Solar Extended Vehicle (S.E.V)

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***Abstract* — Our design of the System consists of two main circuit boards. A charging circuit that has a maximum power point tracker, which is being fed by the solar panels, that outputs the maximum current to charge the lithium polymer battery in order to extend the flight duration. The second board is the autopilot board which autonomously flies the plane based on a pre-written code that flies the plane and shuts off/on the motor at specific altitudes to conserve power. A radio controller can be used to override the autopilot mode in case of emergency.**

***Index Terms* — Accelerometer, global positioning system, motor , open source software, servomotor, solar energy, Zigbee.**

I. INTRODUCTION

Our motivation for this project is to experience solar power systems and control systems via programming. Solar powered systems do not have to refuel which gives a great advantage over the fuel powered systems. Also what motivated us was to achieve an autonomous system. This software task makes the project unique in our eyes. Solar powered systems are not common in our daily lives due to the dependence on foreign sources such as oil. Products that run on fuel are not environment friendly which puts the load on us as electrical engineers to fight for healthier environment. Therefore, we choose to power our project via solar panels.

II. FUNCTIONALITY

The first and most important function is flight. The SEV is designed to fly effectively, hint, flying effectively critically depends on the weight of the overall system. Once the SEV takes off the benefit of its wing span and area come into the picture. The solar panels are installed on top of the wing to keep charging the battery during flight to extend the flight time. Its third functionality is that the motor shuts off and on during flight in order to save power as well. The fourth function is to follow a predetermined way points. Its final functionality is to return to its take off point and land when the battery detected low. Figure 1 below demonstrates the functionality of the system during flight. In case of an emergency the autonomous system is interrupted by a radio control to be manually controlled. Once the radio controller is turned off, the autonomous system takes control the plane.

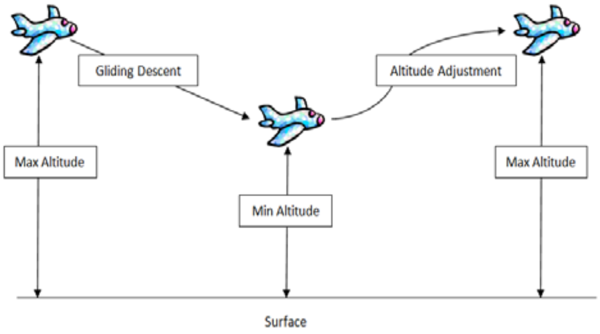

Fig. 1. Flight Functionality

III. AIR FRAME

Our design is built around a hollow frame that is able to carry two circuit boards, two servos, a motor, an electronic speed controller, and a battery. Yet the wing area is very crucial which guided us in installing the solar panels. Therefore, RQ11 by Projet was chosen as a frame to our design. It meets all the requirements. On the other hand, for testing purposes, since we are beginners in flying RC planes, we chose to test the project on the Apprentice 15e by Eflite.

Another key aspect of the S.E.V.'s functionality is its in-flight maneuverability. Our design differs from the majority of traditional planes in the way that it changes direction during flight. One feature that relates to this is the static main wing in contrast to a wing with hinged ailerons attached to each side. In most cases, a plane is maneuvered almost exclusively from the shifting direction of the ailerons while the rear rudders and elevator play a minor role by comparison. The S.E.V. does not contain ailerons, hence the static main wing. The function of the ailerons is replaced by several innovative components in our design. There are bends in the wing which allow the plane to make smooth turns during its flight path. Also, the Raven RQ-11B features a rear rudder and elevator similar to those included on a traditional plane. However, the role of the rudder and elevator is much more important to changing the orientation of the Raven compared to most other planes. The rudder and elevator are designed to work in conjunction with the curvature of the main wing to allow for flight maneuverability

The plane is designed to take off by hand using an overhand throw technique. The lightweight nature of the vehicle makes this quite easy to firmly grip the plane with one hand and gently release the plane into the air to begin its ascent. To begin take-off, the aircraft is held by hand with the motor running at full power. Next, the plane is guided into the air in a smooth motion. During this process, the angle of take-off is very important. If the plane is tossed to steep, it will immediately stall and crash. In contrast, if the angle is too low, it will dive straight into the ground. Practice will be a key part of executing this delicate process. There are a couple of techniques available to land the plane. One of them is known as a "deep-stall" landing. Basically, the aircraft descends until it is just a few feet above the ground. Once it is close enough the nose is steeply angled upwards to cause an intentional stall or "deep-stall". Once, the aircraft has successfully stalled it may either fall lightly to the ground or it can be caught by hand. Additionally, it may be possible to create an automated landing function for the plane. This would allow the plane to land autonomously using the same techniques as described previously.

The airframe research section relates to the initial research steps that were taken shortly after our project was chosen. This research began by selecting a plane to use as the frame of our S.E.V. design. We started by looking at RC planes and then later decided to choose an airframe that more closely resembled an UAV. Once we had chosen a hollow frame, we needed to research motors that would be applicable to our project. The motor would be one of the most significant components of the design since it would generate the power for the entire system. Next, we needed to find servos that could be used for the minor mechanical functions. The last component is the electronic speed controller. The ESC would enable the motor and servos to be controlled from a single source. The ESC would serve as the link between the remote control and the plane. All of these components operate as the core system of the plane.

Our design is a plane that uses a primary electric motor powered by a battery. In addition, the plane has solar cells on the main wing that will charge the battery during flight. In order for this to be possible, the airframe needs to be able to handle this as well as any other features. First, the plane utilizes an overhead wing. This is opposed to a wing that goes under the fuselage or in the middle. The reason for the overhead wing is so that the plane will be able to glide easily without constant power from the motor. Also, planes with overhead wings are easier to fly which is very important when flying the plane using only GPS guided coordinates. Since we will be using solar power to charge the battery, there is a good chance of losing power due to a lack of sunlight while in midair. An overhead wing greatly reduces the chances of our plane stalling and crashing due to loss of power from the motor.

The motor of the plane is another significant part of our design. The motor that we have chosen is the Electrifly Ammo 28-35-5100Kv In-runner electric motor. This 94 gram motor is relatively lightweight for its 5100Kv output. It is also worth mentioning that this motor is an in-runner type motor. The in-runner design is necessary because of the way that it is mounted inside the plane. An out-runner motor has an outer shell that spins along with the shaft. In our case we need the body of the motor to remain stationary, hence the in-runner motor selection.

The Raven Rq-11B requires two servos in addition to the motor. While the motor is connected to the propeller, two servos are needed to control the rear rudder and elevator. The rudder and elevator are located on the tail end of the airframe. The rudder runs vertically with the tail fin while the elevator is connected on a horizontal hinge below the rudder. These two flaps will be the main method of maneuvering the plane while it is controlled via remote control or by GPS navigation. For our design we decided to use the T-Pro MG90S micro servo. This servo contains a metal gear to ensure dependable performance and durability through use.

The Electronic Speed Controller or ESC is the third major electronic component that is necessary to allow the plane to fly effectively. The ESC will work in sync with the motor to provide smooth acceleration during flight. Basically, the ESC is what regulates the throttle to the motor. This is a significant role for the electronics portion of our design, so we needed to research accordingly. The Selection of the speed controller would be very dependent on the specifications of the motor that is used. Since there are multiple choices for applicable motors, we needed to research appropriate speed controllers that would work efficiently with each motor. The E-flite 60-Amp Lite Pro SB brushless ESC is the speed controller that we chose for our project. This ESC has a continuous max current rating of 60 amps which is easily compatible with our 30 amp motor.

IV. CONSTRUCTION

The construction process of the RQ-11 started after we had obtained the motor, servos, and ESC. We started by building the tailfin. The rudder and elevator flaps needed to be glued together using super glue. Next, these two pieces were connected to the tail shaft with epoxy. The next component that we put together was the wing. The wing consists of 3 separate pieces that needed to be permanently connected with epoxy. The final step of the framework construction was connecting the fuselage to the tailfin with epoxy.

Next, we needed to mount the servos. The servos were mounted in a small compartment underneath the plane using screws to mount them to the wooden frame. Once the servos were secured, we needed to run cable wire from the servos to the rudder and elevator flaps. The plane is presented in figure 1 below.

Fig. 1. RQ11 by Project.
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V. CIRCUIT BOARDS

Our project has two circuit boards which we called the autopilot circuit board and the charging-circuit circuit board.

We decided to build our charging circuit as a point to point circuit board instead of printed circuit board to gain the experience in soldering point to point circuit boards. However, the autopilot circuit board was designed on EAGLE for two important reasons. The autopilot circuit board has many very small in size components which are difficult to solder on a point to point circuit board, and we were after gaining the knowledge of designing on EAGLE.

Our PCB is a two layered circuit board that is supported by through holes and connectors which are used as Xbee and GPS connectors as well as PCB to PTP connectors. Hint, our boards are placed on top of each other due to the limited area the RQ11 offers.

Our Charging circuit composed of the Maximum-Power Point-Tracker and three connectors to connect the solar panels as an input to the charging circuit and a battery connector as an output as well as a connector to power the autopilot board. Our autopilot system, as presented in figure 2, is composed of 3 microcontrollers, two gyroscopes, a triple axis accelerometer, barometric pressure sensor. It also has several connectors which are used to connect the GPS, Xbee transceiver, radio controller receiver, servos, and the electronic speed controller.

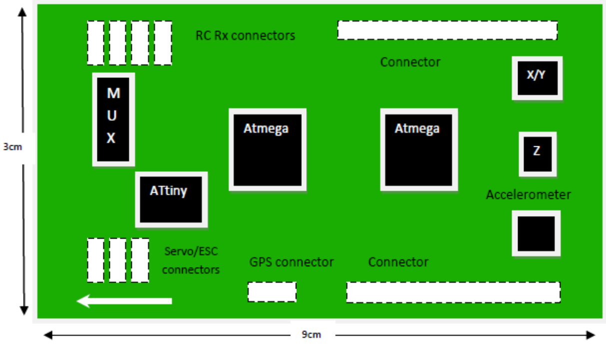

Fig. 2. Autopilot layout

VI. HARDWARE

Our hardware design of the system, as shown on figure 3, is composed of three major subsections which are navigation unit, autopilot unit, and ground station. The navigation unit and the autopilot unit together form our autopilot circuit board which is powered which powered by the circuit board.

A. Navigation Unit

The navigation unit is composed of the following components: GPS, barometric pressure sensor, single-axis gyroscope, double-axis gyroscope, and a triple-axis accelerometer. Collectively, they are all connected to a microcontroller. We chose to design our system around those components which collect very important data to help stabilize and track the SEV. The chosen microcontroller is ATmega328. We chose to use Atmel's microcontrollers since they are portable to the Arduino environment.

This unit actually collects the data via all the several components as shown on table 1. The collected data is transformed to one of the microcontrollers, which communicates with the autopilot microcontroller.

TABLE 1
NAVIGATION UNIT

Device	Task
GPS	Set a flight path – reports its current position.
Single-axis/double-axis Gyroscopes	Sensing the pitch – roll – yaw angles of the SEV during flight.
Triple-axis Accelerometer	Sensing the movement of the SEV with respect to the gravity to determine its stability.
Barometric Pressure Sensor	More accurate than the GPS to determine how high the SEV is with respect to the atmospheric pressure 1atm.

B. Autopilot Unit

The autopilot unit is actually the core of our project. Its task is to fly the SEV autonomously. The autopilot microcontroller receives the collected data from the navigation unit to stabilize the system and conserve energy. Based on the collected data, the autopilot unit responds by adjusting the servos and/or shutting on / off the motor to save energy. Once the autopilot detects a signal coming from the RC receiver, it interrupts the code.

It also transfers the data to the ground station via Xbee transceiver that operates at 900 MHz frequency and has a range up to 6 miles.

C. Ground Station

The ground station is composed of a laptop and an Xbee transceiver. Both Xbee's operate at the same frequency to be able to communicate effectively by sending and receiving data to display at the ground station which keeps track of how high the SEV is and its location.

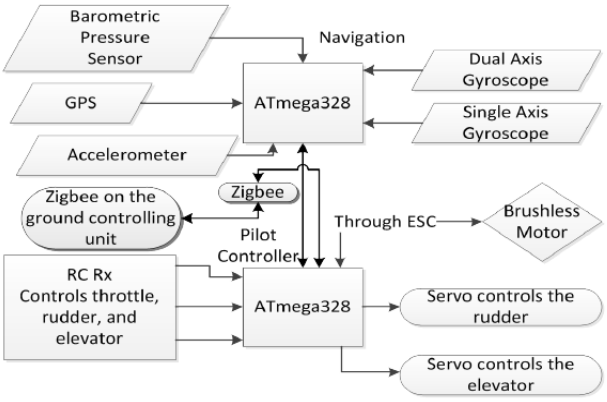

Fig. 3. Hardware design

VII. POWER

Solar panels give a great potential as an energy harvesting power source all they need is a battery system to store all of the energy that was collected. In order for the batteries to be charged there has to be a charge controller that regulates the solar panel voltage to match the ideal charging voltage of the battery system. The ideal device that controls the output voltage of the solar panels to the input voltage of the battery system is called a maximum power point tracker. Maximum power point trackers work by 'tracking' the voltage and current curve of a solar panel so that the total Power (Voltage * Current) is maximized. What this means is that as the light illumination level changes the voltage and the current must be carefully corrected to meet the correct output voltage of the circuit. An interesting correlation exists in solar panels output voltage. Whatever the existing light level illumination is the output voltage will always remain the same. Figure 4 uses the green lines to show the I-V curve of the panel for a given light condition. As the light increases, the voltages stays sort of the same but the amount of current you can draw goes up. If you can keep the DC/DC converters operating on the red line that is the maximum power. Figure 3 portrays the current-voltage curve and the power-voltage curve of the panel for a designated light condition. The maximum power is indicated by the red line.

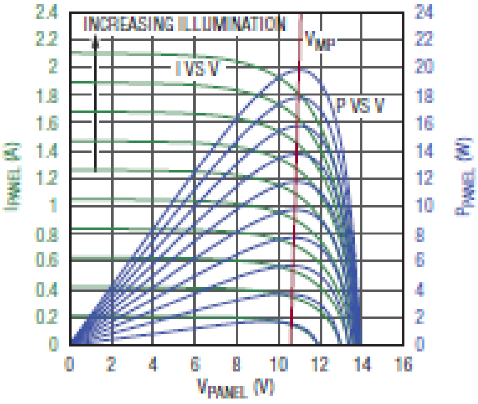

Fig. 4. Current/ Voltage Curve and Power/Voltage Curve Reprinted with permission of Linear Technology

A. Maximum Power Point Tracker

The Maximum Power Point Tracker, (MPPT), was incorporated with a protection circuitry that would enable it to protect the lithium polymer battery pack from overcharging. Lithium polymer batteries are very different from NiCad or NiMH battery packs. Lithium polymer chargers are specifically designed to charge lithium batteries thus certain aspects of a charger have to be taken into account. For instance, a lithium polymer charger has to be set with the correct number of cells and the correct float voltage and these voltages cannot exceed 3.0V-4.2V per cell +/- 0.05V per cell when the battery pack is fully charged. The lithium polymer battery goes through 3 charging stages as shown in figure 5. Stage 1 of a lithium polymer battery is between 0.5C and 1C and typically takes about three hours. The main objective of the Stage 1 charging is that it provides a high current and thus allowing the battery pack to reach its threshold voltage. The charge level at this point is about 70% of the battery pack. Stage 2, saturation charge, of a lithium polymer battery is when the battery pack has reached its upper voltage threshold and then the current begins to drop and level off at about 3% of the nominal charge current. Stage 3 is rarely used but when used it provides the topping charge. Stage 3 is typically used once every 500 hours of use. In our case, the source was an array of solar panels.

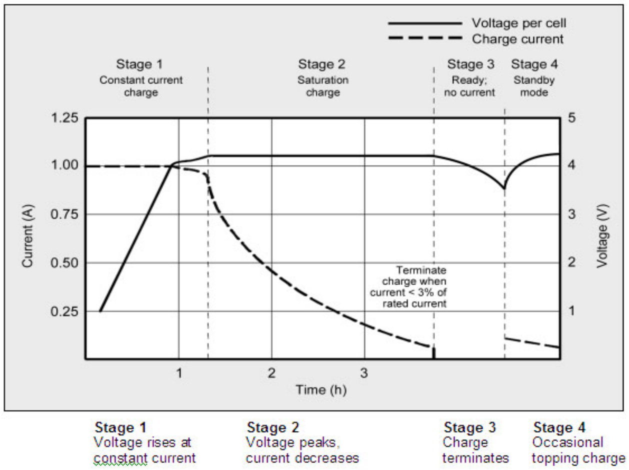

Fig. 5. Charging Stages for a Lithium Polymer Battery
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In our case the input source is 7.2 watts of solar cells which in turn translated to about 19.8 volts of useable input. In brief, a maximum power point charger is a controller that boosts the current and voltage of the charging state of the battery while using the most of the available power of the solar panel.

B. Design

Our maximum power point tracker will incorporate a Linear Technology LT3652 integrated circuit chip that was solely designed to be a power tracking battery charger for solar powered applications. The LT3652 is a complete monolithic, multi-chemistry battery charger that addresses high voltage applications in a compact design. The key features of the LT3652 are wide input voltage range of 4.95V to 32V with an absolute max voltage of 40V, programmable external charge current of up to 2 amps, resistor programmable float voltage up to 14.4V with 5% charge current accuracy and 0.5% float voltage reference accuracy. The LT3652 also has an input voltage regulation loop that reduces the current if the input voltage falls below a pre-programmed voltage level set by the voltage divider resistors. The LT3652 also contain provisions for battery temperature. This implemented by using a thermistor during the charging cycle. As seen in Figure 6 the LT3652 tracks maximum power point to 95% or greater when the charging voltage is set around 12.6V. At higher charging voltages it increase to 98% or greater.

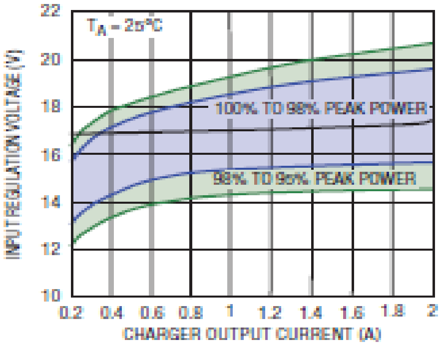

Fig. 6. LT3652 MPPT Current Tracking
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The LT3652 is offered in two separate packages from Linear Technology, the DD package and the MSE package. For our maximum power point tracking charging circuit, we will be using the DD package. The LT3652 has twelve pins with the right combination of resistors, capacitors, and diodes we can have the LT3652 output the correct voltage and amperage that is needed for our charging circuit. Charge current programming is set by choosing an inductor sense resistor. For our particular circuit that we are designing the total expected max current that we would see from the circuit is 649mA. The expected value for R(Sense) would be a resistor with an approximate value of 0.2161 Ω Figure 7. Using a resistor divider is needed to program the desired float voltage, V(BAT-FLT), for the battery system. In particular, resistors R(FB1) and R(FB2) will have to have the correct values to set the 12.6-volt float charge needed in the lithium polymer battery pack. Charge current programming is set by choosing an inductor sense resistor. For our particular circuit that we have designed the total expected max current that we would see from the circuit is 463mA.

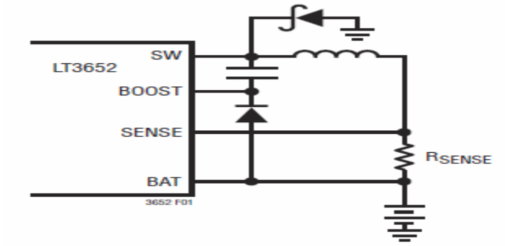

Fig. 7. Programming Maximum Charge Current
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In order to achieve the 12.6V needed we had to use to yield the correct resistors to be used in our design as shown in Figure 8.

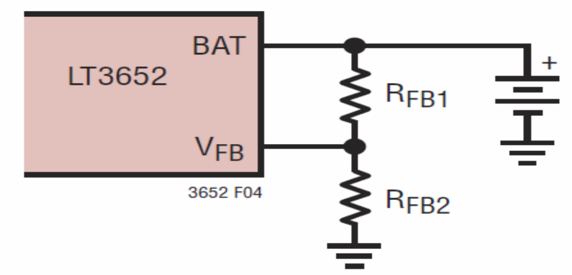

Fig. 8. Feedback Resistors from BAT to V(FB) Programming Float Voltage
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The LT3652, as shown in figure also contains a voltage monitor pin that enables it to monitor the minimum amount of voltage coming into the MPPT. The input supply voltage regulation is controlled via the voltage divider resistor R(IN1) and R(IN2). An operating supply voltage can be programming by monitoring the supply through the resistor divider network. This is done by having a ratio of R(IN1)/R(IN2) for a desired minimum voltage. ΔI(MAX) is the normalized ripple current though the inductor. The LT3652, as shown in Figure 9, also contains a timer termination in which the battery charge cycle is terminated after a preset time. Timer is engaged when a capacitor is connected from the “TIMER” pin to ground otherwise it is directly connected to the ground. A typical timer termination is set to three hours but for our project design we have eliminated this feature from the final design therefore it will be connected directly to ground.

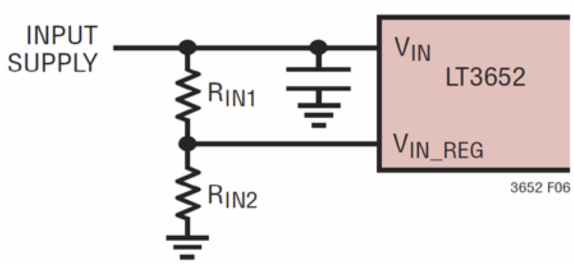

Fig. 9. Resistor Divider Sets Minimum V(IN)
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C. Solar Cells

All solar panels are made of silicon. Silicon is very abundant material on Earth. Just about every element or material that is found on Earth has a trace of silicon. There are three commercial types of solar electric panels readily accessible by consumers: single-crystalline, multi-crystal, and amorphous silicon cells. For our UAV project, we decided to use flexible thin cell solar panels that will be attached to the upper wing structure. We chose to use PowerFilm's RC7.2-75. The PowerFilm RC7.2-75 had the highest current output to weight ratio in the consumer market. By using the PowerFilm RC7.2-75 we managed to have a total array weighing in at 2 ounces.

To maximize the total output of the PowerFilm RC7.2-75 solar panels we will have to arrange the solar panels in a series/parallel circuit. This is being done by having four groups of two cells and one group of two solar arrays. Total power output of the array is 7.2 watts at 19.8 volts. This would yield about 0.463 mA at the source.

D. Battery

Lithium-ion polymer battery packs are an advanced technology battery pack that requires a small deviation in charging voltages. LiPo battery packs need a constant charging voltage opposed to NiCad or NiMH. Each cell in the battery pack will have a nominal voltage of 3.7V and 4.2V when fully charged. The basic algorithm is to charge at constant current 0.2 C to 0.7 C until the battery reaches 4.2 Vpc (volts per cell). Meanwhile a fully discharged 3-cell LiPo battery pack will have a reading of 12 volts across the entire battery pack.

The battery pack that we chose for our project is an E-flite High-Power Series Lithium Polymer EFLB1040 battery. The E-flite EFLB1040 is a 3200mAh 3S 11.1V 15C Lithium-Polymer battery pack. The battery pack has a maximum 15C discharge rate where the maximum current draw that we will ever see from the UAV is 32 amps. Each of the individual battery cells are rated at 3.7V with a total pack voltage of 11.1V.

The average cutoff voltage of the electronic speed controller is 3.0-3.2 volts. This allows for a buffer in the battery system so that the battery is not completely discharged thus avoiding damage to the battery. Thus, the total amperage capacity of the battery pack would remain at 3200 mAh with a 15C discharge rate.

VIII. SOFTWARE

For the hardware to run as we would like, we will need to utilize several different types of software for this project. For this project, we will be using software called ArduPilot version 2.7. This is an open source autopilot platform created by Chris Anderson and Jordi Munoz of DIY Drones. The code that will be used for the flight of the S.E.V. was developed by Jason Short and Doug Weibel. There is also a desktop utility that will be used for this project. The desktop utility is used for entering the waypoints and the home location for the S.E.V. Both the autopilot and desktop utility are published under an LGPL license that allows free use and modification as long the resulting product is open source and retains the DIY

Drones attribution is retained. The ArduPilot allows for programmable waypoints using the desktop utility. These are the destination that the S.E.V. will fly to until it returns to the home location; that is also entered through the desktop utility.

The waypoints and home location are stored on the EEPROM along with the sensor calibration. This is done in case of a system restart. ArduPilot will control the elevator, rudder and throttle. Under the ArduPilot_2_7 tab is where you will find the initialization of the program, there is a main loop that initializes three very important functions, of different speeds, for this program; these functions are loops themselves and are labeled as such: main loop event, medium loop, and fast loop. Below in Figure 10 is a graphical visualization of the flow of the main loop.

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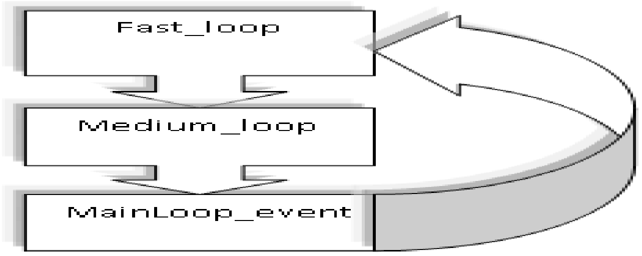

Fig. 10. Main loop

In the main loop the last function that would have been called after each case of the medium loop was finished running. Below in Figure 11 is a simple layout of the altitude gliding code. This code may change before the end of the project.

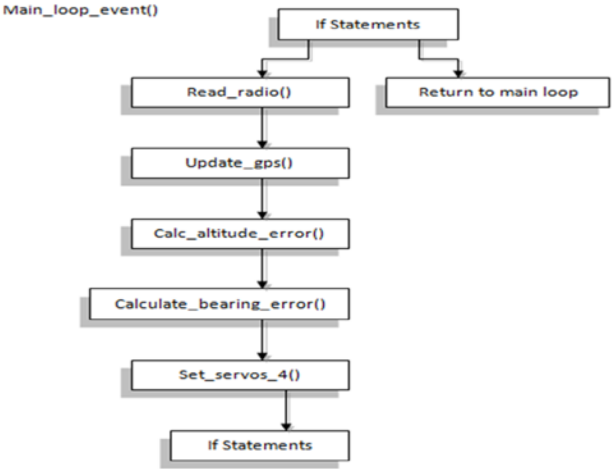

Fig. 11. The main loop event for allowing the UAV to glide.

First we will be using an 'If' statement to check the current altitude against our set minimum altitude. If the altitude is greater than minimum altitude value then the function will end and return to the main loop. But if the altitude was less than the set minimum value, then it would call on the functions required for returning the UAV back to its maximum altitude. First, before returning the UAV to the maximum altitude, it will run the read radio function. It does this to avoid overriding the user, if the user is manually controlling the aircraft. After checking to make sure that the user is not in control; the next function called is the update GPS. This is called to refresh the altitude and location data, so that we are not using old data to adjust the UAV's altitude. After the update, we run an altitude error check, this is so that we can adjust the servos accordantly; doing this will result in the UAV correcting its altitude. Then we will need to check if our bearing is correct; so we will then need to call calculate bearing error function. This function will check, as it name implies, if the UAV is off course and the then correct its bearing. The next function to be called is set servos function. This function will write out the servo PWM values. Last in our code is a set of 'if' statements to check if we are using a simulator or are using a GPS. This is because the program needs to know where to write out the values, into a simulator or to the ground control station.

The ArduPilot will relay on the Altitude Heading Reference System code, this will be loaded onto another microcontroller. The AHRS code is developed using the Arduino IDE; the code will be used to maintain a model of the UAV's orientation in space. This code is based on Bill Premerlani's Direction Cosine Matrix (DCM) algorithm . The DCM is a 3 by 3 matrix array; the gyro data is used in a time step integration to update the matrix. With this data from the sensors and GPS can be used to correct for errors. These errors are caused by numerical errors. With this data we can determine pitch, roll and yaw; but for this project we will only be using the pitch and yaw. With this code we are now able to use the above coding to fly, without the control of a user, our UAV to waypoints. Plus, with code modification that we have designed, we will be able to extend the flight time of a RC aircraft.

The ArduPilot mission Planner is a configuration tool to help you easily plan your UAV's missions. Missions are a set of waypoints for the UAV's flight path. The mission planner uses Google maps for laying down the waypoints. During the flight of our UAV we will be monitoring it using the ground control station. The ground control station is an addition to the project that uses ZigBee modules to communicate to the UAV. The Ground control station is a open source software developed by

DIYdrones that utilizes Google Earth. During the flight of the UAV the ArduPilot code creates a log of the location and altitude; and that is sent to the ground station using the Xbee modules, where it is updated on Google Earth.

IX. CONCLUSION

What you have between your hands has been a great experience for the group members. We worked on this project for nearly 7 months to make it look as you can see right now. From the group point of view, we have learned how to work with each other outside the class; we have learned how to manage a project. We have learned how to stand up for each other and how to manage our times.

This project gave us an opportunity to discuss our work with our Engineering colleagues at the laboratory as well as lead other Engineering students to the right path in terms of managing their work.

Our responsibility as a group is to succeed not only in this project but also in our journeys as Engineers representing the Department of Electrical Engineering and Computer Science of the University of Central Florida.

ACKNOWLEDGEMENT

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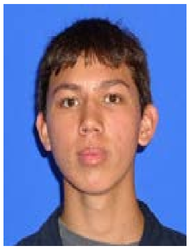
Daniel Grainger is a graduating Electrical Engineering student who is currently working as a System Controls Programmer at Aquarii Services designing a Solar Thermal Desiccant Dehumidification system.



Frank Niles is an Electrical Engineering Major and will be graduating from UCF in December 2011. He is originally from Merritt Island, Florida and began studying at UCF in Fall 2007.

Sergio Roig is a graduating Electrical Engineering student who is currently working for TLC Engineering for Architecture in the health care division of the company, designing electrical systems for hospitals and nursing homes.