Butterfly Robot

Capstone Proposal

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I. Abstract

The purpose of this project is to create a robot that flies using a motion mimicking that of a butterfly. This robot will be designed to handle situations with environmental, safety, or power restrictions that would make a drone unsuitable. The robot will include sensors for obstacle avoidance and carbon monoxide detection to demonstrate how the robot can unobtrusively monitor an environment for potential hazards. Future projects could utilize other sensors to fit the butterfly's monitoring capabilities to a larger range of potential hazards.

II. Introduction

Biomimetic robots are being researched and developed for the purpose of understanding and reproducing the motions of flying and swimming animals, often using nature as inspiration for alternatives to conventional engineering solutions. The butterfly provides inspiration as a lightweight, unobtrusive creature that can perceive and move about its environment with precision and agility.

While drones have proven to be very useful in many research and engineering applications, they are less than ideal for domestic and other indoor settings. Spinning propellers and the risk of collision can cause property damage or personal injury. The high power consumption of drones often doesn't allow them to run more than a few minutes at a time on a full battery. Further, the sound of the motors and sight of the drone can be distracting or overwhelming for indoor settings.

Dr. Alireza Ramezani has conducted related research in developing a biomimetic robot resembling a bat. Ramezani studied the complex structure and movements of the bat, noting the numerous and varied joints in the wings and agile maneuvers. His research led to the development of a fully autonomous bat robot, weighing only 93g, with comparable morphological characteristics and flexible silicone membranes [12]. Some of the design decisions and robotics engineering practices that enabled Ramezani's Bat Bot can apply in developing a robot butterfly, with similar considerations of weight and biomimetic flight patterns.

A butterfly robot can provide an alternative to drones in situations where they may be unsafe or otherwise unsuitable to operate. The lightweight design and low power consumption will allow the butterfly to move more delicately, quietly, and for longer periods of time than a drone. In this way, the butterfly robot will be able to act as a "cobot", a robot that can seamlessly fit into a human workspace without disrupting work and peace. The ideal cobot would patrol vigilantly around the user's defined target area, prone to sensing any potential danger and immediately notifying surrounding humans.

Cobots, such as the Avansig drone produced by German company Skysense, have already proven their worth in society. Current models of the Avansig are already being deployed by companies and households alike for security purposes, and are completely autonomous in that they guide themselves back to a stationary charging port when it is running out of power. Instead of having a sensor in every room, companies can cut costs significantly by simply using one or two drones per floor.

Figure 1: Avansig Drone

Many sensors today have been built to be easily interfaced to a simple microcontroller, and are lightweight enough to be carried by a small drone. While our butterfly robot will serve as a mobile carbon monoxide detector, our goal is to highlight the versatility of these kinds of drones. They can be deployed on the coastline to detect oil spills, in sensitive medical labs to scan for sudden changes in temperature, pressure, and humidity, or in forests to scout for wildfires, for example. These lightweight sensor drones could be applied to almost any situation which requires delicate maintenance and quick threat detection.

III. Problem Formulation

Our goal is to create a user friendly, fully autonomous lightweight drone that has the potential to replace networks of stationary sensors in the average household as well as larger buildings such as schools or company offices. We also want to highlight the importance of implementing biomimicry into designs, as these products can hopefully become well adapted and blend in with the natural ecosystems that they will be tasked with managing and protecting.

The first challenge of our design is creating a robot that is lightweight enough to fly without any risk of damage to users and their property, yet flexible enough that its durability is not in question. The second challenge is ensuring that our drone is fully automated so that it can blend into the background of the users' day to day activities, without them having to constantly worry about the drone's functionality.

The most important part of solving the first challenge involves selecting the right material for our butterfly's wings. The most common materials used in lightweight drones today include wood, aluminum, and mular. Since our robot is small enough that affordability should not be an issue, we will likely opt for a mylar frame since it is lighter and tougher than our other options. As we need the robot to have as little baggage as possible, the mylar wing itself will act as the printed circuit board (PCB), and will be able to hold components such as our power source and any necessary connectors to the motor, batteries, etc.

Since traditional copper traces would weigh down the carbon fiber wings, a good alternative is using conductive ink, which provides comparable conductivity without placing too much of a burden on our robot. For accuracy and efficiency, we will laser cut our own PCB stencil using the flexible and lightweight carbon fiber and use it to paste on all of our component footprints at once.

Another challenge the robot faces is flying pattern of its wings. Many researchers have attempted to develop MAV and micro-flight robot with various actuators and devices so far. However, their studies have not led to practical applications yet, and one of the reasons is that the flying mechanisms of birds and insects have not yet been clarified [8]. A butterfly combines flapping motion of its wings and gliding to fly and it does not perform linear flying motions such as a dragonfly [8]. A study has been done on butterfly flying patterns and clarified that flapping angles of the butterfly have periodic triangular waveforms and the ratio of the time needed for flap-up and flap-down is approximately 1:1.25 [9].

In [8], the authors conclude that a free flight will be enabled by the robotic butterfly flaps by largely changing feathering angles in the wingspan direction and butterfly's wings should be elastic enough to realize twisting motion and stable flights. Since silicon is very elastic, our challenge would be to changing featuring angles and to determine flap-up and flap-down times through software.

Autonomous flying will be implemented by processing ultrasonic sensor values. Multiple ultrasonic sensors can detect indoor environment and get distances between the robot and obstacles. Ultrasonic sensor distance measurements are based on the evaluation of the time-of-flight or on the determination of the phase difference between transmitted and received signal [10]. Ultrasonic sensors have greater accuracy, high frequency, sufficient sensitivity and penetrating power, and easily interface with microprocessors. These advantages over other sensors make it our best option. However, due to cost and weight limitations, only a limited number of ultrasonic sensors will be used for the design of the robot. This means the robot might not have complete information in a 3D space given that ultrasonic sensors usually have less than 20 degree beam angles. A novel system needs to be designed to give us enough knowledge about the environment to perform effective obstacle avoidance.

In addition, a path planning algorithm and a trajectory planning algorithm will need to be chosen to perform navigation in an unknown environment. As our design requires that all the electronic parts on the robot to be as lightweight as possible, the processor may not have powerful processing power to do complex computing tasks. An optimal algorithm would be efficient in its memory use and has a fast computing speed to do real-time robot control.

In [11], it is argued that the lack of exact algorithms for path-planning problems and difficulty inherent in characterizing approximation algorithms makes it impractical to determine algorithm time complexity, completeness, and even soundness. This makes it difficult to design a guidance system and to choose an algorithm. Authors in paper [11] survey and compare a range of path planning algorithms and trajectory planning algorithms.

These path planning algorithms include: roadmap methods, exact cell decomposition, approximate cell decomposition, potential field methods, probabilistic approaches, and weighted region problems. These trajectory planning with differential constraints include: state-space sampling methods, minimum distance discrete path followed by trajectory forming, mathematical programming, potential field methods, and solutions given uncertainty. More research needs to be done to decide which algorithms are suitable for our design, and tests have to be done to ensure our decisions.

Another challenge arises as this butterfly is used for carbon monoxide detection. Data from carbon monoxide sensor have to be filtered and processed to give a reliable prediction of a real carbon monoxide leak. Furthermore, since the robot is not stationary, it may miss a carbon monoxide leak while flying randomly. As a result, in the path planning algorithm, the carbon monoxide should be a trigger for the robot to stay stationary when carbon monoxide detection is triggered or flying to the detected direction of carbon monoxide, and give out LED signal to humans.

IV. Analysis

A. Mechanical Hardware

1. Robot Frame

For the frame of the butterfly robot, we needed something that was rigid enough to withstand the flapping motion of the wing while also being extremely lightweight to allow the robot to take flight. To satisfy these criteria, we chose carbon fiber.

Compared to traditional metals such as steel or aluminum, carbon fiber offers both higher rigidity and lower weight. In addition, carbon fiber has a low density which allows it to be easily machined which will be crucial to our design as we will be aiming for a thin and light frame for the robot. Since carbon fiber isn’t a metal, unlike steel and aluminum, this means that it isn’t conductive which will be beneficial to our design as the frame will house many electronic components.

Figure 2: Carbon Fiber Quadcopter Frame

B. Electrical Hardware

1. Mylar and Conductive Ink (Flex PCB)

Mylar is a thin, completely transparent polyester film. We will be using this material for the wings of our robot as well as the main material to place our electrical components on. The goal is to select material that can be as thin as possible to imitate the delicateness of a butterfly's wings. A benefit of Mylar is that it is durable and will not tear easily. Other types of materials that may have similar characteristics to mylar are aluminum or vinyl.

To ensure the butterfly will be light enough to fly, conductive ink will be used to create electrical connections on the wings of the butterfly. Conductive ink is simply a liquid solution composed of conductive material, mainly metals. It has gained popularity due to its advantages of being a more cost-effective, light-weight alternative to PCBs. Another option is to use other types of flex PCBs such as double-sided and multi-layer flex PCBs.

2. LiPo Batteries

Lithium Polymer (LiPo) batteries have become popular in many consumer electronics such as quadcopters. The two main alternatives to LiPo batteries are Nickel Metal Hydride (NiMH) and Nickel Cadmium (NiCd) batteries. LiPo and NiMH batteries have dominated the hobby industry for the past couple of years, serving as the power source for RC cars, buggies, and drones.

NiMH batteries are the more traditional choice, and hold a couple of advantages over LiPo batteries. On average, they last between 700 to 1000 charge cycles, compared to 150 to 250 for LiPo batteries. They are also much easier to charge and maintain, while LiPo batteries have more inherent risks associated with improper charging and maintenance.

Despite the risks of using LiPo batteries, many people convert their setups to use them in favor of NiMH batteries simply due to their higher capacities and discharge rates. Their higher discharge rates lead to quicker and more efficient power transfer compared to NiMH batteries. In addition, they are much lighter than NiMH batteries, which is especially important in lightweight drone applications. Many LiPo batteries weigh less than 1g, adding little to no bulk to the drone setup.

3. Processor

There is an abundance of development boards which are capable of providing a platform which we can test the ultrasonic sensors and gas sensors prior to them being placed on the robot. This allows us to evaluate the sensors and gain an understanding on how they operate. With this development board we can easily prototype and implement new ideas.

The development board that will help us achieve our goals is the STM32 Nucleo Development Board. The advantages of these boards is that they are inexpensive and we are able to add-on hardware components which we deem appropriate to test our sensors. These nucleo boards are categorized based on their flash size as well as their performances. There can be an emphasis placed on low-power or high performance.

4. Brushless DC Motors and Controller

In order to mimic the movement of a butterfly's wings, we must use a motor which has the ability to be controlled as precisely as possible. It is important to perform this action with accuracy because we will be relying on this flapping motion to lift the robot off of the ground. The two different types of motors we are considering are the brush dc motor and the brushless dc motor. They are both a type of DC motor which focus on converting electrical energy into mechanical energy. Most DC motors can be powered at a voltage as low as 1.5V.

The brush dc motor is easy to make, cheap and simple. A DC power is applied, which will charge the coil and cause a magnetic field to be generated. The brush DC motor has magnets located on the stator and electromagnets on the rotor. The magnetic field will cause the rotor to rotate. As it rotates, brushes that are located on the rotor will brush against the commutator and inform the motor when its torque is zero and the magnetic field needs to change direction to allow the motor to rotate a full 360°. The brushes that are located on the motor can be a hassle due to its constant maintenance. If the brushes are damaged, the performance of the motor can be compromised.

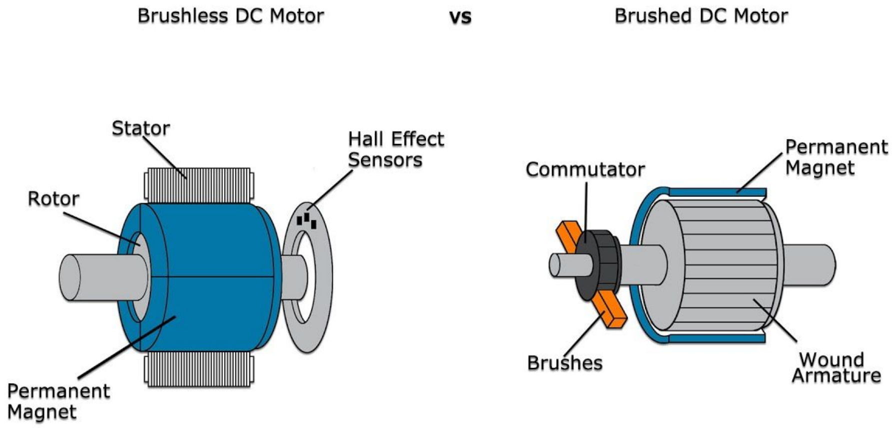

FIgure 3: Brushless versus Brushed DC Motor

Unlike the brush DC Motor, the brushless DC motor operates without brushes. The permanent magnets are located on the rotor and the coils located on the stator. The various types of DC motors have diameters ranging from 13mm to 30mm. It is lightweight, low noise, has a longer lifespan and does not generate as much heat because there aren't any brushes brushing up against the inside of the motor. This in turn will allow the conversion of more power because the friction from the brushes no longer applies. The brushless DC motor can be controlled electronically and the current that is being sent to the motor can be monitored using a computer. Hall sensors are used to inform of the position of the rotor which will notify when the magnetic field needs to be changed in order to allow the full rotation of the motor. The only downfall of using a brushless DC motor is that it is quite expensive.

5. Sensors

In order to prevent our robot from encountering obstacles that may obstruct its flight pattern, we must place sensors which will help maneuver our robot around objects in its path. There are many types of sensors that can help us achieve that. Two types of sensors we were considering were infrared sensors and ultrasonic sensors.

Infrared sensors are capable of determining whether there are obstacles by emitting infrared waves. These sensors are also capable of measuring the heat emission of an object and detecting motion. The common range at which these sensors can detect is at least 4-5 meters. These sensors utilize very little power which allows the sensors to be long-lasting. The disadvantage of infrared sensors is that they may not function properly when placed outside in the sunlight.

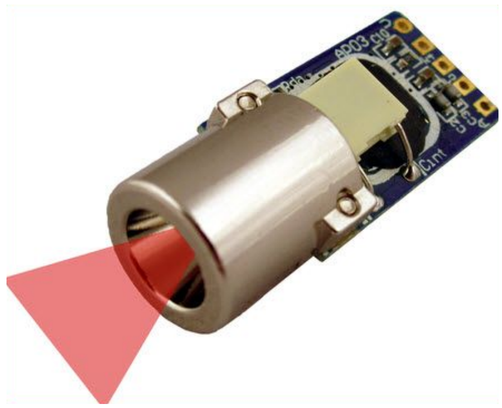

Figure 4: Infrared Sensor

Ultrasonic Sensors utilize sound waves to determine its distance from an object by measuring how long it takes for the waves to bounce back. They are resistant to factors such as mist, smoke, vapor and light. Depending on the type of ultrasonic sensor, the range of detection can be between 5mm-1200mm. Ultrasonic sensors are more reliable and are extremely sensitive. They are easy and safe to use, especially in environments where there might be people present. The only disadvantage to ultrasonic sensors is that they may not be able to capture the existence of extremely small objects.

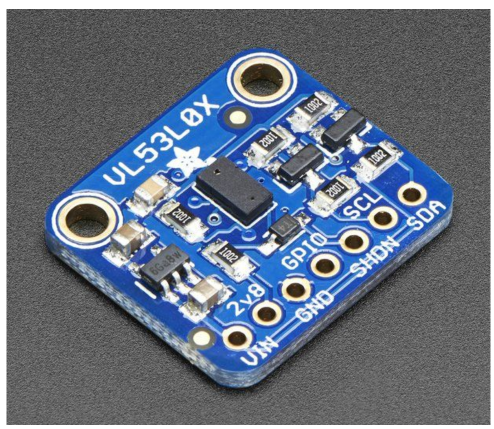

Figure 5: Ultrasonic Sensor

Another characteristic which our robot will have is the ability to detect carbon monoxide. To do this, we will place a type of gas sensor on our robot which will report data of the air in the area surrounding which the robot will be circulating in. There are various types of carbon monoxide sensor, each with their own unique capabilities. The two carbon monoxide sensors which we are deciding between are the Adafruit CCS811 and the Adafruit BME360.

The Adafruit CCS811 is a sensor which can detect volatile organic compounds. In other words, it is able to detect carbon compounds such as carbon monoxide, carbon dioxide, carbonic acid and more. It utilizes I2C and provides a total volatile organic compound reading as well as a carbon monoxide reading.

The Adafruit BME360 is also a digital gas sensor which is able to determine the gas, pressure, temperature and humidity readings in the surrounding area. These features can be specifically enabled and disabled depending on what we would like to use. It utilizes a MOX sensor which is capable of detecting gasses and alcohols such as Ethanol and Carbon Monoxide by noting the changes in resistance which is caused by volatile organic compounds in the air.

6. LEDs and Drivers

For our butterfly drone to be of any use after it detects an anomaly, it must signal to the users that there exists a problem. We plan to use red LED lights that will flash when an influx of carbon monoxide is detected, and will turn off in a normal state.

To properly power our LEDs, we will also need the necessary LED driver. Unlike most bulbs which operate at high voltage AC, LEDs run on low voltage DC, and require the driver to convert the electricity current. The two main types of LED drivers are constant current (CC) and constant voltage (CV). Constant current drivers have one specified output current and a range of voltages that it can operate at, depending on the wattage rating of the LED. Since they maintain a constant brightness, they are often used for signs and commercial LED displays [14]. Constant voltage drivers require a consistent DC voltage, usually 12V or 24V. They are used to run multiple LEDs in parallel, such as strip lights and rope lights. It is important to keep in mind that the CV driver’s voltage output must meet the voltage requirement of the entire LED string.

C. Software

The sensor data collected by the would ultimately be processes by the butterfly robot and shall response with a change to its flying pattern and its LED colors. The robots will be collecting data from Carbon Monoxide sensor and ultrasonic sensor. Data will be converted to digital form through Analog to Digital converter to the microprocessor where the software shall perform the computations. In order to support fast processing and filtering, an efficient and robust data processing algorithm is needed. This algorithm shall be able to discriminate against false data and leave out true data which will be sent to path planning algorithm and trajectory algorithm to calculate the path for the robot. In this way, the robot will be able to navigate around in indoor environment and perform tasks like obstacle avoidance, and send out signal when CO leak is detected. Later add-on features for the software could include IoT feature which can allow human directly control the robot through a tablet or smartphone.

For the development of the algorithm, C and C++ will be an ideal embedded programming language to use on a processor eval board. C is a procedural programming language and is relatively much easier to use than object-oriented programing language. C++ on the other hand is an object-oriented programming language and provides more funcationaly than C. Therefore, both programming languages will be ideal choice for the development of the algorithm.

V. Design Strategies & Approach

A. Mechanical Hardware

1. Carbon-fiber frame

Carbon fiber was chosen as the material for the frame of our robot because of its light weight and rigidity. It's a strong and light material that is made from graphite fibers. Each of these fibers can be thinner than hair. When these strands are twisted together, it gives carbon fiber it's strength.

The carbon fiber will be used at the frame of the butterfly robot as well as a stencil for us to create our flexible PCB. The material's rigidity and lightweight nature makes it a perfect candidate to use for the robot's frame. It's low density makes the material easy to work with and with a laser cutter, a very precise stencil can be made with the carbon fiber. This precision is crucial since circuit components are very small and even the smallest deviations in the stencil could cause electrical shorts.

B. Electrical Hardware

1. Mylar and Conductive Ink (Flex PCB)

Mylar was chosen as the material for our flexible PCB because of its thin and light nature. Its thickness can be as small as .5 mil to 1 mil. This material is non-conductive, which is essential as it will act as the base for the PCB. Mylar can also withstand temperatures between -100°F to 300ºF, so any heat dissipated from the electronic components will not affect the performance of the material. Another benefit of Mylar is that it is resistant to a number of chemical reagents. Due to its robust nature, we will not have to worry about the environment in which we place the robot in.

Figure 6: Mylar

As previously mentioned, we will be using Mylar to attach and connect our electrical components. It is very different from the standard inflexible, layered PCBs, which are made of copper and carved out to reveal the traces of a board design. With Mylar, the copper layer does not exist. Instead, the electrical connections will be created using conductive ink, allowing us to paint our own traces, which will then serve as a path for electricity to flow through them. Conductive ink can be made up of a variety of conductive materials such as graphite and silver. Depending on the kind of surface being drawn on, there are specific types of conductive ink for each layout.

Conductive ink becomes conductive by having metal particles, in the form of flakes or powder, infused within a liquid. In order for electricity to be conducted, the liquid must be cured or dried after its application onto the surface. There are certain types of inks which can be cured at a low temperature of 110 °C. Once the ink is dried, the route which electricity can travel through will be permanent.

A disadvantage to using conductive ink is its characteristic of having a high resistance. Since the metals which are infused within the liquid will be flakes or powder, the conductivity of the ink will not be as high as when using pure metals. However, with the design specifications in mind of keeping the robot as light and agile as possible, conductive ink will prove to be most efficient in achieving our goals of imitating certain features of a butterfly.

2. LiPo Batteries

We have chosen LiPo batteries to use in our design, as we are prioritizing keeping our drone as light as possible while packing enough of a punch to sustain flight for extended amounts of time. We are aware of the potential risks of LiPo batteries if not maintained properly, and will take necessary precautions to ensure that the batteries and the drone itself are not damaged due to misuse.

Figure 7: LiPo Battery Pack

Proper maintenance of our LiPo batteries include making sure we purchase a LiPo compatible charger. These specific chargers are different than regular chargers in that they keep the charge rate constant until the battery reaches peak voltage, while regular chargers charge batteries in pulses, which can have damaging effects on LiPo batteries. LiPo compatible chargers usually also come with a built-in charge balancer, which equalizes the voltages of each cell in the battery pack, and ensures that each cell discharges the same amount. This will greatly increase the number of cycles of our battery's lifespan. It is also imperative that we don't charge the battery too fast. A good rule of thumb to stay on the safe side is to charge a LiPo battery at 1C, or 1 times the battery capacity in amps, unless otherwise stated by the manufacturer.

Storing the batteries properly is also imperative once we are completed with the testing phase of our butterfly robot. The optimal storage voltage for LiPo batteries is around 3.7V to 3.85V per cell, or around 50%-70% capacity. Storing LiPo batteries with a full charge can lead to harmful gases building up inside the cells and damaging our batteries. Following these important guidelines will keep our butterfly robot and LiPo batteries safe from harm and operating at peak performance.

3. Processor

The highly affordable processor eval board nucleo board from STM allows easy programming and integrating. This board has features which are beneficial for the design of the butterfly robot such as multiple types of extension resources, flexible onboard power supply, USB re-enumeration capacity, comprehensive free software HAL library, and supported by a wide choice of Integrated Development Environments. Microcontroller has advantage over microprocessor in that microcontroller has internal memories, Input/output interface, memory, clock, timer and other peripherals. In addition, electrical hardware can be connected directly to this microcontroller and receive commands.

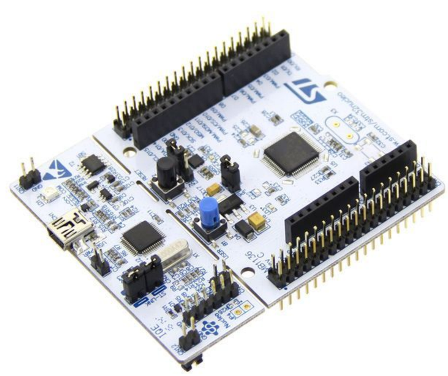

Figure 8: STM32 Nucleo board

4. Brushless DC Motors and Controller

The flapping motion of a butterfly is more intricate than an ordinary up-and-down pattern. In fact, butterflies use a form of "figure-8" motion to fly. To mimic this motion, we have chosen the brushless DC motor because we are able to control it electronically. With the ability to use a computer to control the electrical currents that are being sent to the motor, we can design the movements of the motor with more precise rotations. The brush DC motor was not ideal because it requires maintenance of its brushes fairly often and the sizing selection does not compare to how small the brushless DC motor can get.

5. Sensors

We have chosen the ultrasonic sensor because of its accuracy. Since it does not depend on measuring infrared light, we will not have to worry about placing the robot in sunlight. The sun also emits infrared light which may cause the infrared sensors to have some discrepancies in its reading. The ultrasonic sensor which we chose is about the size of a quarter which follows our criteria of keeping our hardware components as small and light as possible.

As for the carbon dioxide sensors, we have chosen to use the Adafruit BME680 which measures temperature, humidity, pressure and gas. It is capable of measuring more properties than the Adafruit CCS811 sensor and ideal for analyzing indoor air quality. We chose this particular gas sensor because it also fits in with our constraints for the voltage limit which we have set for our robot.

6. LEDs and Drivers

We will most likely use LED strips for our butterfly robot, as these lights are commonly used in many drone applications. It is quite simple to cut the desired number of lights from the strip and connect them directly to our LiPo battery pack through soldering. We can apply double sided tape to our LEDs and set them up on the outer edges of our butterfly's wings.

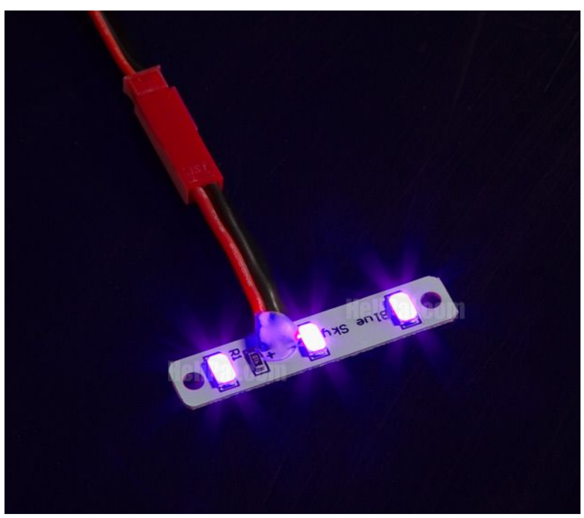

Figure 9: LED Strip

As we will be using LED strips, we will have to use the CV driver to run multiple LEDs in parallel. This is beneficial in the case that a single LED breaks, so that the rest of the lights won't be affected. We must make sure that the voltage rating of our driver matches that of the battery pack, which will depend on finding the lightest supply possible that still has enough power to sustain flight. Undervoltage will result in dim LEDs or no light output at all, and overvoltage will burn out our LEDs.

C. Software

To process data and interface with the hardware components, software will run on an STM32 microcontroller. This component was chosen for its affordability and ease of development. The microprocessor has an accompanying development board, the Nucleo Board, which we can use to become familiar with the microcontroller's development environment and begin software development before the hardware components are fully implemented.

Developing software to run on the selected microcontroller requires consideration of the space and processor throughput available. For the functions of the butterfly robot, the software will have to support the motors that make the wings flap, the LEDs which will visually communicate with the user, the CO sensor, and ultrasonic sensors. Additionally, the flight pattern will eventually be determined by searching for higher CO concentrations in the air. The software we develop will need to be able to perform all of these tasks without a delay that would negatively impact the performance of the robot in flight.

We will implement most of the software for the robot in C and C++. These languages provide the benefits of lower level control and programming while still holding familiar development patterns of higher level languages. These development capabilities will support the variety of tasks we will accomplish in the software, covering both the hardware interfacing and the more computational sensor data processing and flight pattern determination. C and C++ are widely supported across microprocessors and require little overhead to run, making them ideal for this project.

The ability to process and respond to sensor data will be essential to making our robot able to fly and search for CO without direct human control. On a basic level, the butterfly should be reasonably able to avoid running into walls, objects, and other obstacles. This obstacle avoidance will be accomplished with ultrasonic sensors that can detect the robot's proximity to objects in a given direction, and a program that recognizes danger and changes the flight pattern to avoid the detected obstacles. In looking for CO, the LEDs on the butterfly will indicate the detected carbon monoxide level, but the robot will be even more useful if it can locate the source of the CO. To accomplish this, the software will implement a searching algorithm which leads the butterfly to pursue higher levels of CO.

As the development of the software will begin before the hardware components are completed and we can't safely create test environments with abundant CO, we will be using simulated data to test the software data processing and response to varying levels of CO. In one way, we will use a set of data simulating that from the sensor and check that the systemic behavior is what we expect. Another test we will implement is unit tests, which test isolated components of the code to ensure that the correct outputs are produced for given inputs.

The software team will utilize Git version control software to collaborate throughout development. Git will allow multiple team members to work on different components of the project at the same time without the risk of losing work to overwriting or untracked changes. We will keep the code in a team Github repository, and utilize Github's task management feature to track the status of development tasks and bug resolution.

D. System Operational Block Diagram

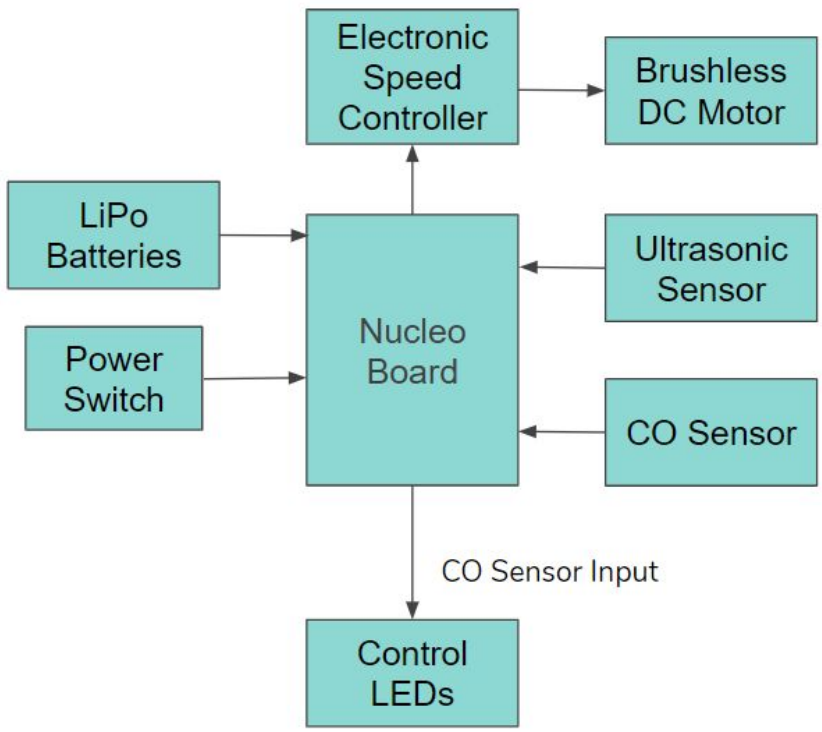

Chart 1: System Operational Block

VI. Cost Analysis

Product	**Quantity**	**Cost**	**Actual Cost**
Mylar Sheets	1	$25	$25
Carbon fiber plates	1	$200	$200
Conductive Ink	1	$60	$60
Processor Eval Boards	3	$75	$75
Brushless DC Motors and Controllers	2	$70 + $110	$180
Batteries and charger	4	$40	$40
Wireless Receivers	2	$120	$120
Sensor Eval Boards	3	$60	$60
Circuit Components	1	$200	$200
Total			$960

Table 1: Cost Analysis Table

VII. Division of Tasks

Task	**Task Leader**
Schematic Design	Erick Dang, Derek Chou
PCB Layout	Derek Chou, Breonna Liew
Mechanical Design	Erick Dang
Interfacing with BLDCs	Jun Jie Chen
Interfacing with Sensors	Hao Jiang

Combined System Interfacing	Erin Burba
Final Integration	Erick Dang

Table 2: Division of tasks table

VIII. Timeline

Project Brainstorming	■					
Research	■					
Proposal		■				
Presentation		■				
Final Report					■	■
Final Presentation						■
Purchasing Materials		■	■			
Schematic Design			■			
PCB Layout			■	■		
Mechanical Design			■	■		
Connecting Eval Boards			■			
Interfacing with BLDCs			■			
Interfacing with Sensors			■			
Combined System Interfacing				■		
Final Integration					■	
	Jul 2019	Aug 2019	Sep 2019	Oct 2019	Nov 2019	Dec 2019

Table 3: Timeline table

IX. Conclusion

We propose a design of a butterfly robot that aims to be a robot that can operate alongside humans. Our design specifically has the butterfly robot act as a mobile carbon monoxide sensor to show that the robot can perform its duties without interrupting the people around it. However, the implementation of this butterfly robot can be expanded to a much broader scope. This project aims to show that a flying robot can be safe around humans and also perform different tasks alongside humans. Our final product will be a butterfly robot capable of reading the carbon monoxide levels in the air and report these findings with the use of it's LEDs. The robot will also be capable of obstacle avoidance with the help of the ultrasonic sensor. By following the proposed timeline, we will be able to complete this project within the specified timeframe.

X. Appendices

A. List of Charts

B. List of Figures

C. List of Tables

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