Urban Planning and Air quality management using Autonomous Quadcopters

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Abstract— Most major metropolitan areas are facing the growing problems of urban sprawl, loss of natural vegetation and open space. Almost everyone has seen these changes to their local environment but without a clear understanding of their impact. From a long time remote sensing has been used for land management due to the multiple possibilities offered by air borne space satellites but these are very expensive to build and operate. Moreover, Satellite data is particularly useful for detecting major changes in urban land-use because of their low resolution images. Additionally, the movements of people into urban areas together with the increase in consumption patterns and unplanned urban and industrial development have led to the problem of air pollution. So, here we propose a system which gives urban planners a clear statistical data about large areas of land, road mapping and land usage using autonomous quadcopter with onboard image processing techniques. So that ground crews can save a lot of time by eliminating labor intensive field work. Moreover, it informs us about content of different gases in our atmosphere in different parts of cities. So, that quick action plans can be taken if air pollution levels near traffic intersections/busy roadways are exceeding the permissible levels. The versatility of our proposed design simplifies overall land management by allowing the integration of geo-registered images with current GIS systems.

Keywords — Beaglebone Black, 9-axis IMU, OV5640, GPS sensor, Sensor Booster Pack, TM4C123GH6PM

I. INTRODUCTION

Our design is a low cost, mobile and renewable energy based efficient urban planning and air quality management system. It reduces the number of stages in urban planning and air assessment methods with its on board data and image processing. The processed results and atmospheric gas concentration are transmitted via GPRS network to mobile station.

The availability of geographic information through internet greatly contributes to the awareness of citizens about environment and land management issues. An increasing number of surveyors or land administrations make use of these aerial images to provide context information in order to communicate with non expert partners or with a wider population about land management projects. This is because an aerial image is “neutral” information in which each citizen can preserve his own culture and his own approach of environmental issues. We have used various numbers of sensors, starting from gas sensors to motion sensors for navigation of the quadcopter. Whole system acts as a data acquisition system with on broad array of sensors which provide us atmospheric conditions and other ailments like moisture, temperature conditions.

The aim of the project is to create a working solution which can be easily scaled up to manage and monitor large metropolitan areas.

A. Technical Background

Nowadays there is large growth in the field of unmanned aerial vehicle. The design and size of the quadcopters are getting better day by day. So, we thought of designing some agile copter which can handle multiple natural issues. We mainly got help from International Journal of Advanced Research in Computer Science and Software Engineering by Madhuri Kalapala Assistant Professor, Department of CSE, Vignan’s Institute of Engineering for Women, Visakhapatnam, AP, INDIA titled “*Estimation of Tree Count from Satellite Imagery through Mathematical Morphology”.*

B. Proposed Solution

For stable flight, we have implemented Attitude and Heading Reference System (AHRS) using Accelerometer, Gyroscope and a magnetometer on all three axes. The accelerometer measures earth’s gravity field minus acceleration, the magnetometer measures earth’s magnetic field, the gyroscope sensor measures angular velocity. Sensors readings are fed to the DCM algorithm, which provides a complete measurement of the orientation, relative to the earth’s magnetic field and the direction of gravity, expressed by the Euler (roll, yaw, and pitch) angles. TM4C123GH6PM can handle all the communication with motion sensors via I2C protocol. This leads to lower power consumption and higher CPU performance in the system, since they can request raw data or the orientation angles at any given time, meanwhile they can be in sleep mode, or they can perform other tasks that could have been delayed by the calculation of the orientation. Quadcopter navigation is simpler during capturing and analyzing the aerial images since it can take the use of GPS sensor at high altitude.

It consists of a multiple gas sensor board. Gas sensor board consists of Carbon Dioxide gas sensor (MQ811), Ammonia gas sensor (MQ135), Acetone, formaldehyde and other organic gas sensor (MQ138), Ozone sensor (MQ131), Carbon monoxide and flammable gas sensor (MQ-9), Hydrogen sensor (MQ-8) and Methane gas sensor (MQ214). These sensor provides the concentration in parts per million (ppm). Every sensor requires some heating voltage for operation which is 5V or 6V. Since nearly 100 or 200mA of current is drawn by each of these sensors, microcontroller pins can't source these much current. So, we have used mosfet driving circuit for providing enough current to sensors.

C. Organization of the Paper

The paper is organized as follows. Section II has a brief description of various components present on quadcopter and base station. Section III gives a detailed working description of various hardware and software components and gives an idea about where all of them fit in the big picture. It also gives a detailed description about the implementation of hardware and software parts and it has two subsections. Section IV explains the results obtained from testing the system and Section V explains the conclusions derived from our work.

II. PROPOSED SOLUTION

The system is implemented with many sub-modules communicating with each other. Our system can be divided in two parts; one is responsible for stable flight of quadcopter and controlling the brushless dc motors via electronics speed controller. Flight parameters and quadcopter's locations is being send to the ground station via XBee module. The complete block diagram can be seen in Figure 1.

Other part is responsible for sensing the atmospheric concentration and capturing the aerial images. Other Tiva Launch pad is communicating with Beaglebone Black via serial communication. Whenever GSM/GPRS module receives the instruction to send sensor details, Beaglebone Black instructs the Tiva Launch pad to read the concentration of the gases. Then it starts heating the gas sensors by turning the relay circuitry on. Some gas sensors like MG811 provides very low output voltage and very high output impedance. So, for accurate measurement of output voltage proper signal conditioning circuits are required. The complete block diagram is shown in Figure 2.

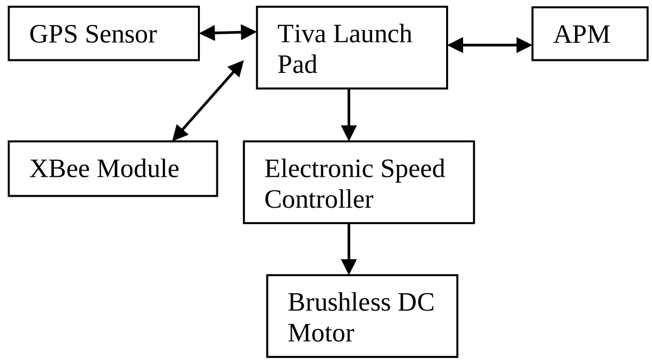


Figure 1: Block Diagram of the Flight Control

The quadcopter is built for normal day conditions only, any windy or gusty day can crash the quadcopter or provide some improper gas sensor readings. These are affected by the atmospheric temperature, humidity and the pressure. So, to correct the output concentration, humidity and temperature sensors are used (available on APM booster pack).

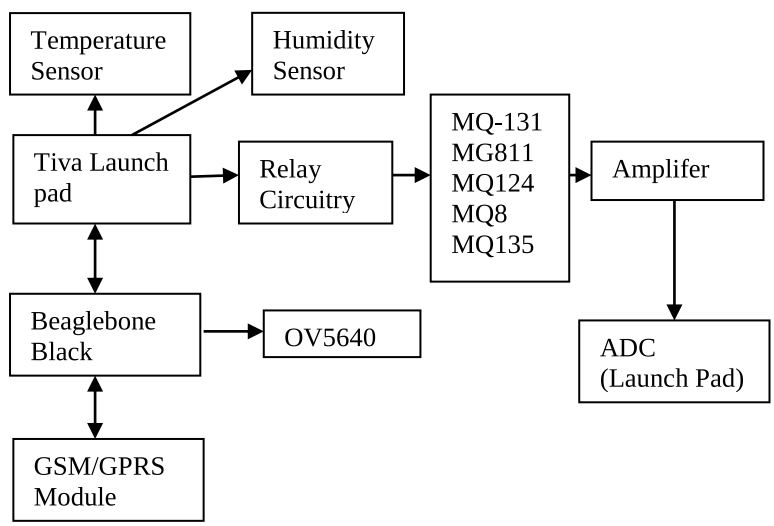


Figure 2: Block Diagram of the Data Acquisition and Transmission

Currently our quadcopter weights near around 2250grams. And a rule of thumb is required that thrust of each brushless motor should be (Weight x 2) / 4 i.e. 1125grams and our brushless motor have ability to provide thrust up to 1370grams. Brushless DC motors consumes very large current, so the average flight duration of our quadcopter is about 15 to 20 minutes. Hence proper power management is required to measure the voltage and the current in the real time. For the same we are using INA169.

III. IMPLEMENTATION

A. Hardware Implementation

i. APM Booster Pack

The heart of quadcopter is APM booster pack. There were many reasons of using APM booster pack. Firstly; it was designed hand in hand with the Tiva C and mounts on the Tiva quite nicely. Along with it, it is very small in size and light weight. Apart from all these, it has large number of sensors on board which will help in sensor reading correction and in sensor fusion (9-axis IMU).

The individual sensors in the MPU can each be used to determine the orientation of the quadcopter. The gyroscope gives a rotation velocity that can be integrated and the accelerometer and compass have reference points (downwards gravity and magnetic north respectively). But individually, they each have weaknesses: the gyroscope will drift over time, the accelerometer is susceptible to outside forces, and the compass is not very accurate. Therefore, to improve overall accuracy, measurements are combined using a complementary filter, described in the equation 1. Basically, it is a weighted average of each sensor's prediction. Code for the filter was provided in the Tivaware API.

$$\text{angle} = \text{Gscale} * (\text{last Angle} + \text{Gdata} * dt) + \text{Ascale} * \text{Aangle} + \text{Mscale} * \text{Mangle} \quad (1)$$

ii. Wireless Module

Zigbee Wireless modules are used in both quadcopter and base station. The XBee modules made by Digi International were selected because of their ease of use and the ability to transmit a signal from the Master (Coordinator) module to its base station. This ability is very essential in order to avoid interference with 2.4GHz remote. The Xbee modules in the base station are configured as Routers and the Xbee module in the master is configured as the Coordinator. The modules are configured in AT(Transparent) mode where the data given through the UART (SCI) inputs is exactly transmitted to the correct destination node. Since the XBee modules have pins with 2mm pitch, separate adapter modules have been used to solder the modules in project boards having hole pitches of 2.5mm.

iii. Battery and Power Supply Circuits

One of our primary targets was to make the entire system completely mobile and compact. An 11.1V, 5000mAh Lithium Ion battery pack with inbuilt charging and protection circuits, is used.

INA169 allows monitoring of the battery's voltage and current and triggering a return-to-launch when the voltage becomes low or the total power consumed during the flight approaches the battery's capacity. It also allows the copter firmware to more accurately compensate for the interference on the compass from the ESCs and motors.

As shown in Figure 3, I analog output contains a 0.1uF bypass capacitor, but no series resistor. To complete an RC filter into the ADC inputs, we have placed a low value resistor between the ADC inputs and I output.

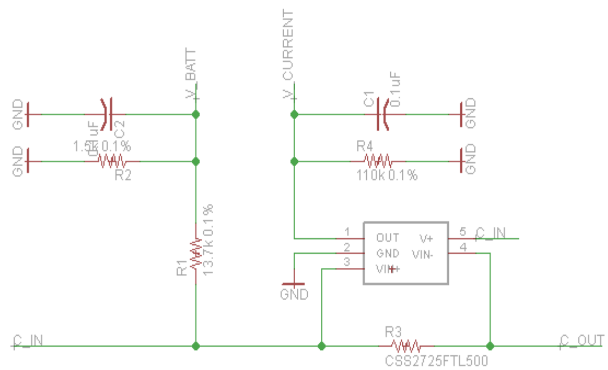


Figure 3: Current and Voltage Sensing Schematic

For power supply, we have used PTH08080W which is a highly integrated, low-cost switching regulator module that can delivers up to 2.25 A of output current. PTH08080W sources output current at a much higher efficiency (~93 %) than a TO-220 linear regulator IC, thereby eliminating the need for a heat sink. This makes it very suitable for our copter.

The detailed circuit diagram can be seen in Figure 4.

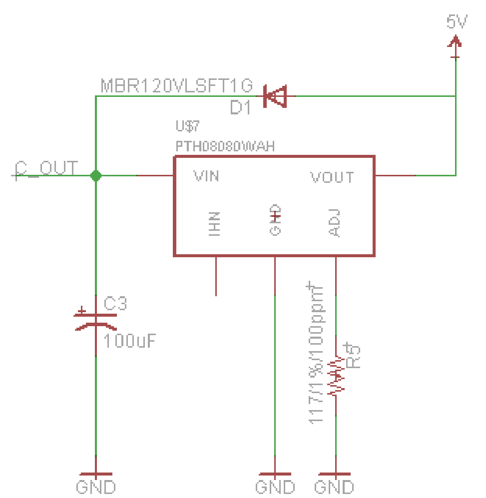


Figure 4: Circuit diagram for Voltage Regulation

The V output has a resistance of 14.7k between the sensed drain and analog output with 0.1uF bypass capacitor for an approximate bandwidth of 108 Hz, via the equation 1/ (2πRC)

The shunt resistors typically need no cooling airflow. Power dissipation by the shunt resistors is 4Watt for 90A current and 0.0005 ohm resistance. Hence gain of the circuit is 15.7. We can even increase the maximum current to 180A by setting shunt resistance to 0.25milli-ohm.

iv. Gas Sensor Module and its circuitry

Large amount of current is drawn by gas sensors. So, continuously reading the gas sensor values continuously is not possible. Hence, the circuit is designed in such a way that whenever base of the transistor is pulled high, relay will be turned on and the sensors will get starts heating up. The relay circuitry is shown in Figure 5.

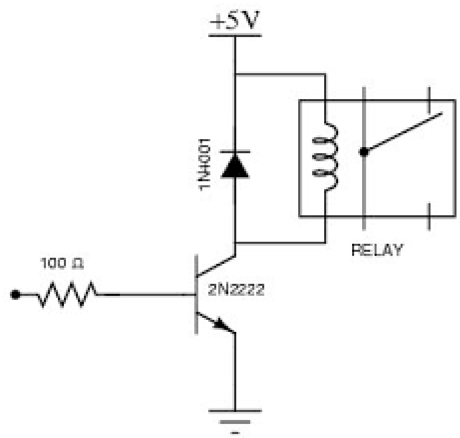


Figure 5: Relay driving Circuit

Sensor circuit is nothing but a resistance divider circuit as shown in Figure 6. The concentration of the gas is calculated using equation 2.

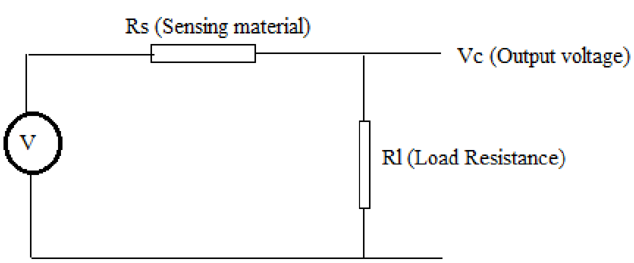


Figure 6: Generic circuit diagram for gas sensor

$$\text{ppm} = ((V/Vc - 1) * Rl/Ro * 10^{-c})^{1/m} \quad (2)$$

where Ro is the sensor resistance in clean air. And this concentration value is send by GSM module.

For amplification, we have used INA122 instrumentation amplifer. Single supply, low offset current and voltage are some features which made us to choose this for our prototype. We selected Rg as 400k, which makes the gain as 5.5 according to the equation 3.

$$\text{Gain} = 5 + 200k/Rg \quad (3)$$

Currently, we have tested five gas sensors. MQ131 sensor measures ozone gas in range between 10 – 1000 ppm and its heating voltage is 5V and consumes 350mA of current. MQ8 sensor measures hydrogen gas in range between 100-1000 ppm with heating voltage of 5V and consumes 200mA. An MG811 sensor measure CO_2 gas in range from 400 – 10000 ppm and its heating voltage is around 6V.It consumes nearly 150mA of current. MQ135 sensor are used in air quality control equipments which are suitable for detecting NH_3,NO_x, alcohol, Benzene, smoke etc. We are using it for measuring concentration of ammonia in the atmosphere. MQ124 measure methane gas in range from 3000ppm to 20000ppm and consumes around 120mA of current. The output of the gas sensors are connected to 12 bit ADC of Tiva Launch pad. Maximum voltage sensed by its ADC is 3.3V, so our task was to choose the value of load resistance (Rl) such that output voltage lies within the range.

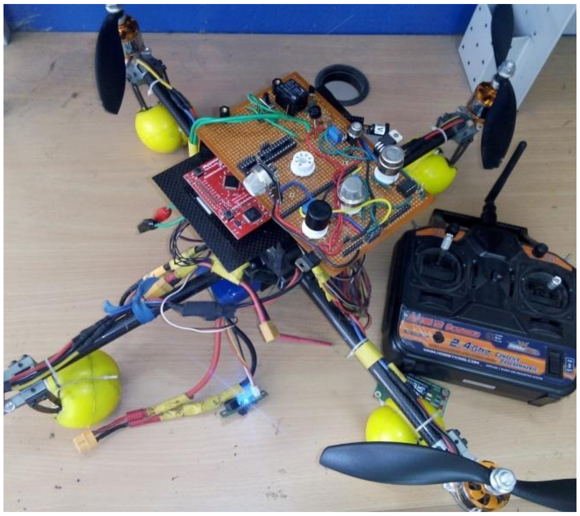
v. ESC, BLDC and propellers

Electronic Speed Controllers or ESCs provide a pulsating signal to the motors to allow variation in speed resulting quad movement. A good ESC is paramount to stable flying. The ESC must be of the proper current rating a too small rating will burn up itself and results in quadcopter crash. We have ensured that our ESCs can support the draw of sufficient current for BLDC motors. We have used the Turnigy 40A ESCs as they will provide sufficient flow of power to the Turnigy BLDCs.

We have used Turnigy 1450kV BLDC motors. These are outrunner motors in which the rotating part is on the outside, and not the inside. Because of this layout this type of motors can generate much more torque. High torque is required for quadcopters, since we need to balance it by changing the revolutions of the motor. The higher torque the faster we can change the speed of propellers.

We have used two clockwise (CW) and two counter-clockwise (CCW) propellers. Propellers are classified by length and pitch. Generally, increased propeller pitch and length will draw more current. Also the pitch can be defined as the travel distance of one single prop rotation. In a nutshell, higher pitch means slower rotation, but will increase in vehicle speed which also increases power. So, while deciding the length and pitch, we need to find a good balance between them. We have used 9 x 4.7 inch propellers.

The final quadcopter is being shown in Figure 6(a). Different subsystems are mounted over each other as shown in Figure 6(b). Bottommost part consists of OV5640 camera module, then comes the lithium ion batteries. APM booster pack along with its Tiva Launch pad lies at the center of the quadcopter.GSM/GPRS module is placed just above it, following another Tiva Launch pad and Beagle bone black boards. At the top gas sensor module is being placed.



(a)

(b)

Figure 6: (a) Final Product with various sub-system integrated in quadcopter (b) Closer look towards different layers of the mounting

B. Software Implementation

The software implementation can be better explained in two parts. First one is related to the image processing algorithm running on Beaglebone Black. Second one is flight control algorithm and gas sensor module.

For calculating the vegetation area (cover), tree count, we have referred [1]. Mathematical morphology tools are being used for calculating the number of trees in aerial image. Two fundamental operators in mathematical morphology are erosion and dilation. These operators are being applied to the image with known structuring elements. To obtain background markers we have threshold the opening and closing by reconstruction.

Separating touching objects in an image is one of the most difficult image processing operations. The watershed transform is applied for this problem in the [1].

Another task was to detect the road from the aerial images. For successful detection of road we got help from [2]. Initially the possible road regions are detected using a histogram based thresholding method and then Local line segment detection is done using a probabilistic hough transform Point Clustering for detecting the final region.

The histogram based thresholding method have following steps:

1. Creating a histogram of the image, with L levels.
2. Counting the number of pixels whose value is below the lower limit of level i ($1 \leq i \leq L$). If the number is more than 95% of total number of pixels, the lower limit of level i is the threshold. Otherwise increment i until such criterion is satisfied.
3. Select region above the threshold. The next stage is to detect all possible line segments in the above detected regions. They have used the probabilistic hough transform for it.

Then we used progressive probabilistic hough line transformation on the above detected regions. The minimum length of a line segment that needs to be detected is set close to half of image's height. The separation between collinear segments is set to 1/40 of image's height. This assumes that the road consists of a relatively long straight line. This allows us to detect straight long roads but will naturally fail on curved roads.

Now coming to another part of software implementation which is related to gas sensor, BLDC control and flight control algorithms.

The ESCs run with DC voltage and require PWM signal controllers. It is important to utilize only the PWM signal controllers when connecting the motors to the Tiva Launch pad. Since the power supplied will be greater depending on how long the switch stays HIGH or ON, the corresponding duty cycle will enable more power into the motors. In order to incorporate the PWM technique, the Tiva Launch board uses its clock and counter to increment the frequency of the duty cycle periodically, and reset it at the end of every PWM period.

For communicating with quadcopter in real time, we have used GSM Module; we can request atmospheric concentration any time by just sending a SMS to the quadcopter. In return GSM module will provide the gas concentration in ppm. The detailed flowchart is shown in Figure 7. Detailed code for interfacing GSM module with Tiva Launch Pad is given in Appendix B.

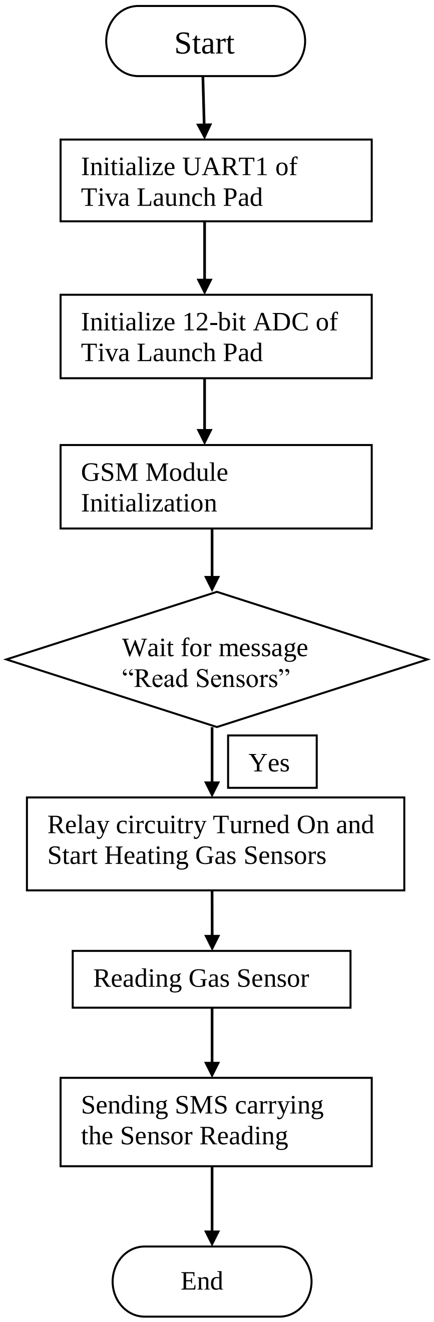


Figure 7: Flowchart of code running on Tiva Launch Pad

V. RESULTS

Calibration details of Gas sensor

Power consumption is a major issue of concern for multicopters. We have calculated the current drawn by various sub-modules of the quadcopter as shown in Table 1. In whole about 56.05 A of current is drawn from batteries.

Sub-System	Current Consumed
Gas Sensor Module (Sensors, GSM Module, Tiva Module)	4.25 A
Flight Controller, XBee and Tiva Module	3.2 A
ESCs and BLDC	46.8A at 85m (depends on altitude of copter)
Beaglebone Black and OV5640	1.8 A

Table 1: Power consumption in various sub-systems

V CONCLUSIONS

As it is mentioned in earlier section that we still need some improvement in terms of weight of quadcopter and the power consumption will automatically reduce. But, till now we are successful in calculating atmospheric gas concentration and performing various algorithms on aerial images.

Some other issues like deviation of sensor reading due to pressure and wind velocity need to be resolved. We can resolve it by mounting some wind velocity measuring device.

Solar Panels can be placed at the base station so that quadcopter can get automatically charged in critical situations. Still we are working on it. Gas localization and mapping is our future task.

Multiple small drones moving in coordination with each other can be used to analyze a locality.

If the accuracy and reliability can be improved, the system provides an excellent, cost efficient solution for urban management, pollution monitoring and control.

ACKNOWLEDGMENTS

We thank Mr. K.P Upla, Assistant Professor, SVNIT, for his guidance.

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APPENDIX B – BILL OF MATERIALS

	Component	Manufacturer	Cost per component	Quantity	Total cost of component	TI Supplied/ Purchased
1	Beaglebone Black	Texas Instruments	$45	1	$45	TI Supplied
2	APM BoosterPack	Texas Instruments	$49	1	$49	TI Supplied
3	Tiva C series Launch Pad	Texas Instruments	$25.98	2	$51.96	TI Supplied
4	OV5640	Omnivision	$45	1	$45	Purchased
5	Brushless DC motor	Turnigy	$25	4	$100	Purchased
6	Electronics Speed controller	Turnigy	$10	4	$40	Purchased
7	GPS Sensor	Leadtex	$20	1	$20	Purchased
8	TLV70433	Texas Instruments	$0.65	2	$1.3	TI Supplied
9	MG811 MQ135 MQ131 MQ-8 MQ214 TGS2442	Figaro	$75	1	$75	Purchased
10	GSM Module	SIMCOM	$20	1	$20	Purchased
11	INA122	Texas Instruments	$1.6	1	$1.6	TI Supplied
12	LM7805	Texas Instruments	$0.1	1	$0.1	TI Supplied
13	LM7806	Texas Instruments	$0.1	1	$0.1	TI Supplied
14	INA169	Texas Instruments	$1.6	1	$1.6	TI Supplied
15	PTH08080WAH	Texas Instruments	$10	1	$10	TI Supplied
16	Lithium Ion Battery	Turnigy	$60	1	$60	Purchased
17	2.4GHz Wireless Remote Transmitter and Receiver	Turnigy	$45	1	$45	Purchased
	Total Cost of the Project				**565.66**	