The Soft Guided Glider

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This document details the methodologies used to design and build a localizing glider which is capable of delivering vital supplies to people in need when they are in locations that are hard to reach by land.

Keywords—Glider, Soft Robotics, Compact, Compliant, Low cost, Lightweight,

I. Introduction

For this project various methodologies were used in order to design and build a soft, low cost glider with compliant wings. The compliant wings ensure that they don't break when a collision occurs and allows them to be folded for the glider to be compactly stowed.

Much of the mechanical design was completed by using Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) software, and simulations were undertaken with the use of FEA (Finite Element Analysis).

Tensile testing was undertaken on different materials, including soft materials, to measure whether they were appropriate for use in the glider. Additional resources can be found concerning this glider on the GitHub repository [1].

II. Mechanical Design

The mechanical design of the glider was undertaken with an iterative process, and each of the iterations were compared with the glide ratio.

The glide ratio is defined as the instantaneous ratio of rate of fall to horizontal speed for a glider [2]. In order to measure this, the height the glider was thrown from and the distance the glider moved was measured. The goal of the project was to design a glider with a glide ratio of 6:1 which is roughly half of a typical commercial glider.

A. Initial Design

The initial glider design was inspired by bats which have the ability to fold their wings, resulting in a very compact package.

The initial design therefore attempted to replicate the wing folding of bats, using the wing skeleton structure as a baseline. This skeleton was 3d printed in PLA and was wrapped in LDPE (a common plastic used to make bin bags) to form the skin. Online searches established the typical proportions of a glider providing an estimate of how big the wings should be compared with the body.

The first iteration was made with the purpose of developing an understanding of gliding. This concept model was cheap and made from lightweight materials that were easily accessible.

Upon testing, this concept model displayed:

- The importance of weight distribution
- When the wings were fixed in place, they were fragile

It was decided that each component part would be specifically designed. Both the strains to be imposed and the 3d printing orientation relative to the strain were considered in the design. In addition, crumple zones were included to improve the survivability of the glider upon impacts.

Further research established that whilst bats are very agile, they are very active flyers. As they do not spend much time gliding, the model of bat aerodynamics was not appropriate to the design objectives. Overall this version achieved a glide ratio of approximately 1:1.

After testing and analysing the bat glider design it was decided that a more traditional fixed wing design with much larger wings was required. To achieve the small storage volume and compliant wing, consideration was given to either wings that would fold up above the fuselage, or wings that would hinge to fold alongside the fuselage. It was decided that using hinges mounted on the body to fold the wings above the fuselage was the best solution. This would also allow use of existing model glider designs but with the acceptance that the glider would consume a larger overall volume than that of a bat design.

B. Wing Design

1) Prototype Wing Design

For the second iteration the wings were the primary focus. To prototype and test the aerofoil (wing profile), a sheet of

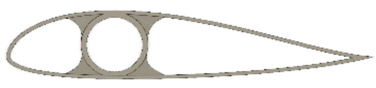

Figure 1 - An image of the 3D printed model of the wing aerofoil.

cardboard was folded around a CAD drawn model of the aerofoil (See Figure 1).

The cardboard wing was hollow with a wing span of 1.2m and a depth of 95mm. The aerofoil used for this prototype was the HS130, although it is hard to find data as to why this is a viable aerofoil it is a commonly used one for model gliders within the hobbyist space [3].

Once the wing was created a rudimentary body and tail was also made from cardboard and test flights were undertaken on this prototype glider (See Figure 2). For the cardboard prototype we found after a series of test flights its glider ratio was 2:1. It was decided that a lighter weight and larger surface area would allow a larger glide ratio along with a more refined design of body and tail.

Figure 2 - An image showing the cardboard glider prototype.

2) First Wing Design

To ensure that the wing was lightweight a skeletal structure was designed. In order to get the best balance between rigidity and weight, a test print was created (See Figure 3) with different thicknesses of the aerofoils. It was found that 1mm of thickness offered the best balance between weight and rigidity.

Figure 3 - The test piece used to find the optimum balance between rigidity and weight.

The further optimised aerofoils were printed and slid onto a PVC pipe so that the aerofoils were perpendicular to the pipe and evenly spaced. Next, 2 carbon fibre rods were glued to the leading and trailing edge on the aerofoils, and a lightweight shrink wrap material was stretched and glued around the wing, this material was later heated to shrink and tighten it further to the skeleton to leave a smooth surface.

The carbon fibre rods were added to:

- Add more rigidity to the wing and stop the aerofoils from becoming out of alignment
- Prevent the wrap from 'drooping' between the aerofoils when the heating element was applied.

To test the glider, the wing was initially designed to be fixed wing. However, it was designed so that the wing could be cut in half, when the folding mechanism was created.

The final dimensions of each wing were 390 x 145mm. Upon testing this wing configuration with a skeletal body as well, a glide ratio of 6:1 was achieved. A graph showing the results can be found on the GitHub repository [1].

3) Final Wing Design

Figure 4 - An image showing the fixed wing design.

For the final revision of the wings, only slight adjustments were made.

- Each wing was made longer going from 390mm to 630mm (with no change in depth).
- The carbon fibre rod used on the trailing edge of the wing was replaced by a carbon fibre strip, this was to reduce the protrusion of the carbon fibre into the shape of the aerofoil.
- A different heating element was used to shrink the wrapping material moving from an iron on low heat to a heat gun. It was found that this gave a better more even finish on the wrapping material.

For this wing, simulations were undertaken to see the vertical displacement that would be produced by gravity between the mounting point of the wing to the tip of the wing. This value was calculated by hand and using FEA. For the FEA simulation it was found that there was a displacement of 1.149mm, a very small amount of vertical displacement when considering each wing is 630mm in length. The hand calculations were completed using the following equation:

$$Deflection\ under\ load = \frac{WL^3}{3EI}$$

Where:

- W = the moment that is acting on the wing.
- L = the length of the beam.
- E = the young's modulus of the PVC tube.
- I = the second moment of area of the PCV tube.

The moment acting on the wing was calculated by finding the centre of mass relative to the mounting point and the mass of the wing, both of which could be found from the simulated model in fusion 360. The moment was found using the following equation:

$$W = FD = 0.6047N * 0.320m = 0.193504Nm$$

The Young's modulus of PVC pipe was found to be 3.4GPa [4].

To find the deflection of the beam the second moment of area was used. As the PVC pipe was a hollow tube the following equation could be used:

$$I_{NA} = \frac{\pi}{4}(R^4 - r^4)$$

Where R is the outer diameter at 7mm and r is the inner diameter at 6mm. From these values, a second moment of area of $867.86m^4$ was found.

The length of the wing was 0.69m. With these values the deflection under load was calculated to be 4.96×10^{-6}m. Although this number did not reflect that of the simulation, both numbers are sufficiently small enough to be negligible in the consideration of the wings. The difference is likely due to materials selections in fusion.

C. Body

1) Initial Body Design

Once the cardboard prototype and its testing were complete a body was designed in parallel with the first revision wings, this body was skeletal in structure having minimal internal support structure to allow internal space for electronics and the wing retraction mechanism. This allowed for lightweight design.

Figure 5 - An image showing the skeletal structure of the glider body.

All the sections of the body were 3D printed and connected together using dove tail joints. A test piece was printed with different sizes and tolerances of dove tails to see which would give the best fit, this can be found in the GitHub Repository [1]. Once this was done the body was design printed and assembled.

This body was then tested with the wings as the first revision of the 3d printed glider. From testing this design it was clear that there were several issues with this design:

- There was not enough structure at the nose of the body leading to this being flimsy
- The point of the nose being so sharp meant that when the glider fell and landed nose first the body would shatter.

2) Secondary Body Design

For the next revision the body was altered in several ways:

- It was made more modular by increasing the number of pieces from 8 pieces to 16.
- The nose of the body was given more supports and was adjusted to be more rounded to better absorb impacts.

These adjustments resulted in a 6:1 glide ratio being achieved and less parts being broken. However, if a part was broken, it was removed easily, reprinted quickly, then reattached to allow testing to continue.

On this version some calculations were done to ensure that the body was balanced optimally for efficient flight [5]. The Static Margin (SM) was calculated to measure the stability of the plane. In order to find the SM, the Aerodynamic centre of the wing was calculated. This is the point where the force can be said to be exerted when the glider is being lifted. As the wings are rectangular, this was found easily as it fell 25% of wing length back from the leading edge, which was 37.5mm. The Aerodynamic centre of the tail was then found. The Aerodynamic centres were used to calculate the Neutral Point (NP). The NP is the centre of lift for the whole glider and was found using the following equation:

$$D = L * \frac{tail\ area}{tail\ area + wing\ area}.$$

Where:

- L is the distance between the aerodynamic centre of the tail and the wings.
- D is the distance the natural point is from the aerodynamic centre of the front wing.

It was calculated that the natural point of the glider was 69.28mm back from the aerodynamic centre of the wings.

Finally, the centre of gravity (CG) was found to be 56.78mm back from the leading edge of the wing. The glider is deemed to be stable in flight if the distance between the NP and the CG was ~10% of the Mean Aerodynamic Chord (MAC) which was found to be 145mm (the distance between the trailing and leading edge) [6]. This distance was found to be 12.42mm which is ~10% of the MAC. For this reason, it was concluded that the glider was optimally balanced.

3) Tertiary Body Design

For further iterations of the body design small changes were made to the structure to ensure that the centre of gravity was still positioned at the same point. Subsequent iterations had minor changes to improve structure such as:

- Increasing the size and material around crucial dove tail joints to make sure they did not break

- Changing the position of structural support pieces to allow for easier housing of the electronics along with reorientation of dovetail joints to make the body more rigid in all axis

For the final iteration, testing was undertaken to the nose piece using different combinations of Ninjaflex (a rubberised flexible material that can be 3D printed) and PLA. After comparing several combinations of these materials, it was found that using Ninjaflex support pieces along with PLA body pieces gave a good balance between malleability and rigidity, as when the glider impacted nose first the combination did not shatter, unlike an all PLA nose, but also absorbed the impact well and held its structure while in flight, unlike an all Ninjaflex nose. After these changes and minor iterations through testing, a final body design was produced.

D. Tail

The tail was once again designed as a skeletal structure and wrapped similarly to the wings to minimise weight. After researching it was found that there were 2 main tail designs intended to simplify control of the plane; the conventional tail and the T-tail [7]. The T-tail was designed with the purpose of getting the horizontal fin out of the prop wash and the wing wake. Seeing as a glider does not have an engine, the prop wash was not of concern. It was therefore decided that the simplified mounting of the conventional tail would be implemented for this glider as it allows a more skeletal design, resulting in reduced weight.

Research was then undertaken to establish the proportions of the fins. It was found that the surface area of the 2 horizontal fins together should be 25% the surface area of the wings and the vertical 50% of that [8], but the shape was not as important. Therefore, due to the size limitations of the 3d printer we were using, it was decided to make the fins square.

The horizontal fins were designed to be easily adapted to incorporate elevators to allow steering once the electronics had been incorporated. It was decided that elevators would be used for steering since the wing's design would make it very hard to include flaps or ailerons. The secondary reason was that all the control we needed could be achieved through elevators while minimising the effort required to control the glider.

E. *Wing Hinge*

For this glider, a requirement was that it should be able to be stored compactly and for it to be compliant. In order to achieve this, the wings were designed to be placed on hinges at the body so that they could move from their flight position (perpendicular to the body) to parallel with the body.

For this design, considerations were made to ensure the wings were supported but would also be able to pivot. For this a system of two bearings were used to attach the body of the glider to each wing. From the bearing protruded a rod that had a mount for the wing to attach perpendicularly and grooves at the top and bottom. These grooves were used to attach bands between the two bearing rods, these bands would counter leaver each wing against each other and allow the wings to pivot smoothly. This meant detail would have to be put towards the bands to make sure they were strong enough to hold the wings. Figure 7 depicts this mechanical arrangement.

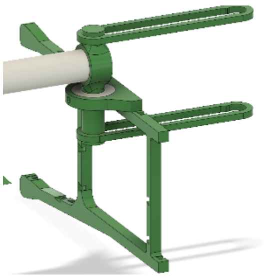

Figure 7 - An image showing the arrangement for the Wing Hinge.

Finite Element Analysis (FEA) was done on the models to calculate several things:

The safety factor of the bearing mount was investigated initially without the support bands. If the value of the safety factor is less than 1, there is a guaranteed breakage. For this test, the minimum safety factor of 0.108 was collected, showing the necessity of the support bands.

The next two areas that were tested for their safety factor and displacement were the rod and the bands. For these tests a torque was found that would be produced by the wings due to gravity and these were applied to the two models in simulation. The safety factor for the rod and band where 4.491 and 8 respectively while the displacements were at maximum 0.16mm and 8.758E^-4mm respectively. These results showed that the wings would be supported by this mechanism.

Once the support for the separate wings was designed, the pivoting design was created, for this all that was needed was a bearing. Several different bearings were investigated, and a nylon bearing was chosen that ensured a lightweight design whilst still allowing for the wings to pivot.

The final attribute of the pivoting design was a stopper that stopped the wings from hyper extending past the perpendicular and moving in front of the glider body. This part was tested using FEA and a force that was calculated using the mass of the wing and the acceleration of the wing when it hit the stopper. The acceleration was found using an accelerometer attached to the wing, which detected the acceleration as the wing unfolded and hit the stopper. The safety factor was found to be 8+ and so the part was easily capable of preforming its role.

All of the finite element analysis reports can be found in the GitHub repository [1].

F. *Retraction Mechanism*

The glider was designed so that the wings would passively be in the gliding position due to the Filaflex elasticated material pulling the two wings together at the leading edge, where they were held against the stopper.

In order to retract the wings, an active system was designed by using a servo and gear train to spin a spool. This spool would then turn coil tethers connected to the trailing edge of each wing, in order to retract them.

The gearing was designed to have a point at the end of the retraction that would disconnect the driving gear from the spooling gear. This allows the spooling gear to unwind and uncoil the tethers that are in direct competition with the Filaflex material.

To drive this gearing a 180° 9-gram positional servo was used. From some simple calculations on where the tether would connect to the wing and that connection's distance from the pivot point, it was found that the tether would have to coil in at least 141.37mm to fully retract the wings. This value was used to design the two gears.

For the driving gear there were a few restrictions to its design:

- It could only have 135° of teeth to drive the gear due to the release section of the gear needing the additional 45° to fully disconnect from the spool.
- The size of the glider itself causing the maximum radius the gear could be to 30mm otherwise the gear would protrude from the glider body.

With these restrictions, the driving gear was made to be 25mm in radius. The spool gear was designed by having the spool directly attached to a gear that would connect to the drive gear. It was found that the spool gear with a radius of 6mm and a spool with 15mm radius attached to the smaller gear would give enough rotation to retract the tethers fully. The calculations describing this and a model can be seen in the following equation:

$$Ratio\ of\ drive\ gear\ to\ spool\ gear = 4.16{:}1$$

This ratio indicates that for each degree the drive gear rotates the spool gear rotates 4.16 degrees. From this we can say that as there is only 135° of driving gear rotation that the spool gear will turn:

Rotation of spool gear = 135° * 4.16 = 561.6°

Knowing this we can look at the spool section of the spool gear and find that it has a circumference of:

C =2πr where r is 0.015m

C = 2π *0.015

C = 0.0942m

We can then divide this number by 360 (a full rotation) to find the distance retracted by 1° then multiply it by 561.6 to find the total distance retracted.

0.0942 / 360 = 0.00026167m/deg

0.00026167*561.6 = 146.952mm

From these calculations we can see that the gearing system would retract the wings far enough for them to be fully folded. The gear system and its mount to the body can be seen in figure 8.

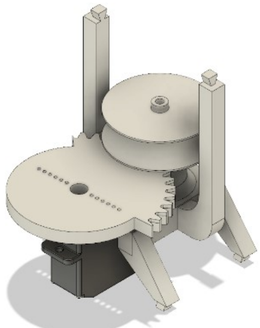

Figure 8 - The gearing system designed for the retraction mechanism.

In theory this system would be able to coil the desired length of tether to retract the wing but when tested in practice it was found that the large torques needed to retract the wings could not be supplied by the servo. The main two reasons for this failure were:

- The rotational distance of the servo was increased on the gearing to provide enough rotation to coil the tether but this led to a decrease in torque applied to the coil meaning that less force could be used to pull the wings inwards.
- The wing was being pulled at a large angle from the parallel meaning that only a portion of the force was being applied from the tether to close the wings.

For these two reasons, the elastic force of the filaflex was not overcome and the wings were not retracted.

III. Tensile Testing

Tensile testing was undertaken to better understand the materials used and to see if they were suitable for their roles.

We started with the filaflex elasticated material that passively holds the wing in the gliding position. Through testing it was ensured that the material would not snap or plastically deform when used in the glider. Before testing the filaflex, other materials and mechanisms were investigated such as different springs and heavy duty (3mm thick) rubber bands. It was found that the springs would plastically deform due to the high extension they would have to endure. For the elastic band it was found that its elastic retraction force was not sufficient enough to hold the wings in place.

The filaflex was strong enough to hold the wings in position but did not hold them when initially thrown. To test the displacement capabilities of the material a tensile test was performed. 20mm of the material was used and the displacement of the material was measured with respect to the

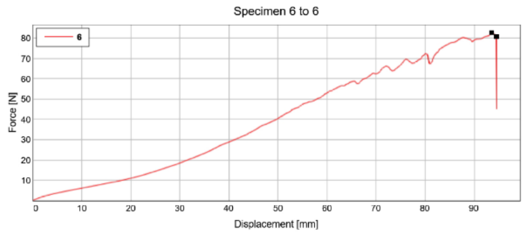

Figure 9 - A graph showing the displacement of filaflex.

force. The results can be seen in Figure 9.

The material was able to displace over 60mm before it began to deteriorate and eventually snap, it was found that this was also in the elastic region of the material. Due to the high extension of the filaflex, it was decided that this would be a useful material for the glider.

The next tensile test that was preformed was on the wing band. This was to test what force the band could take before plastically deforming or fracturing. The tensile test data can be seen in Figure 10.

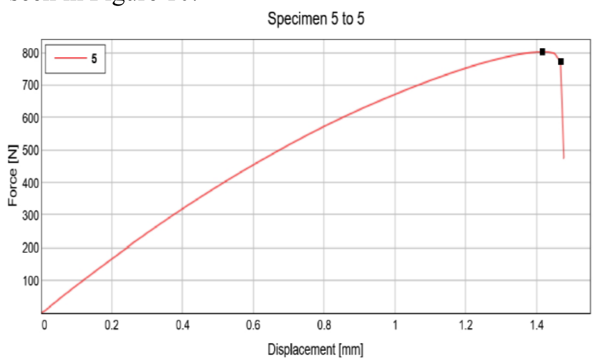

Figure 10 - A graph showing the displacement of the band

This data shows that the band can hold a large force of 800N before plastically deforming and then later fracturing. This means the band is more than sufficient for use on the glider for supporting the wings.

Finally, the ninjaflex 3D print material was compared with PLA material. This was done by comparing the displacement of the gliders body strut that was present in both PLA and in Ninja flex. The the results for the tensile tests can be seen in Figure 11.

These graphs show that both materials have very different properties: Where the ninjaflex began plastically deforming after 100N of force it didn't fracture until it was displaced by ~45mm. However, the PLA strut held a much larger force at over 1000N but then fractured very quickly afterwards as seen by the sharp fall in the graph.

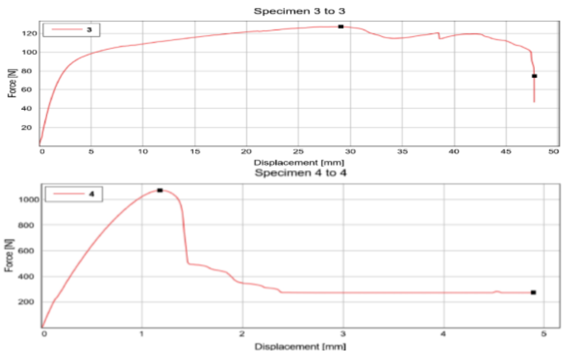

Figure 11 - A pair of graphs showing the comparison between Ninjaflex (specimen 3) and PLA (specimen 4)

Other tensile tests were performed and can be seen on the GitHub repository [1].

IV. ELECTRICAL DESIGN

The electrical design focuses primarily on the stabilisation of the flight, localisation, steering and finally stalling the flight when the distance to the ground is low enough.

A. Power

In order to achieve electronic control, the power requirements were investigated.

Various batteries were considered for the use of powering the electronics. It was required that the battery was as light and compact as possible with enough charge for stabilised gliding for the duration of the glide. The battery used was the 200mAh 651723 battery due to its low weight, low cost and compactness. This battery outputs a voltage of 3.3V.

The LM2937 Voltage Regulator was used so that the 3.3V would be boosted to 5V, which would be sufficient to power the Arduino Nano and the servos. It was found that the voltage regulator did not successfully regulate the 3.3V to 5V, therefore, two 651723 batteries were placed in series to produce 6.6V. Due to the lightness and compactness, this did not have too negative an effect on the glider. This higher voltage was successfully regulated to 5V to power the Arduino nano and the servos.

Testing the battery life consisted of running the system with two servo constantly moving for the entirety of the test, this was achieved by editing the sweep.cpp programme provided by Arduino. Whilst running this code, the batteries lasted for an average of 1 hour 5 minutes and 16 seconds when run five times. This time is deemed to be the worst-case scenario for the gliding time. The data can be found on the GitHub repository [1].

B. Wing release mechanism

A requirement of the system was that the wings would spread out when the glider was initially dropped. This was achieved by taking regular readings with an accelerometer and measuring the difference between the readings. For the purposes of this, only the magnitude of the accelerometer readings was required which was collected using Pythagoras' theorem:

$$Magnitude\ of\ acceleration = \sqrt{X^2 + Y^2 + Z^2}$$

In this equation, the X, Y and Z components represent the three directional readings from the accelerometer.

The wing was released when the difference between the current magnitude and the previous reading was greater than 0.4. The code implemented, and a demonstration video can be found on the GitHub repository [1].

C. Stabilisation

1) Accelerometer Testing

The Accelerometer was a useful tool for detecting sudden movements which would allow the wings to be deployed when the glider is initially dropped or thrown. The uses of the accelerometer were also investigated to see whether it could detect the roll, pitch and yaw.

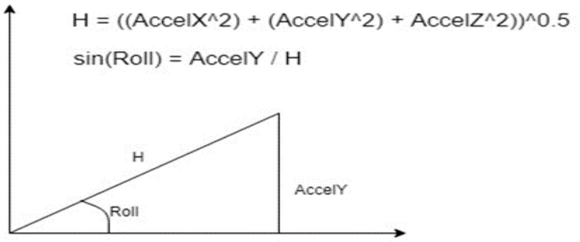

Figure 12 - An image showing the calculation required to find the Roll of the glider from accelerometer data.

By applying the equations found in Figure 12, it was found that the roll, pitch and yaw could be calculated with respect to the Earth's surface. From further research it was found that this is only effective when there is no acceleration except for the acceleration due to gravity [8]. For this reason, the gyroscope was researched.

2) Gyroscope Testing

The Gyroscope naturally measures the angular velocity in the X, Y and Z axis. These velocity values were integrated in order to approximate the angular displacement. With this methodology, the angular displacement calculation was not dependent on being without acceleration. However, because a continuous integration was not possible, there was a drift in the system.

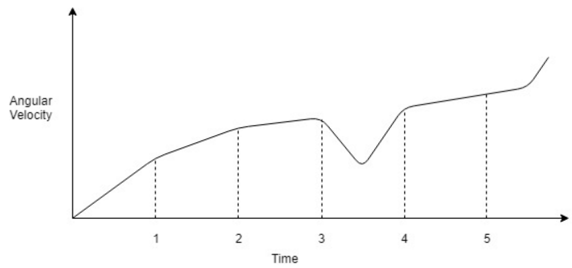

Figure 13 - A graph showing the time intervals for measuring the angular velocity from the gyroscope.

The drift is caused by not having a high enough frequency to detect all the changes in velocity. As can be seen in Figure 13, between T=3 and T=4 there is a dip in velocity, however this would not be detected. It is these missed changes in velocity that cause drift. This drift can be minimised by maximising the frequency at which the readings of the sensor are taken.

$$Angular\ Displacement = \int_0^t Angular\ Velocity\ dt \approx \sum_0^t Angular\ Velocity * Ts$$

From these investigations, the use of the accelerometer and gyroscope together was investigated.

3) Stabilisation with Accelerometer and Gyroscope data

In order to minimise the effect of the drift of the Gyroscope, a complimentary filter was used between the Gyroscope and the Accelerometer.

$$(Gyro\ Angle\ * 0.98) + (Accelerometer\ Angle\ * 0.02) = Rotation\ Angle$$

With this complimentary filter, the drift from the Gyroscope was negated. However, it was recorded that if the frequency became too low, so that the drift returned, the complimentary filter would be adjusted to give more weighting to the accelerometer reading to negate it once more.

Upon proving this method with a separate gyroscope and accelerometer, the circuitry size was minimised by using the MPU6050 that incorporates the accelerometer and gyroscope together for this exact purpose, and the accompanying library was used that is fully optimised for the MPU6050 and uses the same method that was proven and tested.

4) PID Control

The PID was later introduced so that greater control would be accomplished. For the PID to work, the required angle from the pitch and roll was initially set to 0, however, this value would later be changed to a different value in order to steer the glider. To tune the system, the proportional value was initially set to two as the servo output would be taking only half of the input due to the complimentary filter between the roll and pitch.

In order to protect the servos, the maximum and minimum values of the output were set so that if the final PID value became too large, the servos would not be sent to an angle that exceeded their limit and caused them damage.

The differential part of the PID was next to be set which took into account the rate of growth of the error and acted to negate it. Finally, the integral part was tuned so that any residual error is minimised, and any correction is completed smoothly without jitter.

From the output of the PID, the servos were programmed to move against the roll or pitch. This was achieved by using a complimentary filter with the two inputs.

$$Right\ Servo\ Output = (Roll\ Value * 0.5) - (Pitch\ Value * 0.5) + 90$$

$$Left\ Servo\ Output = (Roll\ Value * 0.5) + (Pitch\ Value * 0.5) + 90$$

The Pitch is inverted for the right servo instead of the roll, due to the fact that the servos are placed on the opposite sides of the plane and facing in opposite directions. The code implemented, and a demonstration video can be found on the GitHub repository [1].

D. Localisation & Steering Research

To be able to turn the glider from an actively stabilising glider into an autonomous glider that could safely travel to a specific position, some extra sensors for finding the glider's position relative to other objects were necessary.

1) GPS

The purpose of the GPS sensor was to localise the glider to a global position in order to calculate the required direction of travel for the glider to reach the target location.

The Adafruit 746 GPS module [10] was selected due to it being affordable and a well-supported module that came with example code which could be used to test the GPS tracking and would be easily integrated into the glider.

The GPS module was tested to see what information was provided and investigations took place to understand how to implement it into the glider design. The code started up the GPS satellite tracking of the module and waited to get a fix on its location. When the location fix was achieved, the longitudinal and latitudinal position of the module, along with the direction in which it was travelling, and the current GMT were provided.

From the code provided, elements could be altered in order to obtain the module's position and direction of travel. Once this data was collected, the next step was to establish a target position for the glider to reach; by comparing the glider's original position and direction relative to the desired target position, a vector was calculated. This vector acted as a guide for the glider and would allow for its flight course to be altered in the direction of the target position. The equation for this can be seen below as Direction angle.

$$Direction\ angle = \tan\left(\frac{Target\ Longitude - Current\ Longitude}{Target\ Latitude - Current\ Latitude}\right)$$

The vector informed the glider if it was heading in the correct direction and which way it needed to turn in order to face the correct direction and ultimately reach the target position.

Once this information was obtained the direction that the glider needed to turn would be fed to the PID, which would bank and turn until the GPS sensed it was facing the right direction. At this point, the glider would stop banking and level itself off and head straight.

Although this type of localisation provides a reference of where the glider is relative to the earth and can help with direction of travel to a target position, it will struggle to deal with obstacles in the glider's direct vicinity that may need to be avoided. It will also not be able to calculate the height of the glider from the ground and would thus fail to stall for landing.

2) Close-Proximity Sensors

It was considered that the glider should detect obstacles and avoid them by banking. Additionally, in order to land smoothly by stalling the flight, the distance to the ground needed to be considered. In order to achieve this, Close-Proximity sensors were investigated.

These close-proximity sensors would be fixed to the front and bottom of the glider in order to detect any approaching obstacles from the front and to calculate the distance to the ground.

a) Ultrasound sensors

The HC-SR04 [11] and the SRF05 [12] ultrasonic range finders were investigated for this, due to both being relatively easy to use, the former being very cheap (≈60p each) and the latter having a high working range.

Once the distance was calculated, the sensors could be calibrated to adjust the accuracy of the distance measured by setting the sensors at a set distance from an object and calculating the error at each set distance. An equation could then be formulated to adjust the sensor readings to increase the accuracy of the readings.

If the sensors detected an object within a threshold distance of the front of the glider, a new required angle would be sent to the PID telling it to turn away before collision.

When the sensor underneath the glider detected that it was within close proximity to an object, it would assume this object was the ground and would prepare for landing. At this point, the glider would get the PID to try and stall the glider by pulling up and then folding in its wings, so it could ensure a safer landing.

The problem with using an ultrasound sensor is that it can easily pick up refractions off to one side of the glider and interpret these responses as objects being closer than they are.

b) Infra-red Sensors

The infrared (IR) sensor was also investigated, that used light instead of sound to calculate distance to other objects. The IR Sensor emits light towards an object in a single line rather than a cone, and the intensity of the light bounced back will affect the analogue voltage on the IR sensor module. This analogue reading is then calibrated, similarly to the ultrasound method, to calculate the distance.

c) Evaluation of Close-Proximity Sensors

While IR sensors are typically cheaper than the ultrasound sensors, they do not usually detect the same distances unless more expensive sensors are used.

While the ultrasound sensor picks up some false distances from refraction, the IR sensor will not, but it can instead pick up some parts of the visible spectrum as false distances and make it difficult to calibrate distances.

Due to IR distance sensors normally operating under 1 metre and the HC-SR04 ultrasound sensor having an operational range of approximately 0.5 metres, the optimal sensor, which was ultimately selected for this project, was the SRF05 Ultrasonic range finder, with its superior operational range of 4 metres.

V. Integrating Electronics into Mechanical Design

For the final revision of the glider, the stabilisation electronics were incorporated into the mechanical design. This involved creating a mount for both the servos and the electronic circuitry. This was done with ease as an area had already been allocated for this purpose in the previous versions. The servos that controlled the tail fins were placed in the body and controlled the back elevators via metal rods which would push and pull the tail flaps to steer the glider.

The tail fins were designed with a connector for the metal rod so that when they were pushed or pulled it would pivot the fins in the desired direction.

VI. Conclusion and Further Development

The development of the glider proved to be successful, achieving a 6:1 glide ratio. However, the retraction mechanism and compliant wing design was less successful; Although time and consideration had been put into the design, not all real-world factors were considered, such as the force exterted on the wings when initially thrown.

Given more time, the areas in which further development would be undertaken would be in:

- Implementing the localisation and steering research into the glider design
- Implementing an Agonist-Antagonist joint for the retraction and compliancy of the wings instead of the active-passive arrangement.

The Agonist-Antagonist joint would adjust the stiffness and the orientation of the wings with respect to the body with the use of two motorised pulleys, mounted on the fuselage. If the front pulley was coiled up, then it would pull the wings forwards and if the back pulley was coiled up, then it would pull the wings back. If both pulley's tightened then the wings would become stiffer and if they loosened, the wings would become more compliant. The designs for this can be found on the GitHub repository [1].

VII. Acknowledgment

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