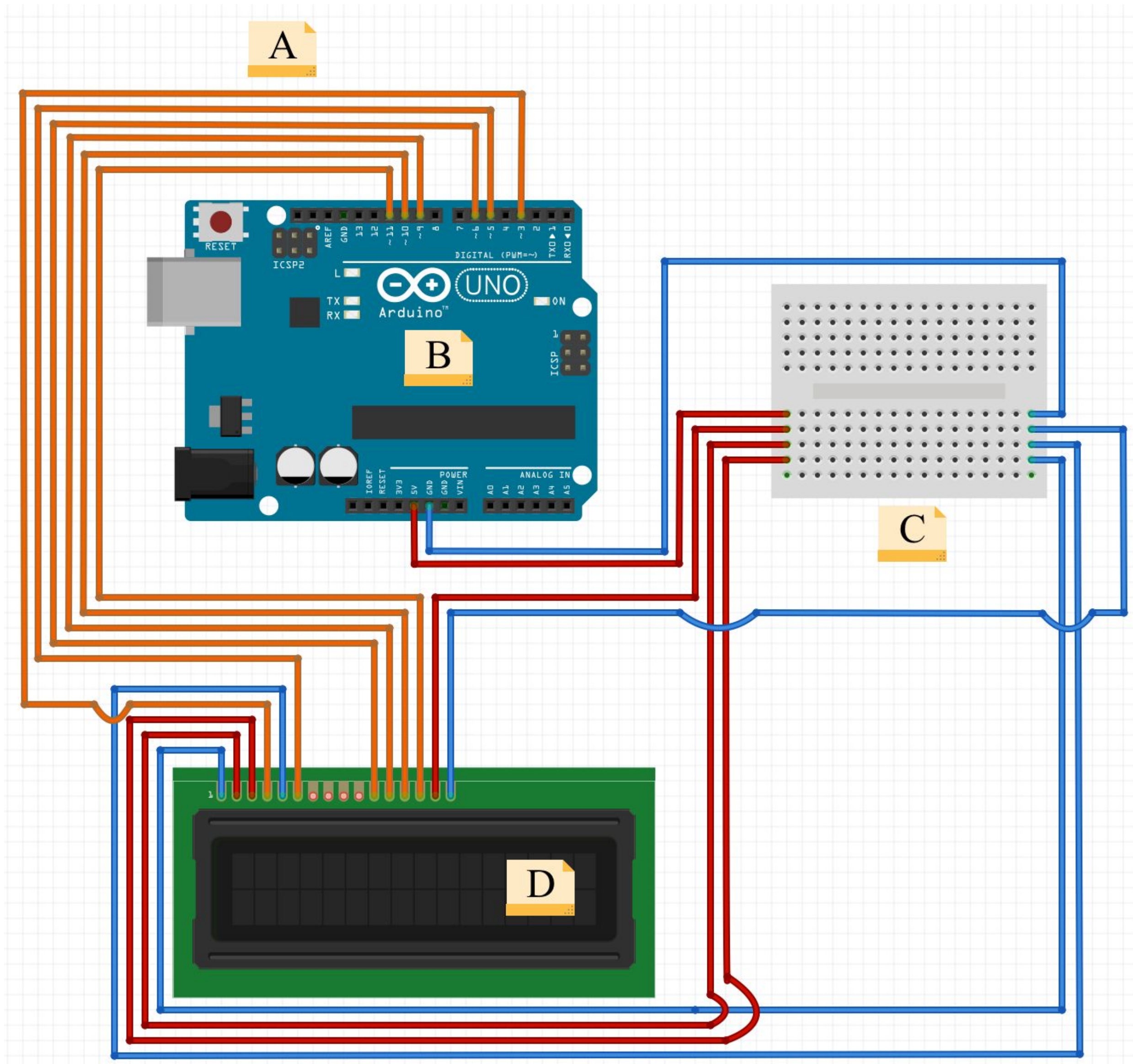

Fig 4. Arduino and LCD Schematic. Above outlines the circuitry for the communication-dedicated Arduino and the LCD to be attached to the side of the spacecraft. PWM ports are used to specify which characters are displayed on the LCD. LCD contrast is set to high at all times, as seen with Pin 3 of the display.

Legend:

A) PWM wires for LCD character inputs
B) Arduino Uno, 5V voltage
C) Mini breadboard for extending potential and ground
D) LCD for displaying orientation information

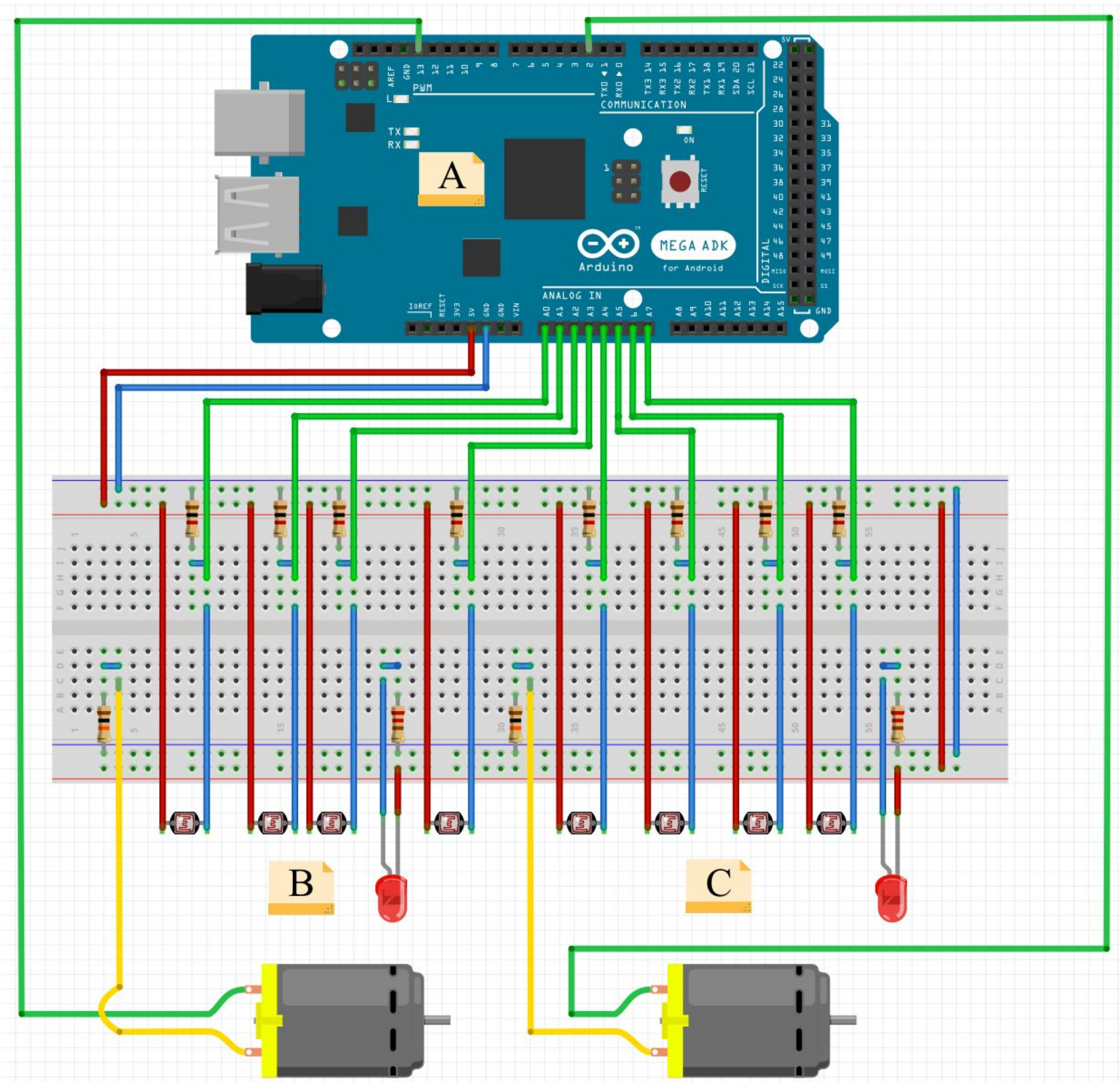

Fig 5. Photoresistor and LED Schematic. Above outlines the circuitry for the eight photoresistors used for the three-axis system, including the LEDs for the two gyroscopes. Note that the photoresistors and LEDs will be located within the spacecraft as detailed in the Design section. Some duplicate parts omitted for clarity.

Legend:

A) Arduino Mega 2560 Rev 3, 5V voltage

B) Four photoresistors (connected to 1kΩ resistors), LED (connected to a 220Ω resistor), and DC motor (connected to 10kΩ resistor) for gyroscope 1

C) Four photoresistors (connected to 1kΩ resistors), LED (connected to a 220Ω resistor), and DC motor (connected to 10kΩ resistor) for gyroscope 2

5 Program Flowchart

The following flowchart details the logical procedure of the spacecraft's software. The final product will have a similar logical approach to calculating orientation and updating displays.

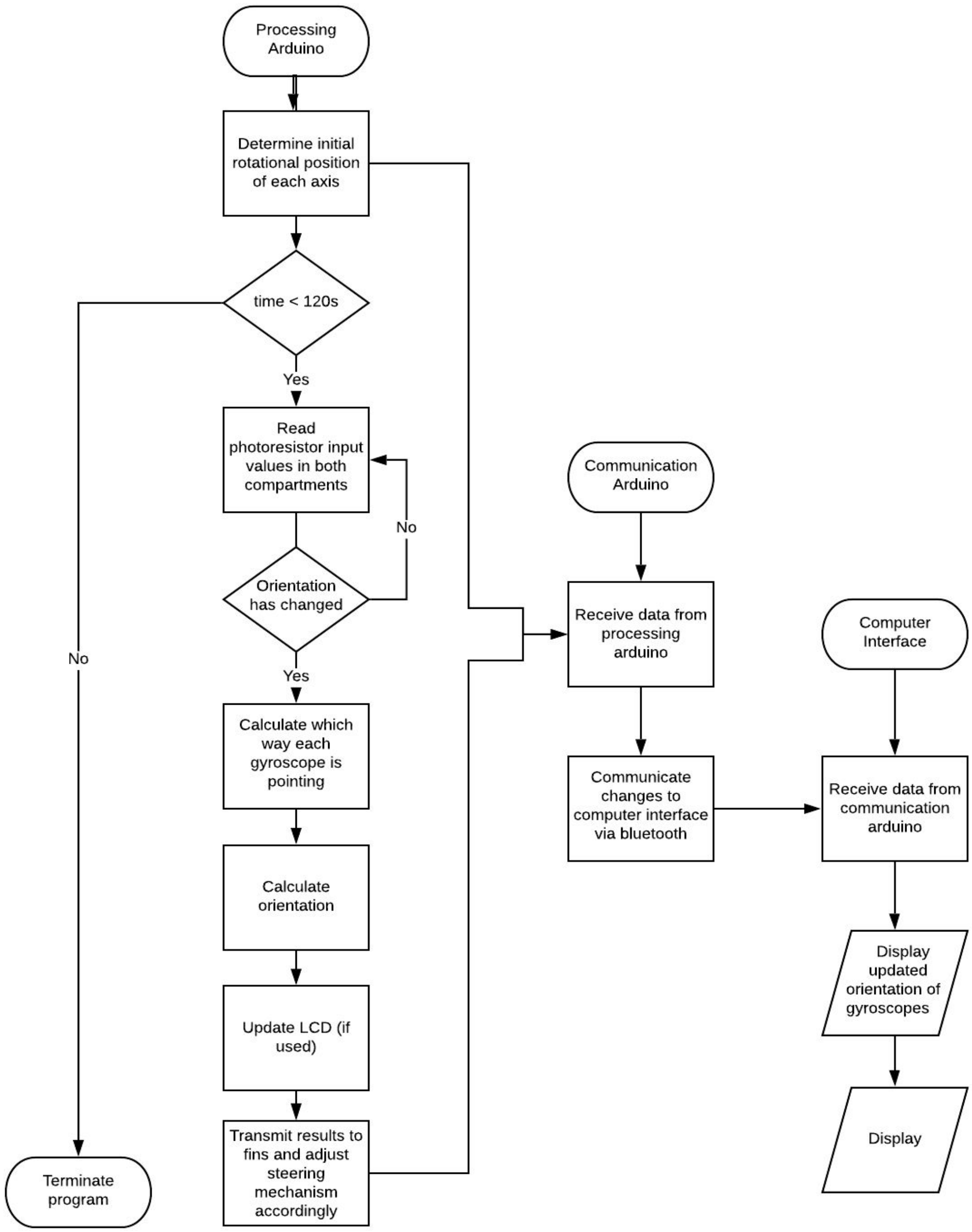

Fig 6. Flowchart. Above outlines the basic mechanisms of the software program. The functions of both arduinos are demonstrated, along with the transmission of data throughout the experiment.

6 Procedures for Construction

6.1 Gyroscope

The gyroscope will not be a conventional spherical shape, but a crane shape instead. This would be made up of two straight planks, with the rotor at the end of one. The rotor will be constructed out of a malleable material and heat-treated for 10 minutes at 350°F to add structural integrity in order to control the molding and shape of the final product. The density of the selected material was chosen to be as high as possible to increase the mass of the rotor, allowing for a higher angular momentum when spun. The first plank will be perpendicular to the base on which the gyroscope is mounted, able to turn about the longitudinal axis. A pivot will be drilled into this, so that the rotor axis can be attached. From the two axles, each of the gyroscopes will possess two degrees of freedom, one for the base axle, and the other for the rotor axle. Each pivot point provides two axes of direction, and by the two angles calculated, a position will be found with respect to the reference orientation. This process uses the same fundamentals principles as the two angles required in astronomy to locate an object. A DC motor will be attached on the end of the axis with the rotor on the end. From the side of the rotor axis, a light will be set up, pointing parallel to the rotor axis. This attachment will be included such that the source of light will remain stationary relative to the rotor axis. Thus, it will be independent of any rotation or revolution of the planks. This device will be used to emit a beam of light, which will be picked up by the photodiodes to provide a reading of the angular position. Two of these gyroscopes will be constructed to obtain an unobstructed view of angles in all three axes.

6.2 Housing (Spacecraft)

A reinforced cardboard box will be erected about the system. The housing will have three major objectives: a secure housing for the gyroscopes, able to block the passage of any stray light rays, and provide an appropriate opening mechanism that adheres to the two other constraints. The housing will be rendered sturdier with thicker walls and other layers, such as duct tape and/or paper on edges. This will have to be well-sealed and opaque so that ambient light cannot penetrate into the house. To access the internal components, whether it be for the initial construction, testing, or final demonstration purposes, the box will need a reliable opening/closing mechanism. A velcro-shoebox system is proposed for this. The five other walls of the shoebox will be held shut; this is to prevent any ambient light from seeping into the gyroscope, thereby skewing the readings of the light sensors. However, one wall will be used as the opening hatch, and the connective material chosen was velcro. Velcro was selected based on its ability to successfully lock together surfaces and its longevity. With its individual strands, light will have difficulty passing through the crevices, which is optimal. Around the box, any holes will be covered first with cardboard, for stability, and then black duct tape, for opacity.

Additionally, a partition will be created between the two halves of the box to separate the reading of each gyroscope. Again, this divider will be subject to the same reinforcing and duct tape treatment along with the rest of the walls. As mentioned, reflective material such as aluminium foil may be lined on the inner walls, depending on the degree the sensors are able to receive reflected light.

6.3 Sensor Setup

Apart from the construction of the mechanical portions of the gyroscope, the sensors must be held under consideration. Though a crane-style gyroscope was elected, the range of motion of the rotor remains a spherical path. Using symmetry, four sensors per compartment will be placed around the center pivot point of the gyroscope. This allows for coverage of all the possible areas that the rotor may traverse. Specifically, four sensors were chosen to cover the blindspots of the three others, with the exception of the axle point that is drilled into the cardboard housing. So, to account for the possibility that the direction is pointed directly at the axle connection point, a second gyroscope was constructed.

For the one axis ring, the sensors in an asymmetrical manner will be fashioned so that they can cover the full circumference of the motion. Extrapolating to a three axis guidance system, two gyros, with two tetrahedrons in each compartment will be built in order to effectively map the path of the motor. Further, a photodiode was selected instead of the traditional photoresistor as the sensors will be used in a spherical chamber, so photoresistors are not appropriate in this application.

6.4 Ardunio and Connection System

The Arduino and its connection system will provide the reading required to determine orientation. However, due to the nature of the two gyroscopes and eight sensors, the delays in computing and communication between the sensors and the output must be considered. Thus, efficiency in algorithm and hardware is imperative to the success of this device. One such issue in the hardware, is a possible failure in the breadboard circuit system. In this case, soldering may be needed to restore the connection. Wires will provide a communications media between the microprocessor and the surveillance system of the house, going around the sides of the house so as not to obstruct the lighting system. Thus, the placement of the microcontroller, communication device, and the wiring is another important consideration as improper placement can allow for reflected light and a non-homogeneous sphere of detection for the photodiodes. Thus, the control system will be placed on the exterior of the housing in order to minimize the amount of obstacles inside the housing. Small holes will be drilled into the cardboard to allow for the wiring to escape through. Apart from the locations of the various parts, the system itself will not need to be constructed per say. Its wiring configuration is detailed above.

7 Procedures for Testing

During the design and construction of the device, extensive testing of equipment, materials, and various components of the product is required in order to ensure accuracy and precision during operation. Thus, prior to assembly of the final product, individual components will be tested based on predetermined expectations for required functionality of the product. Before the final product is assembled, the individual components will be first tested.

The design process involved several rounds of idea generation in order to achieve a theoretical design that will meet all constraints of the project pursuant to van Bemmel (2019). However, there are still several possible working methods to design individual components of the project. Each component would be analyzed separately in order to achieve an optimal and efficient working design for the final product. In the event that a component does not perform up to its set expectations, the following procedure would be to determine whether the result was caused by faulty equipment or a structural design flaw. Replacement parts will be tested in the case of equipment failure. However, structural design flaws would be more detrimental, and solutions must be devised to resolve them and precautions must be taken in the design process in order to limit this type of error. The following sections detail how various equipment and components of the project are to be tested and evaluated.

7.1 DC Stepper Motors

The purpose of using motors is to be able to achieve an angular velocity in the gyroscope as its function is based on rotational motion and control the steering mechanism used. The gyroscope device must be operational for a minimum of 120 seconds, therefore the angular velocity must be kept at a certain value for that period of time. In an ideal case, once the gyroscope reaches a desired angular velocity, the DC motor can be turned off and the angular velocity will remain constant. However, there is too much air resistance and friction forces for this to be possible. Therefore, if the angular velocity cannot be maintained for 120 seconds, the DC motor must be mounted onto the device in order to function continuously for that period.

The exact value for the required angular velocity cannot be determined now, as the friction caused by the rotor and axis is unknown. Once this value is known, that would aid in determining the specific velocity requirements. Then, by marking a point on the edge of the gyroscope, it will be rotated using the DC motor. The angular velocity can then be approximated by filming the rotation at a high frames-per-second and determining the time taken for one complete revolution. Furthermore, this system is able to function because of the conservation of angular momentum. In order to obtain a greater angular momentum, a larger moment of inertia and angular velocity will be required. As the DC motor is only able to affect the angular velocity, then that is the only parameter that can be tested. Again, the exact value of the required angular velocity is not significant as long as the device is still functional. The DC motors are expected to achieve a minimum angular velocity that allows the gyroscope to function accurately. This velocity will be measured and recorded. The stepper motor will orient the fin/throttle components according to perceived orientations. It must be assured that the motor is pointed in the correct direction according to the input PWM signal, otherwise the steering mechanism may be incorrect during runs.

7.2 Photoresistor

A primary concern regarding the photoresistor functionality is the presence of external light sources that can have effects on the resistance. As such, the spacecraft housing contraption must be opaque enough to ensure that the only readings received by the photoresistor are the LEDs on the interior of the apparatus. To test this, bright, encompassing flashlights will be shone on the box and the readings of the photoresistor will be compiled to determine if the results vary. After the results remain constant for a series of tests, it will be concluded that the photoresistor is receiving light exclusively from internal lights, and that other external sources such as overhead artificial lighting or natural light cannot seep through the housing walls.

Next, it is also important to make sure that the photoresistor is able to detect and respond appropriately for a full range of light intensities. For the photoresistor (5 mm GM5539), they are expected to respond to light intensities from a scale of 0 to 1024. Using a digital multimeter, the efficacy of the photoresistor can be tested. Since the resistance is proportional to the amount of light directed onto the photoresistor, its operation must be tested at both extremes to prevent any imprecise readings. In accordance with the GM5539 properties, the photoresistor will be exposed to both direct sunlight and an opaque surface to verify that it is functional in these circumstances. The multimeter will be used to ensure that the resistance is directly correlated to the amount of light taken in and compared to the values on the actual specifications sheet of the photoresistor. Parameters such as maximum operating voltage, resistance under conventional illumination, and peak wavelength will be measured.

7.3 Software

The software must also be tested to gauge its efficiency and precision. A set of three tests were devised to test the various aspects of the software, which includes the input from the sensors, the algorithm that converts the reading of light to a linear value, and finally the output from the LCD, if actually implemented. The first procedure would be first to tilt the contraption by a known angle, somewhere around 15 degrees, a non-trivial amount. This measurement can be effected by a protractor. Then the LCD will be verified to see if it displays the same angle with a tolerance range of 1% of the initial angle. The second test involves trying a combination of angles on all axes to see if the software can precisely deconstruct all of the components. This can be done by configuring the orientation of the device so the light signals of each photoresistor can be compared with the reference angles. Finally, the software should run in real time, the delay between the input and the output results should be as minimal as possible.

7.4 Gyroscope

After the gyroscope is constructed, it must be tested to ensure it performs the intended task complying with the specifications set above. The main function of the gyroscope is to maintain the orientation of the spin axis, so a laser pointer will be used to verify this. The laser pointer will be situated on a stationary part of the axle so that it does not rotate. Once the pointer is turned on, it will be aimed against a target, which will be roughly 30cm away from the gyroscope. Next, the motor will be turned on to spin the rotor and calibrated to obtain the initial orientation. The gyroscope will be rotated with respect to its center and the laser's distance from the target will be evaluated to assess the precision of the device. A tolerance range of around 1% of the laser deviation distance is expected.

An important consideration in the operation of the gyroscope is that it can maintain roughly the same angular velocity for the testing period if the DC motor is not used to spin it throughout. During its motion, kinetic energy is converted to thermal energy by friction, which reduces its angular velocity. Although frictional effects cannot be wholly removed, they can be minimized to ensure the consistency of the gyroscope movement. Friction can be reduced through the application of a lubricant such as cooking oil.

7.5 Wiring and General Hardware

The wiring and general hardware component of the device are essential to the readings generated by the gyroscopes and thus must be examined in greater detail. First, it is important to ensure that the schematic works properly and that everything is wired correctly for the desired results. Besides the wiring, the breadboard connecting circuit must also be tested with programs and trials. The Arduino communication with the computer must also be sufficient and done in real time, adequately close. Finally, the LCD or the computer displaying the orientation and angles should be displaying the correct values.

8 Production Schedule

Phase	Task	Start Date	End Date
Planning and Design	Idea generation	31/10/2019	05/11/2019
	Idea screening	05/11/2019	08/11/2019
	Concept development	08/11/2019	08/11/2019
	Prototyping	04/12/2019	08/11/2019
	Component requirements	05/11/2019	08/11/2019
	Compilation of supplies	05/11/2019	08/11/2019
Prospectus	Introduction	24/11/2019	25/11/2019
	Blueprint, Design Description	25/11/2019	26/11/2019
	Wiring Diagram	26/11/2019	27/11/2019
	Procedure Outline	27/11/2019	28/11/2019
	Flowchart of Software	28/11/2019	29/11/2019
	Budget	29/11/2019	30/11/2019
Housing Contraption	Design and Blueprint	11/11/2019	26/11/2019
	Construction	13/12/2019	20/11/2019
Gyroscope	Idea brainstorm for gyroscope design	11/11/2019	26/11/2019
	Design of gyroscope	11/11/2019	26/11/2019
	Gyroscope construction	01/12/2019	20/12/2019
	Gyroscope connection to sensors	14/12/2019	23/12/2019
Sensors	Idea generation for sensor type	15/11/2019	16/11/2019
	Wiring of photoresistor sensors	16/12/2019	24/12/2019
Fins	Design of fins	11/11/2019	28/11/2019
	Fin construction	19/12/2019	21/12/2019
	Attachment of fins to housing system	21/12/2019	27/12/2019
Testing of Equipment	Gyroscope Operation	04/12/2019	7/12/2019
	Sensor Precision/Operation	07/12/2019	08/12/2019
	Display of results	08/12/2019	10/12/2019
	Arduino Operation	10/12/2019	12/12/2019
	Wiring/Breadboard	12/12/2019	14/12/2019
	Light detection algorithm	14/12/2019	16/12/2019
Software	Arduino connection to computer	05/12/2019	06/12/2019
	Arduino connection to sensor	06/12/2019	08/12/2019
	Arduino connection to motor	08/12/2019	10/12/2019
	Arduino connection to LED	10/12/2019	11/12/2019
	Sensor processing to effect orientation	11/12/2019	14/12/2019
	Graphical display of performance	14/12/2019	15/12/2019
	Correcting deflections/inputs of fins	15/12/2019	20/12/2019
Essential Final Report Information	Operations Manual	25/12/2019	26/12/2019
	Marketing Pamphlet	26/12/2019	28/12/2019
	Explanation of final product deviations	26/12/2019	28/12/2019
	Presentation of testing data	28/12/2019	31/12/2019

9 Budget

Item	Brief Desc.	Quantity	Price/Unit	Subtotal
Arduino Uno	Microprocessor for communication	1	$13.95	$13.95
Arduino Mega 2560 Rev 3	Microprocessor for computation	1	$26.50	$26.50
Light Emitting Diode (LED)	Emits light in tandem with gyroscope	1 (10 pcs.)	$1.60	$1.60
Photoresistor (5 mm GM5539)	Reads light intensities	1 (30 pcs.)	$9.99	$9.99
Liquid Crystal Display (LCD) (optional)	Displays orientation information	1	$4.87	$ 4.87
Resistor (0-1MΩ, assorted)	Acts as load for circuits, used to control LED brightness	1 (550 pcs.)	$14.99	$14.99
Breadboard	Connects wiring and other electrical components	1	$9.16	$9.16
HC-05 Wireless Bluetooth Module	Used for Arduino to send data to computer wirelessly during runs	1	$7.03	$7.03
DC Motor (16500 RPM)	Exerts constant angular velocity on gyroscopes	1 (10 pcs.)	$12.99	$12.99
Stepper Motor	Direct steering mechanisms	2	$9.44	$18.88
H-Bridge Motor Driver 1A	Controls stepper motor	2	$2.35	$4.70
9V Battery	Powers stepper motor	4	$0.75	$3.00
Wires	Connects circuitry components through breadboard	1 (120 pcs.)	$11.95	$11.95
Cardboard	Acts as outer casing for gyroscopes and sensors. Also serves as material for fins	1	$0.26	$0.26
Aluminium Foil	Reflects LED light, allowing for better sensor reception	1 (roll)	$2.06	$2.06

Duct Tape	Attaches outer casing and shields sensors from external light	2 (rolls)	$2.95	$5.90
Velcro	Seals top hatch of spacecraft with easy reseal	2 (rolls)	$1.55	$3.10
Glue	Attaches housing components	2 (rolls)	$1.45	$2.90
Budget Total				$154.55
Budget Maximum Assigned				$175.00
Remainder				$20.45

10 Sources

- http://www.hmvb.org/apc1920lm.pdf
- https://interestingengineering.com/gyroscopes-what-they-are-how-they-work-and-why-they-are-important
- https://www.britannica.com/technology/gyroscope
- https://www.instructables.com/id/Controlling-a-Stepper-Motor-with-an-Arduino/
- https://www.mpoweruk.com/gyros.htm
- https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5677445/
- https://www.tandfonline.com/doi/abs/10.1080/00107516508204362?journalCode=tcph20
- https://learn.adafruit.com/photocells/using-a-photocell
- https://maker.pro/arduino/tutorial/how-to-use-an-ldr-sensor-with-arduino
- https://www.hindawi.com/journals/js/2018/9684326/
- https://www.w3.org/TR/gyroscope/
- https://store.arduino.cc/usa/components/components-sensors
- https://www.thegeekpub.com/wiki/list-of-arduino-sensors-and-modules/
- https://www.elprocus.com/arduino-sensor-types-and-applications/
- https://www.sciencedirect.com/topics/engineering/photoresistors
- http://www.resistorguide.com/photoresistor/
- https://www.robotshop.com/ca/en/stepper-motors.html