TZS402 Open Technology: Final Report

Project Title: Detecting Real-Time Movement of Flight Control Surfaces on Unmanned Aerial Vehicle

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Abstract

To influence the directional change of an aircraft when in airborne and transmits the detailed feedback to the ground, this project will undertake to build a sensing system onboard the aircraft. As such, a detailed investigation and examination of the UAV is necessary to enable the establishment and integration of suitable sensing system.

Basically, the sensing system will be using wireless technology to transmit the detected signals to the ground. Any interference to the radio control will adversely affect the UAV controlling. Thus, the 'new' transmitter onboard must be capable of transmitting the detecting signals without affecting the existing radio controlling.

Several factors that will contribute to the selection of suitable sensor and wireless system must be considered in order to fit well onto the narrow and light body of UAV. The technical specifications and key features of UAV have to be well adhered. It is very critical to observe its weight and size to derive optimal performance.

All components need to be electrically connected to form the sensing system onboard aircraft. Printed Circuit Board ("PCB") is used for final assembly in of all components, to achieve physical and electrical requirements. This demands great efforts, knowledge and aptitude to derive its utmost features and performance.

Incorporation of the sensing and wireless system has heighten the flight control surfaces management as this project strive to ensure the system's practicability and viability onboard the aircraft and as well as on ground. This certainly accentuates opportunities for future creative learning in the aviation study.

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1. Introduction

Aerospace Industry has since recovered from the 911 and has now progressing into a significant sector, which accounts for the increasing workforce in recent years. According to Singapore Economic Development Board (EDC) News Room dated 2006, the growth in Singapore has reported a compounded annual rate of more than 12% over the last 10 years and is expected to record an even high rate in coming years. (www.sedb.com)

With that, many local institutions have created Aerospace related courses to support a wide spectrum of activities in this specialized industry, in areas such as maintenance, troubleshooting, designing, repair and overhaul of aircraft components. With the aim of attracting more individual to this ever-growing industry, institutions have provided an excellent inspiration and basis for teaching undergraduate aircraft theory and construction. One of which, is to build an unmanned aerial vehicle ("UAV") and make it fly. "*Design and construction of a UAV is an ideal mechanism for early involvement of students because its technical and managerial aspects are both challenging and educational*" (University of Southern California, 2002).

The UAV achieves its flight in the way similar to an actual aircraft operation. Apart from the throttling of the airborne speed, the pilot will also need to be in command of the aircraft primary flight control surfaces, such as aileron, rudder, elevator and etc, to steer the aircraft to the desire flight path. Such directional control is a key fundamental to the techniques of designing and operating the aircraft.

Unlike actual aircraft, the UAV requires a remote control stick to maneuver the vehicle and the operator will need to maintain a constant lookout over the entire flight. In most cases, the operator is uncertain about whether the vehicle has reacted correctly to the input commands because the vehicle may be at a far distance and not within the proper sight. The operator may be too immersed in moving the remote control stick to left, right, up or down. More than often, the operator is not aware on the outcome of the motion interaction between the respective flight control surfaces and the airflow that causes the vehicle steering. There could also be a possibility of flight control movement failure with which the operator unable to notice it immediately.

While formulating and developing this project, a key element needs to be comprehended, that is, the entire aerodynamic forces acting on aircraft and their influence to the primary flight control system. This will include the knowledge of aircraft movement in its 3 principle axes; longitudinal axis, vertical axis and lateral axis, which resulted in various type of directional change. As such, this will assist this project in seeking to establish a mechanism, which is the sensing system, that can enable detailed feedback of aircraft surfaces movement, when in airborne.

It is vital to also understand the selected UAV key features and the technical specifications, in order to determine, to what extent, enhancement can be added / made to that aircraft. Ignorance to the features and technical specifications of UAV will destroy the aerodynamic forces, which affects the flight performance capability. Evidently, the sensing system must not restrict or affect the existing components or surfaces onboard of UAV.

Incorporating a sensor onto the UAV has to seriously consider the weight and size in order not to overload the UAV, which can possibly distort aircraft performance. Thus, the selection of appropriate sensor to detect the position of flight control surface upon every input commands from the ground operator has to be practical. Such detection must be carried out on real-time basis and the installation must not restrict any surfaces movement. Hence, it will be essential to study the connecting linkage and the necessary operating mechanism that move the UAV surfaces before selecting the most appropriate type of sensor.

The wireless means transferring the detected signals to the ground using Radio Frequency (“RF”). Factors such as range of transmission, operating frequency and the bandwidth utilization must be considered and carefully examined. Importantly, this added wireless system should not affect the existing RF operated remote control system. A RF circuit can have one or more channels transmit and receive over a given frequency band. The required number of channels to monitor each flight control surfaces position is expected to be high. Therefore to maximize each channel, it will be vital to combine these detected signals into a one before transmitting. This will involve finding a suitable method of ‘combining’ and ‘separating’.

The final task is to electrically connect the selected sensors and the necessary components to form the sensing system onboard of aircraft. The superlative way of building-up a circuitry is to the use of printed circuit board (“PCB”). The design of the PCB can be complex due to the numerous component placement, routing, correct track size and minimum requirements of electrical clearance. All these have to be properly pre-determined and established prior fabrication and final assembly.

The project initially has considered to establish a ‘spying’ capability onboard of the aerial vehicle, to enables the operator to see the surrounding while the aircraft in airborne. The incorporation of surveillance camera, apart from ground surveying capability, is to examine the possibility of adding future payloads onto the aerial vehicle. Hence, to install a surveillance camera on vehicle undercarriage that could capture a maximum viewing effect.

Prior to any payload installation, the weight and size of the payload that affects the vehicle from taking-off, the transmission of the payload signals to the ground and its functionality has been carefully studied. Regret that the project could not take this part further due to a major letdown: after incorporating the sensing and wireless system onboard, there isn’t much space available to accommodate camera onto the selected UAV. As such, the plan to build-in a surveillance camera onboard aircraft has been aborted.

2. Aims

To develop a sensing system for detecting the unmanned aerial vehicle’s primary flight control surfaces movement. With the build-in onboard sensors, the operator will be able to receive the feedback of the flight control surfaces position during the aircraft maneuvering.

In order to determine the response of the vehicle to the given command, the sensor enables the detection of flight control surfaces movement via the signals transmitted to the ground. This is extremely critical when flying the vehicle in poor visibility condition or at night.

Furthermore, any malfunctions of the flight control surfaces can be noticed at the shortest possible time, whereby instant actions can be taken to eliminate disasters. More notably, the detected signals will allow the operator to witness the position of the flight control surfaces that resulted of the directional change.

With the above incorporations and future enhancement, the operator will be able to understand the directional control principles of the airborne aerial vehicle, which essential benefit keen aviators as well as to aeronautical study.

3. Aircraft Flight Control System

3.1 Aerodynamic Forces

Basically, there are four aerodynamic forces acting on the aircraft when in airborne; the **force** due to gravitational, the **lift** created by air flowing over the wing, the **thrust** generated by the propeller and the **drag** caused by air resistance to the aircraft (refer to Diagram 3.1A).

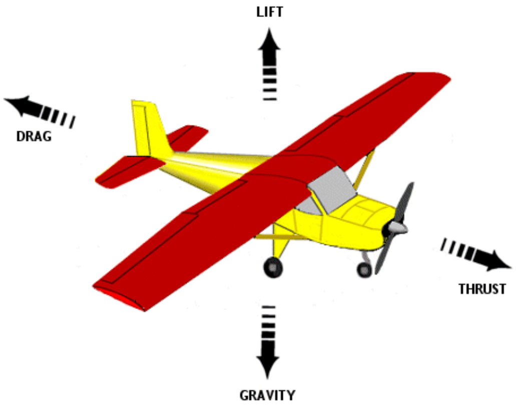


Diagram 3.1A – Forces Acting on Aircraft (Adapted from RC Airplane)

An aircraft obtains the forward motion from the thrust generated by the propeller. The aircraft will maintain a fix height, direction and speed when the thrust force is equal to the drag. The forward motion of the aircraft will then create airflow over the wings and the dynamic pressure changes within this airflow will cause an upward lift, which will be equal to the force due to gravity.

Hence, in a normal cruise flight, the four basic forces acting on the aircraft are said to be in equilibrium. The pilot will then be able to control the speed of aircraft and flight control surfaces in the cockpit.

"*Flight control is an interesting and technically challenging subject for which a wide range of engineering disciplines have to align their skills and efforts, in order to establish a successful system design*." (Roger Pratt, 2000). The aircraft flight control system is primarily made up of the aileron, elevator and rudder system (refer to Diagram 3.1B).

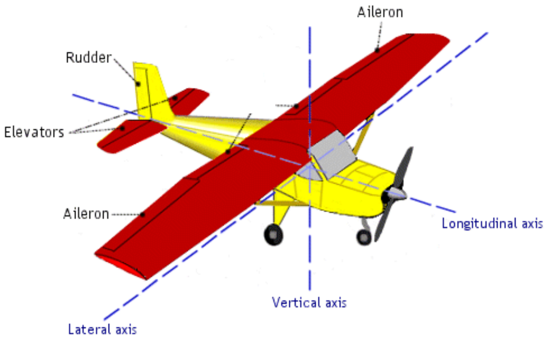


Diagram 3.1B – Aircraft Primary Flight Control System (Adapted from RC Airplane)

3.2 Aileron System

The aileron is attached to the outer trailing edge at each wing. These movable surfaces are used to control the movement along the longitudinal axis that causes the aircraft to roll. Lowering the aileron on one wing will give raise to the aileron on the other wing. The wing with the "downward" aileron position will cause the wing to move up due its increased lift. On the other hand, the wing with aileron on "upward" position will cause the wing to move down due to its decreased lift. Therefore, the consequence of moving either aileron is facilitated by the concurrent and opposite movement of the aileron on the other wing.

In actual aircraft, the rods or cables were used to connect the ailerons to each other and to the control stick in the cockpit. Supposedly, when the pressure is applied to the right of the stick, the left aileron will move to downward and the right will move upward. This will cause the aircraft rolling to the right. This occurrence is actually caused by the down movement of the left aileron that increases the wing camber (curvature) and thus increases the angle of attack. The upward movement of the right aileron will decrease the camber and resulting in a decrease of angle of attack as well. Hence, the decrease lift on the right wing and increased lift on the left wing cause a roll to the right (refer to Diagram 3.2A).

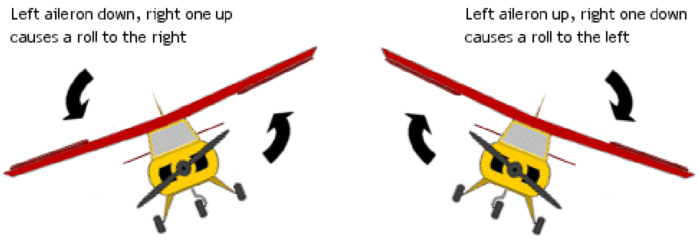
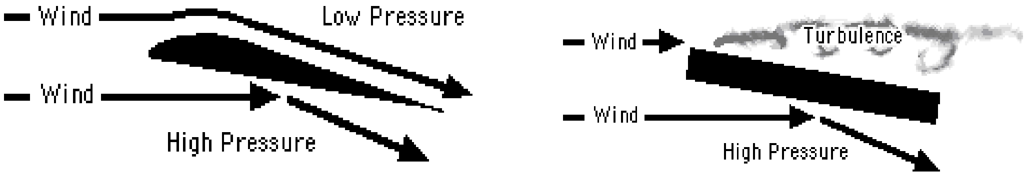


Diagram 3.2A – Aileron System (Adapted from RC Airplane)

An important principal behind this wing lifting is known as Bernoulli’s principle. The airflow across the top of a conventional airfoil will experience constricted flow lines and the air speed relative to the wing will increase. This causes a decrease in pressure on the top and provides a lift force. In general, a curved wing is more efficient than a flat wing. Airflow can move smoothly over the top of the curvature wing as compared to flat wing (refer to Diagram 3.2B), which will cause lower pressure to develop without much drag. Therefore, a wing with an efficient camber does not require as much thrust to achieve lift. Thus, lift is easier to generate and maintain with an efficient camber.


Bernoulli's principal

Turbulence results in more drag and less lift

Diagram 3.2B – (a) Curvature Wing & (b) Flat Wing
(Adapted from Manifield Middle School)

While an aircraft wing is one of the best illustrations of the Bernoulli effect, the Angle of Attack ("AOA") is another contributing factor that enables the aircraft to fly. The AOA is the angle between the chord line and the relative airflow (refer to Diagram 3.2C). The angle of attack will increase or decrease depending on the aircraft directional change and it is also used to determine the aircraft's rate of speed through the air. Increasing the angle of attack gives a larger lift from a higher pressure at the bottom of the wing. At too high an angle of attack, turbulent flow increases the drag dramatically and will stall the aircraft.

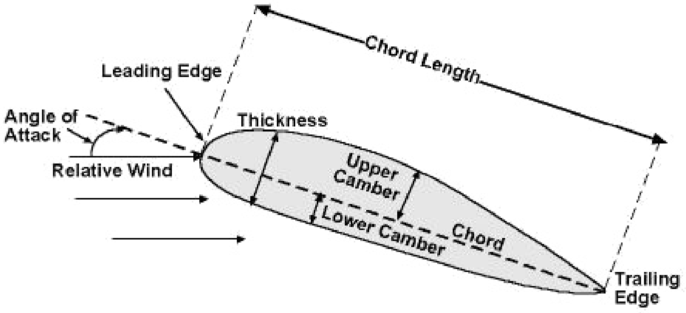


Diagram 3.2C – Angle Of Attack (Adapted from Centennial of Flight Commission)

3.3 Elevator System

The elevator system controls the movement of the aircraft about its lateral axis, this will cause the aircraft to pitch up or down. It is usually located at the rear part of an aircraft and is free to swing upward or downward. They are attached to a fixed surface, the horizontal stabilizer tail assembly, which will form a single airfoil. A change in position of the elevator modifies the camber of the airfoil that increases or decreases lift.

Similar to the aileron, the elevator is connected to the control stick by control cables. When a forward pressure is applied on the stick, the elevator move downward and this will increase the lift produced by the horizontal tail surfaces. The increased lift will force the tail upward, thus causing the aircraft nose to drop. On the contrary, when back pressure is applied to the stick, the elevator move upward and the lift will decrease the lift produced by the horizontal tail surfaces, or possibly producing a downward force. The tail is forced downward and the nose up position (refer to Diagram 3.3A).

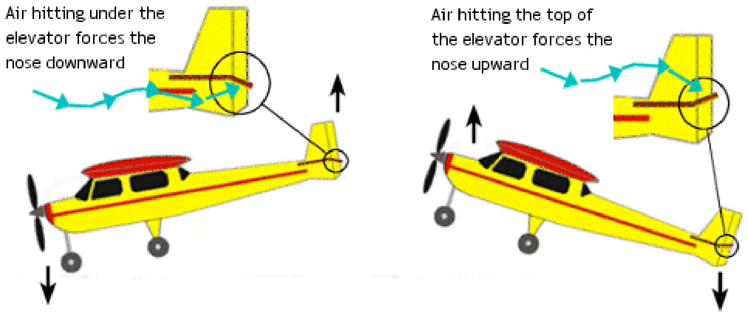


Diagram 3.3 – Elevator System (Adapted from RC Airplane)

The elevator will have an influence to the AOA of the wings. When aft pressure is applied on the control stick, the tail lowers and the nose raises will cause the AOA to increase. Conversely, when forward pressure is applied, the tail raises and the nose lowers will cause AOA to decrease.

3.4 Rudder System

The rudder system controls the movement of the aircraft about its vertical axis. This motion is known as yaw. Like the other primary control surfaces, the rudder is a movable surface hinged to a fixed surface, which, in this case, is the vertical stabilizer, or fin. Its action is very much like that of the elevators, except that it swings in a different plane, from left to right rather than up to down (refer to Diagram 3.4A).

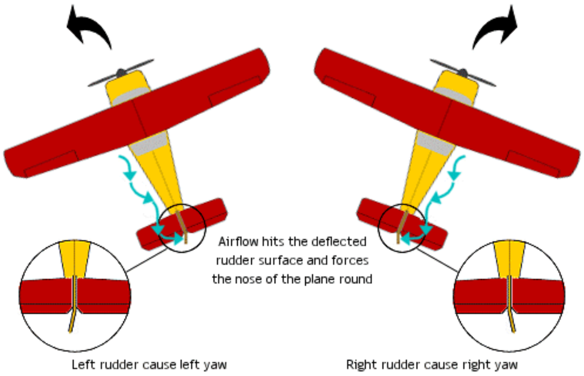


Diagram 3.4 – Rudder System (Adapted from RC Airplane)

3.5 The Unmanned Aerial Vehicle

"Unmanned aircraft have been around almost as long as powered flight. In the first world war they were used as flying bombs and by the second as radio-controlled targets and for reconnaissance missions" (The Economist, 2007). In recent years, the unmanned aircraft vehicle ("UAV") has been commonly used in many educational institutions to provide an early involvement for student acquiring the aerospace engineering skills.

A typical UAV navigates its flight path in a way similar to the actual 'full-blown' aircraft operation, only that the former is in a smaller size and at a lower speed. The four aerodynamic forces acting on the powered flight are still applicable to the UAV when it comes to airborne. Furthermore, the principle construction for each primary flight control surfaces and their motion change about its axis are identical.

Instead of pilot throttling the propellers' power setting and moving the flight control stick inside the cockpit, the UAV uses radio remote controlling to perform such essential flight tasks. With newer technologies such as Electro-Optical (EO) payload and Global Positioning System (GPS) built into UAV, it will enable operator to fly the machine beyond visible range and the controlling the UAV in a ground control station. The operator will have to undergo a specialized intensive training prior to it first flight, therefore, operator has to be certified and qualified.

This highly developed UAV is mainly employed by defense industry to handle 'spying' jobs and usually will incur high production costs. Any major system malfunctioning will require extensive troubleshooting and rectification. Hence, it is rather impossible and impractical for institutions except flying schools, to acquire and maintain such sophisticated UAV. Although, the most of the UAV used in institution may not be as advanced as in military arena, it is enough and definitely be able to serve its purpose of providing emphasis on the aircraft technical aspects as well as understanding the fundamental of aerodynamic.

3.6 UAV Selection

The UAV selected for this project development is the Pico Stick from GWS (refer to Diagram 3.6A), which was built-up by students from Singapore Polytechnic. This type of UAV is sometimes known as a "glider" that is primarily designed for an unpowered flight. The distinguished features are their longer and skinnier wing together with narrow and light body. These combination will allow better lift and easier to maneuver through airflow.

Diagram 3.6A – The Unmanned Aircraft

As mentioned earlier, the primary 3 flight control systems are aileron, elevator and rudder. Due to the complexity of aileron system construction, this selected UAV is built without the aileron system. It is noteworthy that a UAV with aileron system will not have the lift force acting on straight up when it start to roll, thus making the UAV descends eventually because of the weight is greater than life. Therefore, without the aileron, it will be easier and sufficient for the operator to use the rudder and elevator steer the UAV to the desire flight path.

A radio remote control (refer to Diagram 3.6B) is used to control the UAV at a maximum distance of about 200 meter. The most distinct feature of this remote controller is; it is designed in a way that it will correspond exactly to the aircraft directional change, thus, when the rudder control stick on the remote control moves to right, the aircraft will be yawing to the right.

Diagram 3.6B – A Radio Remote Control for UAV

It operates at 40.79 MHz frequency band and uses Frequency Modulation ("FM") technique, which is preferred for its better unwanted signals rejection. There are total of 3 channels for the rudder, elevator and propeller system respectively. Any command on the joystick will cause the controller to transmit a set of sequence of electrical pulses. Each sequence contains a short group of synchronized pulses, followed by the pulse sequence that identifies the specific task, such as rudder to move left.

The controller sends bursts of radio waves that oscillate with a frequency of 40790000 cycles per second. Upon receiving the specific task signals from the controller via the antenna, the receiver (refer to Diagram 3.6C) will send a signal to a filter that blocks other signals except the signal 'riding' on 40.79 MHz. The received signal will then be converted back into electrical pulses. A decoder is used to detect the sequence of the pulses prior to output to the appropriate micro servo (refer to Diagram 3.6D), which will in term deflects the control surfaces or setting the propeller speed.

Diagram 3.6C – UAV Onboard Receiver

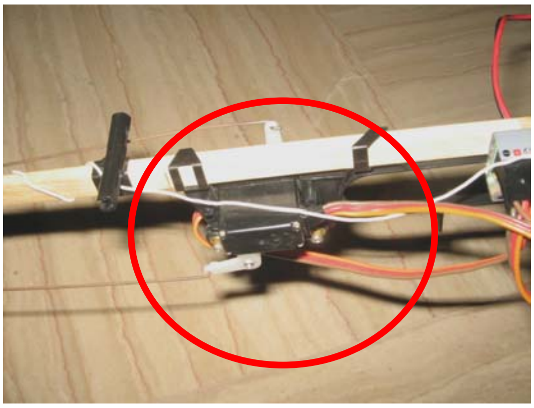


Diagram 3.6D – UAV Onboard Mirco Servo

All onboard circuitries, micro servos and motor are driven by a 1300mAh 7.4V battery. The technical specification is as shown below.

Specifications

Wingspan: 41.3 in. (1050 mm)

Flying Weight: 6.53 to 7.05 oz. (185 to 200g)

Wing Area: 237 sq. in. (15.28 dm sq.)

Wing Loading: 3.6 oz/sq. ft. (11.1 g/dm sq.)

Length: 26.6 in. (675 mm)

Flying Speed: 8.5 to 14 ft/sec (2.5 to 4.2 m/sec)

Flying Duration: 12 to 15 min

Whenever incorporating the sensing system on the UAV, it is important to balance and even adhere to the specifications stated. Without considering the specification can result overloading and causing UAV to fail in meeting the expected flying requirements. There are challenges faced while having the sensing system build onboard: Firstly, the incurred weight to the UAV shall not exceed the maximum flying weight. If incorporate the sensing system exceeds the specified weight, it will increase the force due to gravity and eventually affect the lift of the UAV. Secondly, the selected UAV is supposed to have narrow and light body. Any large size circuits mounted on stick fuselage will change the initial configuration, thus affecting the maneuvering and speed. Therefore, the size of circuits must be kept relatively small, yet still capable of performing the required tasks. Last but not least, the interference to the existing radio control system onboard. Obviously, the sensing system will be using wireless technology to transmit the detected signals to the ground. Thus, the ‘new’ transmitter onboard must be capable of transmitting the detecting signals without affecting on the existing radio controlling.

4. Sensing System

"*A sensor is a device that converts a physical phenomenon into an electrical signal. As such, sensors represent part of the interface between the physical world and the world of electrical devices, such as computer*" (Jon S. Wilson, 2005). Before selecting a suitable sensor to detect the flight control surfaces movement, it is essential to understand how the surfaces on the UAV are fundamentally moved upon each command.

The rudder and elevator surfaces are controlled by their respective mirco servo together with the rods that are attached to the moveable surface (refer to Diagram 4A). The servo will deflect the surfaces, which are made of styrofoam to correspond with operator's intention and steer the UAV to the desire flight path. Logically, the rudder and elevator surfaces will only deflect to either side at any given time. For instance, the rudder surface will either deflect left or right and the elevator will likewise be only up or down position.

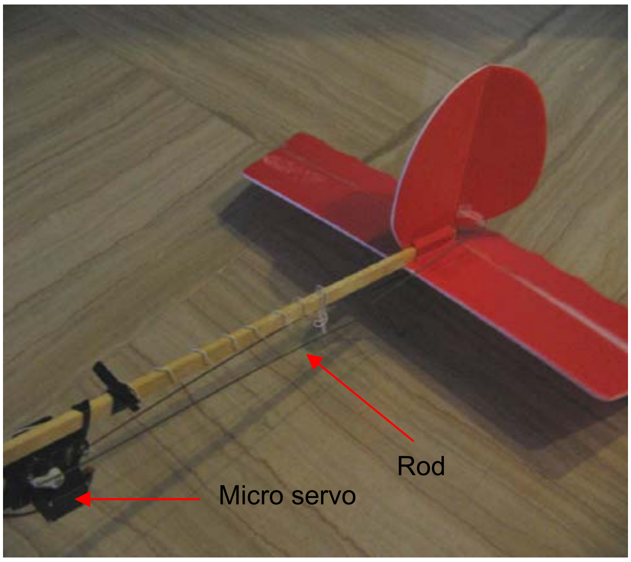


Diagram 4A – UAV Rudder Operation

The function of sensor can be ranged from a very simple sensor that detects the water level, to a more complicated sensor that can identify images. Simply, the sensor is used to measure a physical quantity and converts into some forms of energy, which then can be employed to trigger other system or instrument for reaction. An example of the use of the simplest sensor – in a toilet flush system, the water tab will be opened to fill up the tank when it has detected water at low-level using a mechanical sensing system.

"…the introduction of solid-state electronics created new opportunities for sensor development and control, with the result that sensors today almost exclusively produce an electrical output for use in such applications as computer-based controls, archiving/recording, and visual display" (National Academy Press, 1995). As an integral part of sensing system, there is a need for electrical interfacing and signals processing. Therefore, without interfacing and processing, the sensor of today will be meaningless.

Apart from these necessary requirements, there are other factors to be carefully considered when designing and incorporating the sensing system onto the UAV. Such as the sensing methodology, the power requirement, the viability due to space constraint, the method of mounting the sensor, the accuracy of the measurement, and durability of the system. Importantly, the overall weight and size of the sensing system, meeting the UAV specifications, will be an utmost challenging task to achieve.

4.1 Sensor Selection

One of the appropriate types of sensor to detect the flight control surfaces movement will be the position sensor and the most broadly used is the **l**inear **v**ariable **d**ifferential **t**ransformer ("LVDT") (refer to Appendix 1). This type of sensor will convert linear movement of an object connected to it, into an electrically signal proportional to the amount of movement.

"The SM Series 2.3 mm diameter LVDT is suitable for displacement measurements in narrow places" (www.singer-instruments.com) (refer to Diagram 4.1A). The LVDT have been commonly used in aircraft to detect flight control surfaces position, *"LVDTs fit the aircraft industry well"* (N. George, 1999). Ideally, this type of LVDT is appropriate for a narrow and light body of UAV because of its size and weight but the power requirement is demanding.

Diagram 4.1A – The Smallest LVDT Sensor
(Adapted from Singer Instrument)

The fundamental principle of LVDT operation is by inducing voltage from the primary coil into the secondary coils, using a magnetically permeable core. The voltage that is applied to the primary coil produces a current that will induce the current in the secondary coils. The amount of current induced to each secondary coil is dependent on the mutual inductance, which in turn depends on the position of the core (refer to Diagram 4.1B). It can accurately sense miniature movement down to microns.

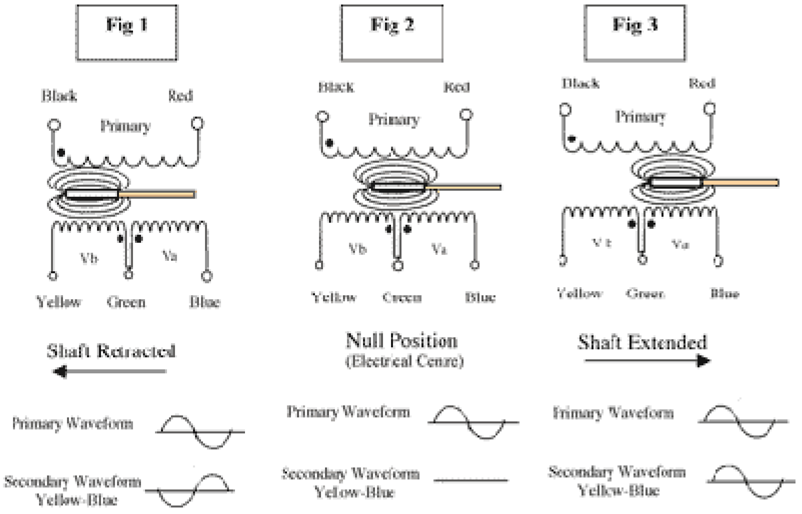


Diagram 4.1B – LVDT Principal of Operation (Adapted from Active Sensors)

LVDTs require **a**lternating **c**urrent (“AC”) power at a nominal frequency to excite the primary and secondary coil. The SM series requires an input voltage of 2.3 V_{AC} at frequency of 5 kHz. An inverter circuit (refer to Diagram 4.1C) will probably be required to power the LVDT. The inverter will take in **d**irect **c**urrent (“DC”) voltage and it passes through Q1 and Q2, which is a pair of power switching transistors and T1 the transformer. Both the transistors will be switching at rapid succession and it will cause the power to induce to the opposite side of the transformer, which will in term generate an AC voltage. Subsequently, the AC will be step up or down to the required voltage level, usually at 110 or 230 V_{AC} 50 to 60 Hz.

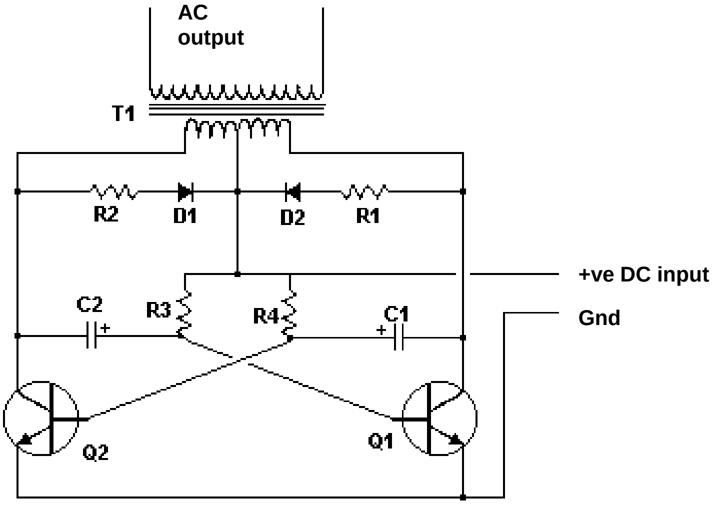


Diagram 4.1C – Basic DC to AC Conversion Circuit
(Adapted from Discovercircuit)

An addition step-down transformer and most probably also a high frequency transformer will be required to obtain the power requirement for the SM series. Although, technically it should be able to operate, however more components mean increase weight and size, resulting complexity to the sensing system. Furthermore, a signal processing will be compulsory to convert the AC voltage obtained from the secondary coils into a DC discrete signal that represents the core displacement, thus making the designing of circuit even much more complex.

Thus, the said LVDT is not exactly suitable for the selected UAV. Due to its power requirements, it involved the use of several power components that necessitate the operation on the AC voltage. In order not to add pressure on the weight and size of the UAV, the sensors selected should be battery-operated. In this manner, the existing 1300 mAh 7.4 V lithium polymer battery pack will be able to power-up the sensing system apart from supporting the existing components onboard of the UAV. Essentially, the power consumption of the selected sensor must be as low as possible in order not to affect too much on operating duration of the UAV significantly.

4.2 Power Source Distribution

The ampere reading of 1300 mAh refers to the battery energy storage capacity and it used to determine how much current in milliamps could be delivered over a period of 1 hour. Therefore, the higher the number, the longer it can provide power. If the flight duration is not to affect much, the battery pack shall be replaced to a higher ampere reading, but at the expense of higher costs. Preferably, the lithium polymer battery once again that promised low-maintenance and the lightest weight around. Conceptually, a circuit board will need to be developed so as to share the power source between the existing components and the sensing system. A simplified power distribution circuit board (refer to Diagram 4.2A) has one input from the battery source and two outputs, whereby one to the UAV existing system and the other to the incorporating sensing system. Enhancement has been made to include a switch that will act as an on-off operation to the whole sensing system for power conservation while system is not required for the flight.

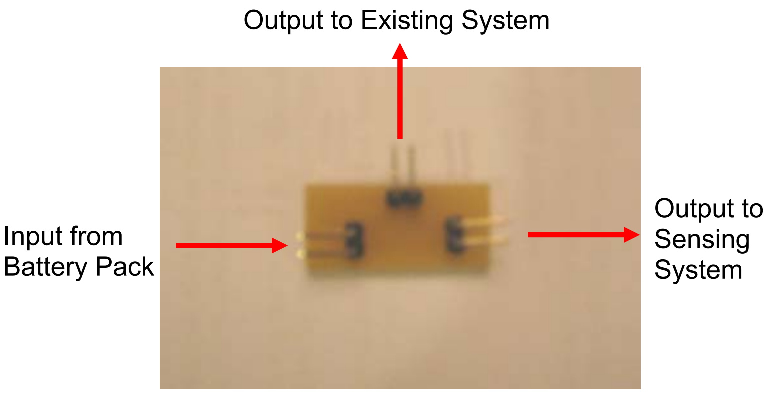


Diagram 4.2A – Simplified Power Distribution Board

4.3 Decoupling

Another improvement is to connect a decoupling (refer to Appendix 2) capacitor between each of the supply line and the ground. *"Decoupling: The art and practice of breaking coupling between portions of the systems and circuits to ensure proper operation"* (www.cypress.com). When dealing with two system circuits sharing the same power source, there might be an occasion whereby one system circuit is drawing additional current due to the motor, servo and Integrated Circuit ("IC") chip switching. In this situation, the current required is more than the voltage source can supply while trying to maintain the voltage levels. This will eventually cause the voltage to drop, causing an unwanted behavior that will affect the other systems.

By connecting decoupling capacitors (refer to Diagram 4.3A) in the final circuit, there is another source for the system circuit to draw this surge current requirement. Under normal situation, the power source will charge the capacitors and when the current from one of the system circuit suddenly went up, the capacitors will release its stored energy to fulfill the demand without affecting the voltage source.

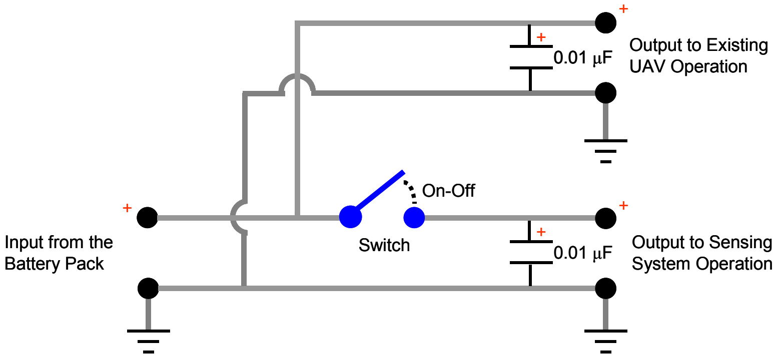


Diagram 4.3A – Improved Power Distribution Board

"Without a clear set of tools and methodologies….many boards would have to be treated in a pessimistic and conservative way and would end up with a lot of unnecessary decoupling capacitors..." (www.cdnusers.org). The selected values of the decoupling capacitors used depend very much on the speed of the circuits. For example, in a circuit with an IC chip that operates at the frequency of 100 MHz, the suitable value will be 0.01 μF. As the frequency increases, the value of the capacitance decreases. For a very high-frequency (> 500 MHz) circuit, it is recommended to use one large value of 0.01μF in parallel with one small value of 100 pF.

4.4 Selected Sensor

With all the prior investigations and study of the suitable sensor for the selected UAV, it was discovered that the most appropriate sensor is the infrared sensor. Infrared is a form of energy identical to visible light, but with a longer wavelength (refer to Diagram 4.4A) and invisible to human eye. Infrared radiation has a range of 750 nm to 1 mm wavelength.

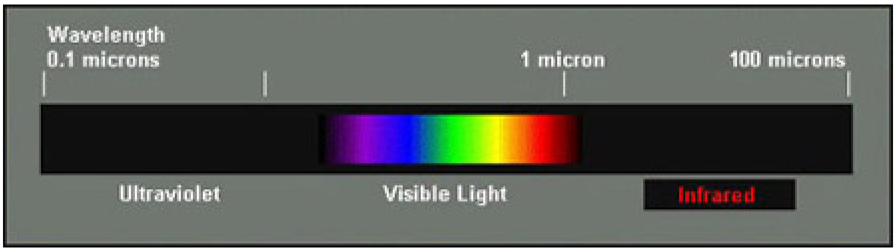


Diagram 4.4A – Infrared Wavelength (Adapted from Infrared, Inc)

This type sensor consists a phototransistor, which is sensitive to infrared radiation, and an infrared emitter (refer to Diagram 4.4B). The phototransistor has peak sensitivity at the wavelength to the emitter, but it is also sensitive to visible light and infrared emitted by other light source. Therefore, the phototransistor should be shielded from the ambient lighting as much as possible in order to obtain reliable result. The light falling on the phototransistor will generate charge carriers in the base region of a transistor, effectively providing base current. The intensity of the light determines the effective base drive and thus the conductivity of the transistor. The greater amount of the light will result greater current flow through the collector-emitter.

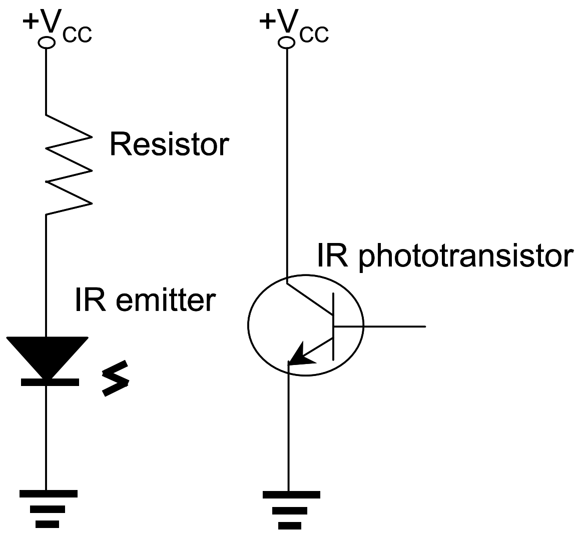


Diagram 4.4B – Infrared Sensor

There are 2 main types of configuration for the phototransistor, which are the common-emitter and common-collector. With common-emitter (refer to Diagram 4.4C), it will generate an output signal that will transition from high to low when the phototransistor detects light or infrared radiation, commonly known as an ‘inverting logic condition’. By connecting a load resistor between the voltage supply and the collector pin of the component, the output voltage will be generated.

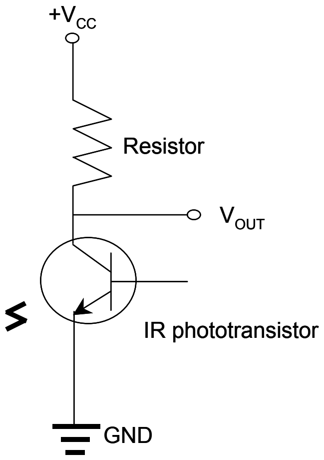


Diagram 4.4C – Common-emitter Configuration

With common-collector (refer to Diagram 4.4D), it will generate an output signal that will transition from low to high when the phototransistor detects light or infrared radiation, commonly known as an ‘non-inverting logic condition’. The output voltage is created by connecting a load resistor between the emitter pin to ground.

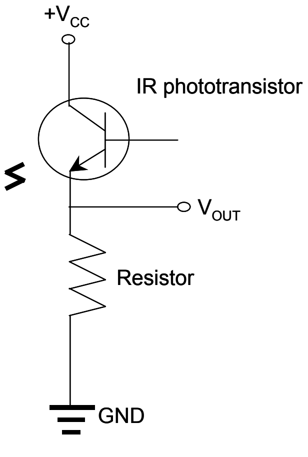


Diagram 4.4D – Common-collector Configuration

In both circuits, the phototransistor can be used in two modes, which are an active or switch mode. Operating in the active mode refers to the phototransistor generates an output directly proportional to the received light up to a certain level. When the amount of light exceeds the pre-determined level, it becomes saturated and the output will not increase even as the light level increases. This mode is useful in applications where it is desired to detect two levels of inputs for comparison. Operating in the switch mode denotes that the phototransistor will be either ‘off’ (cut-off) or ‘on’ (saturated) in response to the light. This mode is useful when a digital output is required for object detection or input to an encoder.

By selecting the load resistor in both of the configuration, one can set the mode of operation. The correct value for the resistor can be determined by the following equations:

Active Mode: $V_{CC} > R_L \text{ X } I_C$

Switch Mode: $V_{CC} < R_L \text{ X } I_C$

Typically, a resistor value of 5 kΩ or higher is adequate to operate the phototransistor in the switch mode. The high-level output voltage in the switching mode should equal the supply voltage and the low-level output voltage should be less than 0.8 V.

A pair of mechanically and compatible matched Gallium-aluminum-arsenide (“GaAIAs”) infrared emitter and phototransistor, has chosen for the sensing system development, which are the OP298 (refer to Appendix 3) and OP598 (refer to Appendix 4) series respectively. *“The data indicate that if the designers needs to measure 880 nm LEDs in environments where background light could be a problem, the best solution is the GaAIAs detector”* (SENSORS, 1996). It is therefore essential to use GaAIAs detector to obtain reliable result, especially when the UAV is operating in the outdoor environment where the light radiation from the sun will distort the detection capability. Both series have a narrow beam angle and a wide operating temperature range. The narrow beam angle will have more intense due to a concentration of infrared over a smaller area and a wider range of temperature will allow operating at adverse conditions.

The phototransistor is configured to a common-collector with switching mode operation (refer to Diagram 4.4E). For supply voltage of 3.3 V_{CC}, a resistor of 180 Ω is used in the emitter to limit the forward current (I_F) to about 7mA.

Calculation

I_F = 20 mA and V_F = 2.0V

R1 = $(V_{CC} - V_F) / I_F$ = (3.3V - 2.0V) / 20mA ~ 180 Ω

For transistor made of GaAIAs, the typical value of collector-emitter voltage (V_{CE}) should be 0.3V. Given that the collector current (I_C) is about 0.5 mA, thus the loading resistor will need at least 6 kΩ to have the output voltage equal to the supply voltage.

Calculation

I_C = 0.5 mA and V_{CE} = 0.3 V

R2 = $(V_{CC} - V_{CE}) / I_C$ = (3.3V – 0.3V) / 0.5 mA ~ 6000 Ω

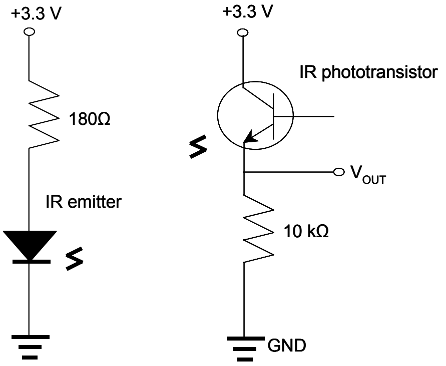


Diagram 4.4E – Infrared Sensor Configuration

Apparently, the infrared sensor has fulfilled many factors laid down initially, but the main concern is the method of mounting the sensor for surfaces detection. One can choose to mount a pair of emitter and phototransistor at each side of the surfaces (refer to Diagram 4.4F) and a minimum of 4 pairs are required for both the rudder and elevator. However, this will inherently impose stress to the styrofoam surfaces as well as induce wire routing complication. In addition, both phototransistor and emitter must be mounted at certain angle so that they will only come in contact when the surfaces start to deflect, making the mounting almost impossible.

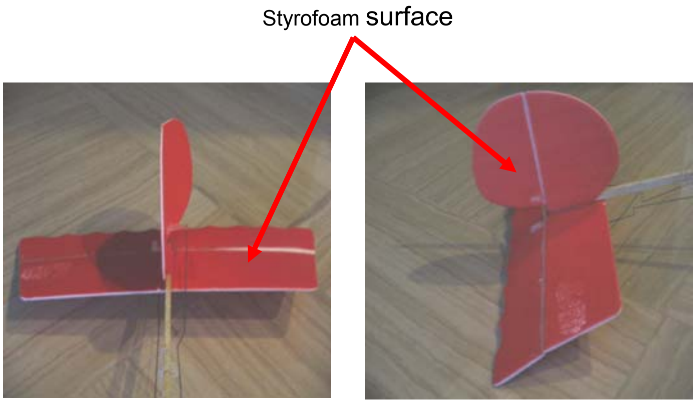


Diagram 4.4F – Flight control surfaces

As explained earlier, a micro servo and a rod are used to deflect each flight control surface. The alternate way of mounting is on the stick fuselage and rod. During each flight control movement, the rod will either travel fwd or aft in order to deflect the surfaces. With two phototransistors mounted on the fuselage and one emitter attached to the rod for each rudder and elevator system, it is able to detect surfaces deflection. The spacing between the two phototransistors is exactly the distance for the rod to move rudder from extreme left to right or elevator from extreme down to up. The always 'on' emitter without any activation of surfaces is placed in the middle of the two phototransistors. Under such condition, both phototransistors are said to be non-conductive, less than 0.8 V, because the surfaces are in neutral position. When any of surfaces start to deflect, the emitter attached to the rod will move towards to either of the phototransistors, depending on the command input and eventually the emitter will come in contact with the phototransistor, which causes an electrical output signal from the phototransistor to indicate the surface deflection (refer to Diagram 4.4G).

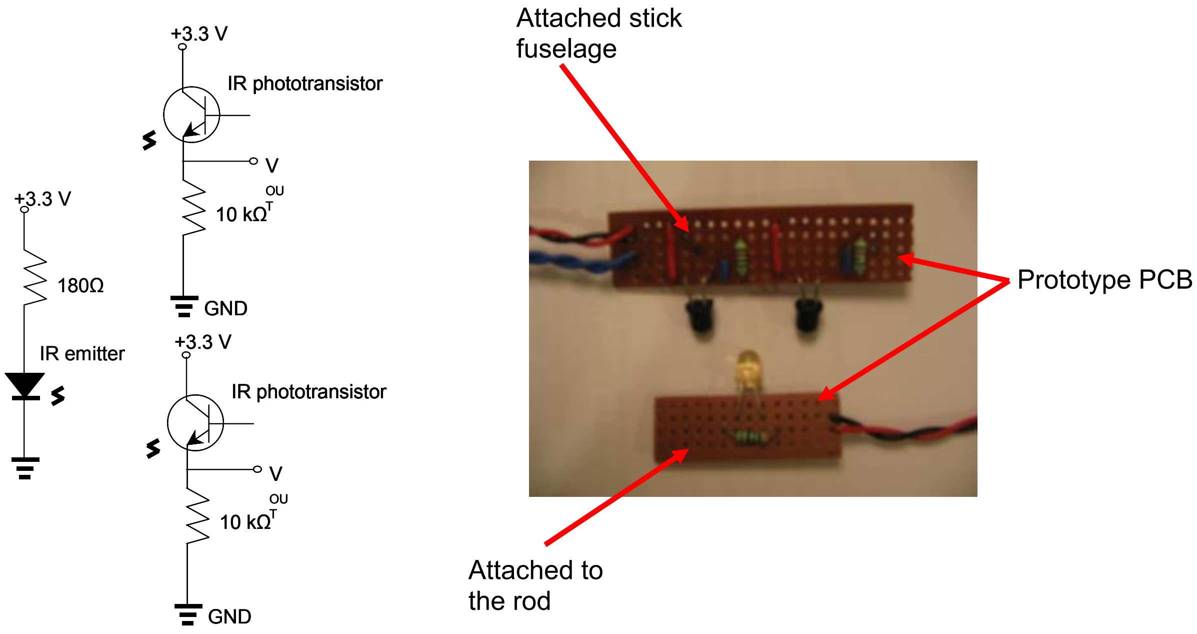


Diagram 4.4G – Mounting the Sensor

This method of mounting the sensor will not obstruct or impose stress to the surfaces movement. The sensing methodology is rather simple and yet it is the most effective way of measuring the surfaces movement. Apart from the sensor itself, only couples of resistors are required, thus reducing the weight and size of the sensing system. An important noteworthy is that the orientation of the phototransistors must be faced downward to avoid the direct contact with the sunlight radiation, which will cause an undesirable measurement.

5. Wireless System

With the implemented sensing system, there are actually 4 electrical analog signals to be transmitted to the ground to complete a feedback loop. Obviously, this will need a wireless mean for transferring such information to the ground. *"Wireless technology a is truly revolutionary paradigm shift, enabling multimedia communications between people and devices from any location. It also underpins exciting applications such as sensor networks…"* (G.Andrea,2005). The simplest way of transferring the information is by Radio Frequency ("RF") that covers large portion of the electromagnetic radiation spectrum, ranging from 9 kHz to thousand of gigahertz (GHz).

Before the information can be transmitted, the low frequency signal from the sensing system will need to convert into RF spectrum. This conversion can be carried out 2 traditional schemes, which are Amplitude Modulation ("AM") and Frequency Modulation ("FM"). The choice of the modulation scheme is based according to power, the bandwidth efficiency and the channel capacity. The power efficiency is a measure of how much signal power should be increased to achieve a particular bit error rate for a given modulation scheme. The AM scheme is well known for its low power efficiency. Bandwidth efficiency is the ability to accommodate data within a limited bandwidth of a channel. The FM scheme requires a larger bandwidth than the AM, but the FM band is considerably larger and this keeps the number of available channels about the same.

There are at least two inherent problems associated with these two conventional schemes that can occur under certain situations. First, whenever a signal frequency is at constant, it is always subjected to catastrophic interference. This will occur when another signal is transmitted on or very close to the frequency of the desired signal. Catastrophic interference can be accidental, as in amateur-radio communications or it can be deliberated, as in wartime. Second, a constant-frequency signal is easy to intercept, thus it is not suitable in applications whereby information must be kept confidential between the transmitting party and destination receiving party. In order to reduce these vulnerability of the conventional schemes, a new and better scheme has been developed, which is known as spread spectrum modulation.

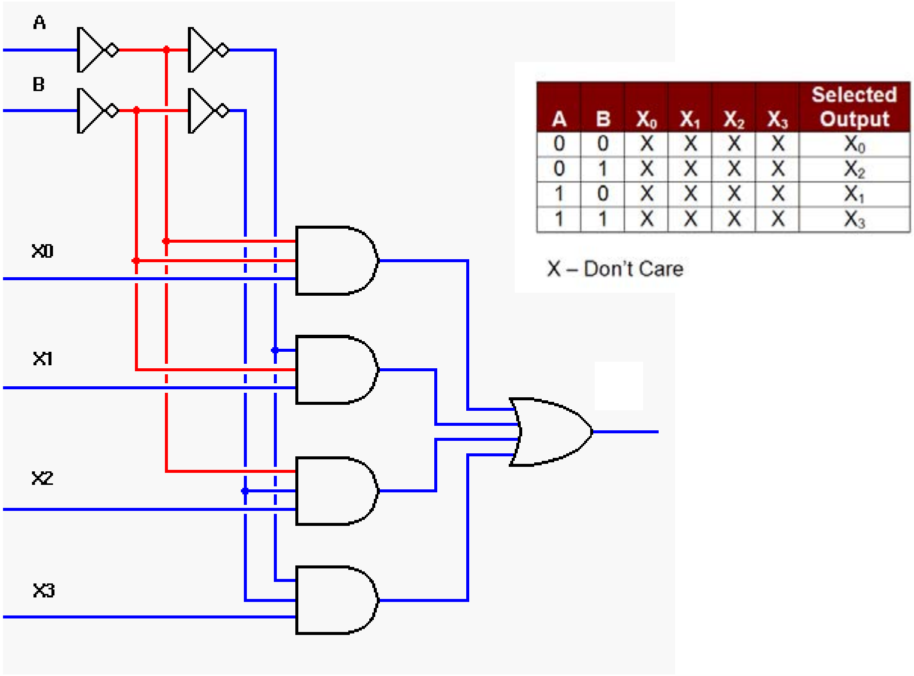
"Spread spectrum modulation techniques have become more common in recent years" (www.searchnetworking.techtarget.com). Spread spectrum modulation is able to suppress interference, making interception difficult, accommodate fading and multipath channels. A spread spectrum signal has an extra modulation, which will expand the signal bandwidth beyond the signal/data modulation requirement. The most practical and dominant methods of spread spectrum modulation are the direct-sequence modulation and frequency hopping. In direct sequence modulation, the stream of information to be transmitted is divided into small pieces and is allocated across the spectrum. A data signal at the point of transmission is combined with a higher data-rate bit sequence, known as chipping code, which divides the data according to a spreading ratio. The redundant chipping code helps the signal resist interference and also enables the original data to be recovered if data bits are damaged during transmission. The transmitter hops between available frequencies based on a specified algorithm, which can be either random or predetermined. The transmitter is synchronized with a receiver, which is tuned to the same center

frequency as the transmitter. After a short burst of data is transmitted on a narrowband, the transmitter will tune to another frequency for transmission again. In general, frequency-hopping devices use less power, but the performance of direct-sequence is usually better and more reliable.

5.1 Combining Signals

In order to combine many analog or digital inputs signals into a single line, a technique commonly known as multiplexing is required. This electronic multiplexer makes it possible for several signals to share one device, in the case of sharing the transmitter onboard of UAV, instead of having one device per input signal. On the hand, a demultiplexer is a device taking a single input signal and selecting one of many data output lines, which is connected to the single input. *"It is concluded that multiplexer designs permit the use of fewer interconnections than conventional designs, while being more flexible and consuming less energy"* (Z.Lotfi & A.Tosser, 1979).

For a 4 input multiplexer (refer to Diagram 5.1A), there are 4 inputs X_0, X_1, X_2 and X_3 and 2 addressing inputs A and B that controls which one of the four data inputs to be transmitted to the final output. If the data inputs are to be multiplexed for transmission to a distant location, the inputs must be cycle through all four possible addresses more than twice for each single cycle of each data input. Otherwise, the input data cannot be reconstructed accurately at the receiving end using demultiplexer. It can be seem that the controlling of the addressing inputs plays an important role in ensuring the right input to be transmitted each cycle. To implement the multiplexer into wireless system, it will require another logic circuit to perform the sequencing of the two addressing inputs at precise and fast interval, i.e at specific interval the addressing input will be jumping from 0,0 -> 0,1 -> 1,0 -> 1,1 -> 0,0. This may not be feasible as addition circuit is required and the overall design of the circuit may be complicated to ensure that the signal is distorted at the receiving end.



A	B	X_0	X_1	X_2	X_3	Selected Output
0	0	X	X	X	X	X_0
0	1	X	X	X	X	X_2
1	0	X	X	X	X	X_1
1	1	X	X	X	X	X_3

X – Don't Care

Diagram 5.1A – 4 Input Multiplexer (Adapted from Play-Hookey)

After much investigation and study, the most effective way of combining four signals into one signal that is suitable for transmission will be the encoder and decoder. An encoder is a device used to change a signal or data into a code, which can be served as information for transmission. On the other hand, a decoder is used to undo the encoding so as to retrieve the original data. The most preferred pair of encoder and decoder for project development is the RF600E and RF600D (refer to Appendix 5) respectively.

Both RF600E/D have been designed to achieve the maximum possible range from any radio set and uses a fully balanced Manchester encoded data protocol for optimum use of radio transmission path. Unlike other encoder/decoder, the

RF600E/D provide a distinctive level of security, which prevents copying or grabbing. The RF600D has an easy learn feature, which is able to learn up to 7 unique RF600E or up to 48 encoder devices when used in conjunction with an external EEPROM.

A RF600E (refer to Diagram 5.1B) only requires buttons and LED to complete a typical application circuit and the output data is readily for transmission. Upon detecting a button press, it will wake-up and delay for approximately 6.5 ms to allow the button to debounce. The internal synchronization counter, discrimination value and the button information will be encrypted to form the hopping code, which will be changed every transmission regardless on the button condition. A code word that has been transmitted will not be repeated for more than 64k transmissions, thus giving it an ultimate security assurance. While in the transmission process, the current code will not be completed when a new button has been pressed. Any button removal will not affect the code word unless no button remains pressed.

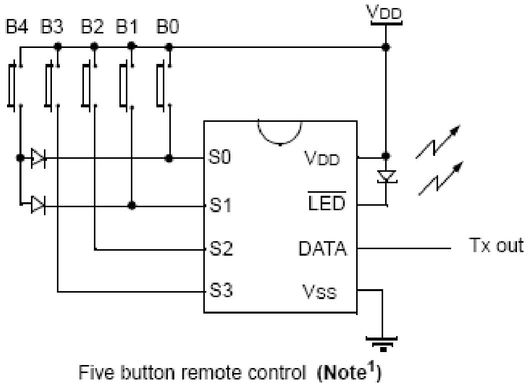


Diagram 5.1B – RF600E Typical Application Circuit
(Adapted from RF600E Data)

From the above reasoning, it is not possible to connect the 4 electrical signals from the phototransistors to the encoder input pins because at certain timing in flight the rudder and elevator system need to operate consecutively to achieve its flight path. For instance, while the UAV is pitching, at the certain height it may need to yaw left or right. Unless these 2 operations are performed concurrently, if not the current code word will not be transmitted when the new input is being triggered. This is an obvious deficiency of using the RF600E. Nevertheless, it can be still use for one flight control system (refer to Diagram 5.1C) instead of two, but at the expense of additional pair of encoder/decoder as well as transmitter/receiver. The output voltage from each conductive phototransistor is approximately equal to the supply voltage and this will be sufficient to trigger the RF600E whereby it only needs a minimum of 0.55 V_{CC}. The output is tied a transistor, BC108, configured as common-emitter amplifier. A small time varying output applied to the base will produce a small variation in the base emitter voltage V_{BE}, thereby producing a large change in the collector current. This will in term generate a large voltage change in the output due to current drop across 2.2 kΩ resistor.

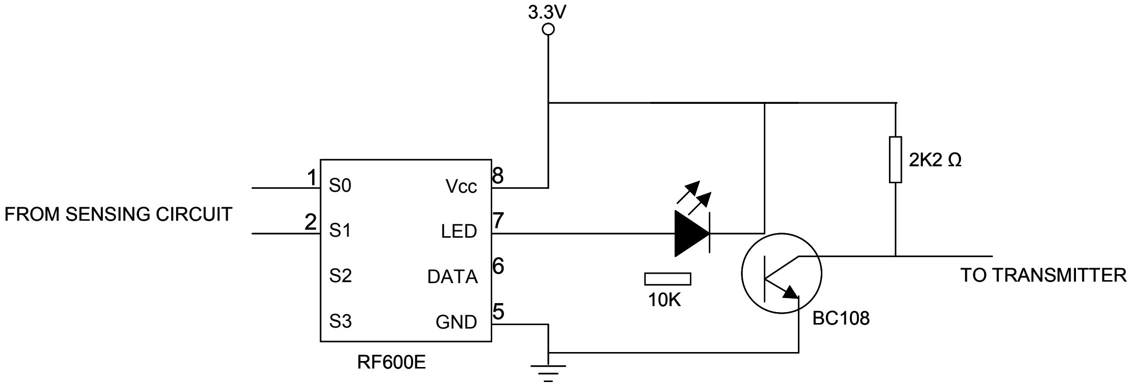


Diagram 5.1C – Encoding Circuit

Similarly, the RF600D (refer to Diagram 5.1D) also requires a minimum number of components to operate. The four digital outputs OP1-4 will only coincide with the RF600E inputs S0-3 after the encoder has been learnt to the decoder. Thereafter, the outputs will be asserted low whenever relevant input from the RF600E went high. The digital outputs indication can be set to momentary and latch action. The former will output for the duration of the transmission and the latter will output on each valid transmitted signal. It also has a serial data output that indicates the RF600E inputs and battery status. These data may be fed directly to a microcontroller or RS232 type driver circuit that may be then fed directly to a PC serial port. The serial data is output continuously while data is being received from the RF600E.

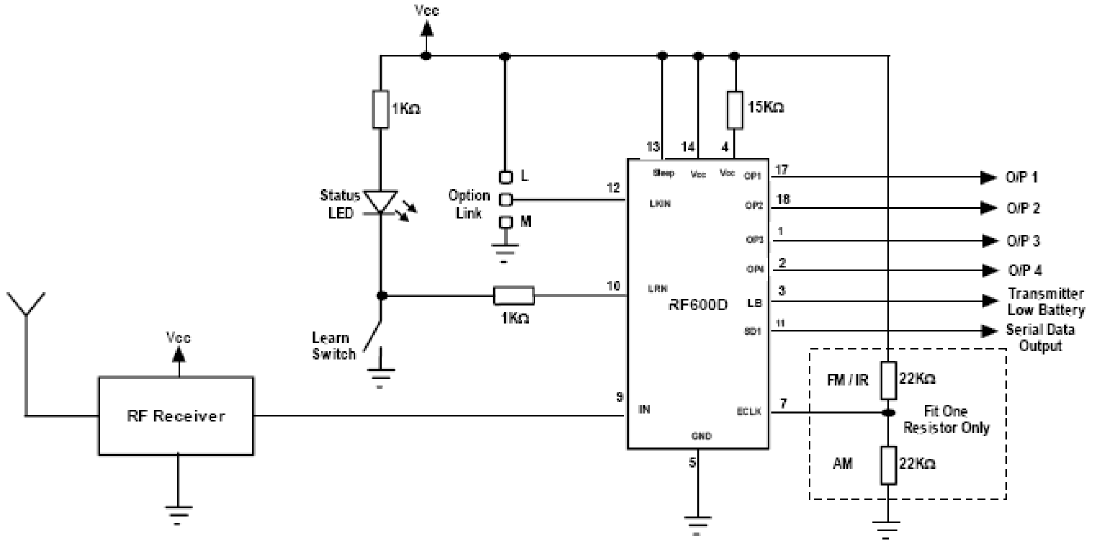


Diagram 5.1D – RF600E Typical Application Circuit
(Adapted from RF600D Datasheet)

The above diagram will be adapted for the decoder system with LEDs installed on the digital output pins for indication of the flight control surfaces movement (refer to Diagram 5.1E) and with the option of momentary and latching indication. An interesting feature is that it will enable future growth of the system whereby the serial data output can fed into a PC for tracking the surfaces movement.

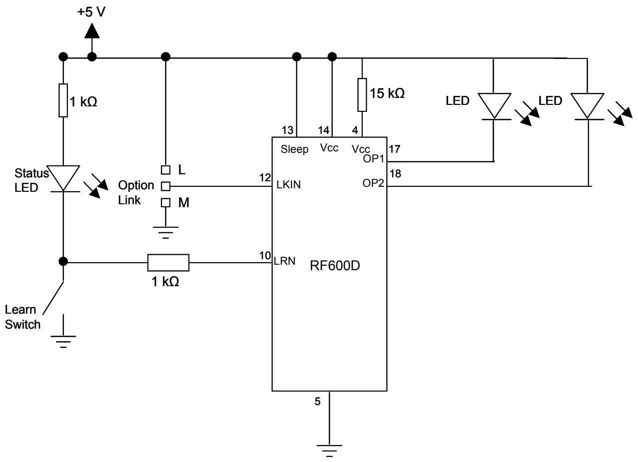


Diagram 5.1E – Decoder Circuit

5.2 Transmitter/Receiver

With the selected encoder and decoder, the next step will be finding a suitable pair of transmitter and receiver. Obviously, one can choose to build a simple FM transmitter and receiver to perform the communication task. However, there are several considerations such as the operating frequency and its stability, the range of transmission/reception, the power consumption and importantly the size and weight, particularly on the transmitter end.

Currently, the receiver onboard of the UVA operate at 40.79 MHz, thus a different frequency band will need to be used in order not to create interference to the existing receiver. However, when choosing the frequency spectrum to be used, one should only select from the amateur radio frequency. Next, the range of transmission/reception must be at least the same or longer range than the existing UVA radio control.

“Mr Tan, resident of Songyuan, China, worked about half a year to create a huge handset…The giant phone is 3 feet tall and weight 48 pounds, meaning almost 22 kilograms.” (www.softpedia.com). Without technological and specialized equipments/ facilities assistance, a FM transmitter can be quite big and heavy in today context. Hence, instead of building a simple FM transmitter with weight and size limitation, which may constitute to system deficiency, it would be wise to use suitable hybrid transmitter or receiver modules to enhance the system performance.

The selected transmitter and receiver modules for dealing with encoded code are the RTFQ1 and RRFQ1 (refer to Appendix 6) respectively. These miniature modules are very cost effective, which can provide FM radio date link, at either 315, 433.92 or 868 MHz. It has tremendously stable operating temperature range and use no adjustable components to obtain very reliable operation. In addition, it can cover up to 250 m with minimum power consumption. A simple piece of wire measured at 17.3 cm can be used as an antenna for RF propagation or reception. Two pair of the RTFQ1 and RRFQ1 (refer to Diagram 5.2) were be used and operated at 433.92 and 868 MHz respectively.

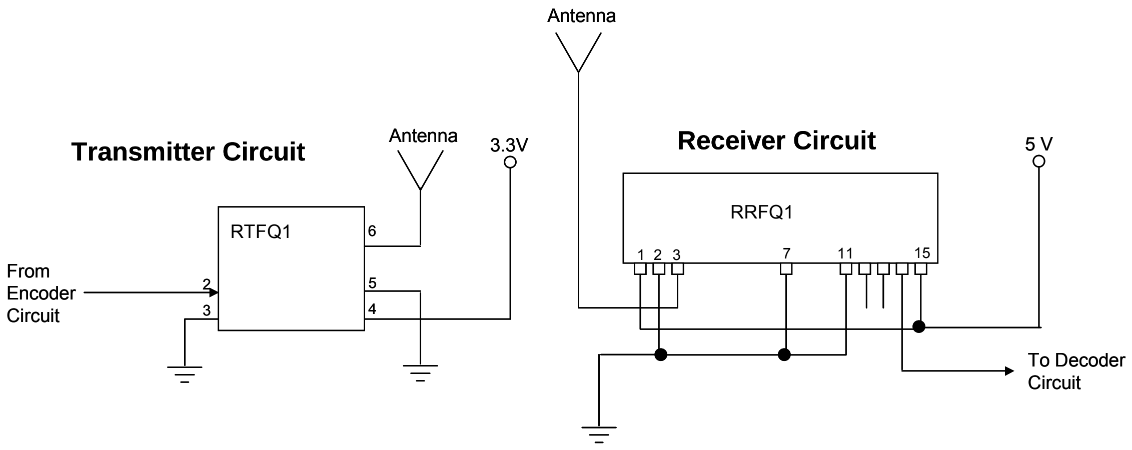


Diagram 5.2 – One pair of Transmitter & Receiver

5.3 Power Supply

With this wireless system integrated, the next is to find the ‘right’ power supply for the incorporating systems onboard. The main source of supply will be from the UAV existing battery, which operates at 7.4 V. Therefore, a voltage regulator is required to step down the voltage to 3.3 V, common to all ‘new’ components onboard and at the same time preserve the battery life. The voltage regulator, LP2951 (refer to Appendix 7), is a very low quiescent current and low dropout voltage. The quiescent current is the current flowing through the system when no load is present and it will limit the performance of the voltage regulator, thus it must be kept as low as possible. The dropout voltage is the minimum input to output differential voltage required to maintain output voltage regulation. *“Low voltage and low quiescent are intrinsic circuit characteristic for increased battery efficiency and longevity.”* (IEEE Journal,1998).

In operation, the LP2951 (refer to Diagram 5.3) develops a nominal of 1.235 reference voltage, V_{REF}, between the V_{OUT} and FB. The reference voltage is acting across R2, and since it is constant, a constant current will be flow through R1, giving the output voltage of $V_{OUT} = V_{REF} (1 + R1/R2)$. Therefore, by selecting R1 = 270 kΩ and R2 = 160 kΩ, the 3.3 V can be obtained.

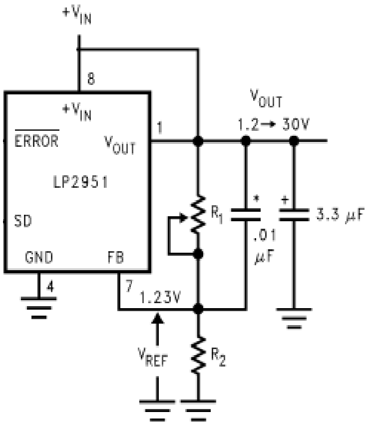


Diagram 5.3 – Voltage Regulator Circuit

After the final testing on all the sensing and wireless systems, the circuits need to be integrated. This will be done using the PCB, which will be explained in next section.

6. Printed Circuit Board ("PCB")

"*In the earliest circuits, larger components (valve holders, capacitors, etc) were built into metal chassis and connected by a nest of colour-coded wires*" (N.Braithwaite & G.Weaver, 1990). In 1920s, a method of producing an electrical path directly onto an insulation surface known as substrate was patented by Charles Ducas, which ultimately developed into "*printed circuit board*".

A **P**rinted **C**ircuit **B**oard ("PCB") is widely known as a module that permits the interconnecting of various electronic components ranging from resistors, integrated circuit (IC) chips to connectors.

"PCBs are almost a necessity, even for prototyping or one-off projects" (Al Williams, 2004). In recent years, PCB is widely populated and an essential module found in almost every electronic device. Completed PCB modules will not only look 'good', it must also achieve the physical and electrical requirements, and this commands substantial amount of efforts, knowledge and aptitude to derive its utmost features and performance.

First of all, before engaging into the fabrication of a PCB for an electronic device, the fundamental principles behind its construction must be well understood. The electrical path is actually made of copper foil, typically with the use of copper thickness of 0.5 oz to 2.0 oz, bonded on top of the substrate where the latter is either polymers or polymer composite materials.

The most imperative property of this substrate used is probably the dielectric constant, typically between values of 3.9 to 4.8. This property, apart from measuring the effects of electromagnetic wave on signal travels on the electrical path, it is also used to measure how much the unwanted stray capacitances can be reduced when adjacent electrical paths are running very close to each other (refer to Diagram 6A). The higher the magnitude, the better it will prevent the signals leaking from one path to another, especially on high frequency when the capacitance reactance 1 / (2π ƒC) between them is low. A substrate with a lower dielectric constant is mostly preferred and the standard woven epoxy glass known as FR4 is commonly use as it is easily available in the market.

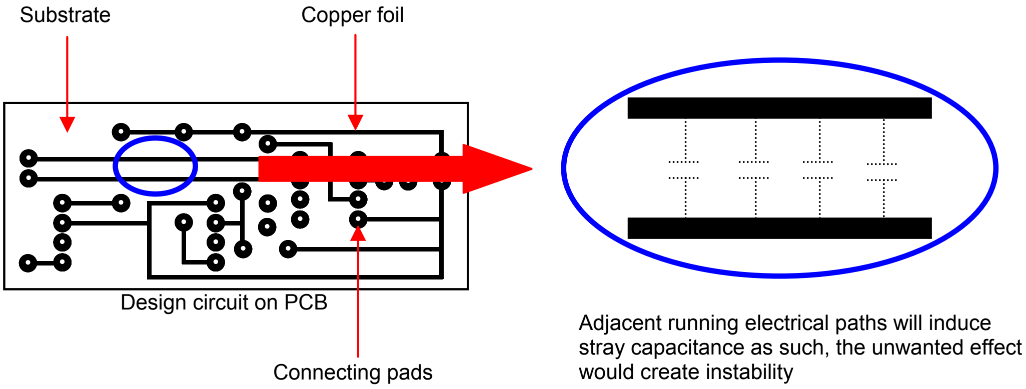


Diagram 6A – Design Circuit on PCB

There is a method of mounting the components onto the substrate surface. At present, there are 2 established techniques; the through hole technique ("THT") and the surface mount technique ("SMT"). With THT (refer to Diagram 6B), each component has thin leads that are inserted into the drilled holes of the substrate surface and soldered to the connection pads on the opposite side, which is on the copper foil.

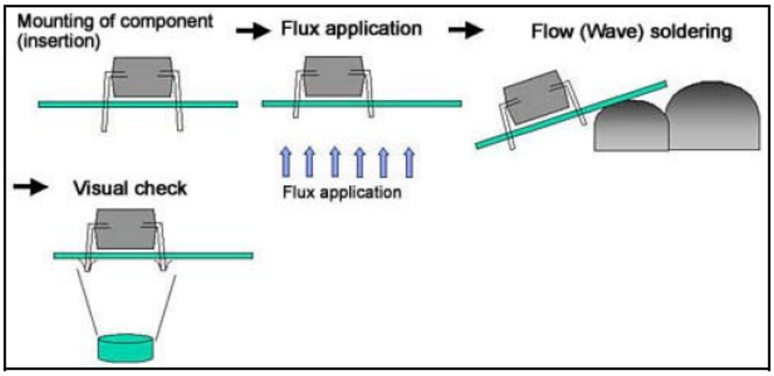


Diagram 6B – Through Hole Method
(Adapted from PCB Design Tutorial by David L.Jones)

With SMT (refer to Diagram 6C), short J-shaped or L-shaped legs on each component, usually smaller as compared to the THT component, are placed directly on top of the PCB contact. A solder paste consisting of glue, flux and solder are applied at the point of contact to hold the components in place before the solder is melted in the oven for the final electrical connection.

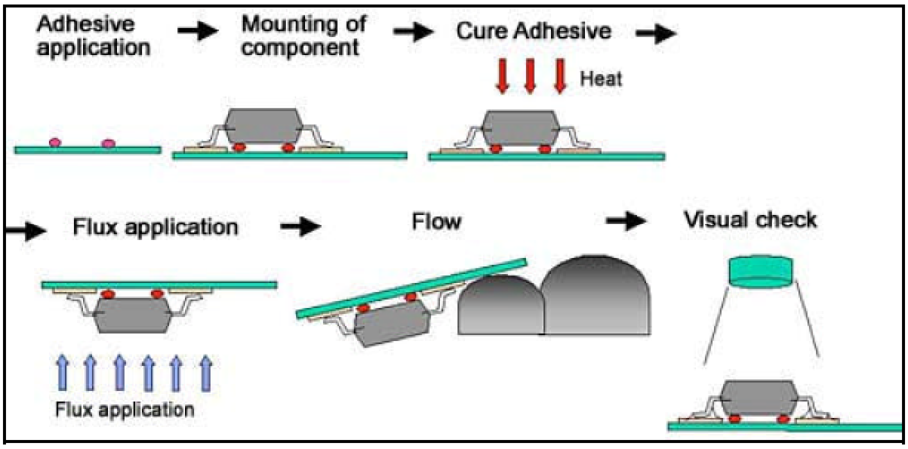


Diagram 6C– Surface Mount Method
(Adapted from PCB Design Tutorial by David L.Jones)

THT requires considerable amount of space for the connection pads and the process of drilling holes on the PCB is time-consuming. Nevertheless, this technique provides a much stronger mechanical bonds and this simplifies the production line as it is easier to produce. On the other hand, the main advantages of SMT, are the smaller component dimension (refer to Diagram 6D), little errors in components placement and less unwanted RF signal affecting the components due to lower lead resistance and inductance, however, at the expense of production costs as it is more complex.

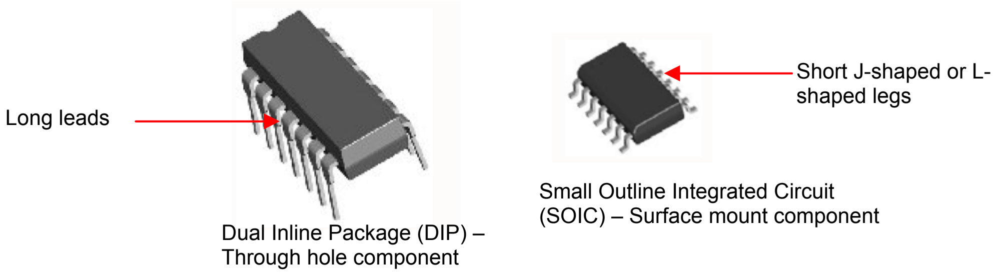


Diagram 6D – Components for Through Hole & Surface Mount Method

"*…the process of designing and laying out a PCB can be a very daunting task*" (L.J. David, 2004) It is apparent that one would need to plan and understand the necessary techniques/skills before proceeding with the PCB design, in order to achieve an overall electrical and functional performance. Hence, for standardization, the Institute for Interconnecting and Packaging Electronic Circuits, known as IPC, has defined various aspect of the PCB design and are widely accepted in PCB manufacturing industry (www.ipc.org)

6.1 PCB Design Phase

The design of a PCB is mainly divided into 3 phases. The first phase is to set-up a schematic, where all the necessary components to be used and their interconnection are defined. This will also include testing of the schematic using bread board to ascertain its functionality. It is critical that the design formulated from the finalized schematic has to be clearly laid, precise and logical. As such, it will set a sound platform for the later design phase execution.

The second phase defines the positioning of all components and routing the tracks that interconnects the components. In early days, the most primitive way of laying the PCB is by hand using adhesive tapes and pads on a clear drafting film. Noticeably, this would account for many hours and required craftsmanship for the cutting, placing and routing detail before the whole layout can be completed. In addition, any mistakes made during this process may cause an irreversible damage to the PCB. The introduction of computer based PCB design has completely taken over this traditional method, where it allows great flexibility in designing and editing with lesser hours spent.

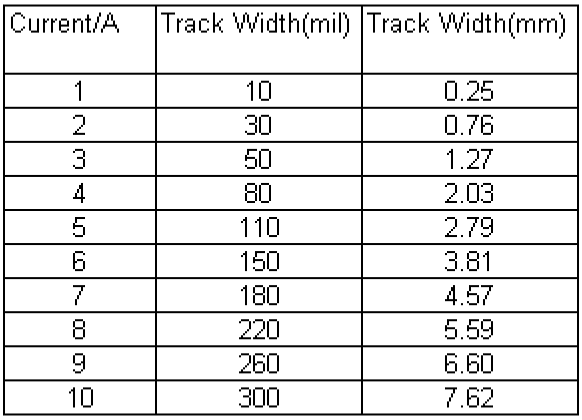
“An old saying is the PCB design is 90% placement and 10% routing…the concept that component placement is by far the most important aspect” (L.J. David, 2004). Indeed, bad component placement will have difficulties in routing the interconnecting track and at the worst case will run out of routing space and produce distorted signals.

The method of components placements, that is the laying of the components and electrical tracks, taking into consideration of the width and the electrical clearance between tracks must been clearly established. For the ease of routing, some would choose to space the components wider or having the required components evenly space out. This will inherently end up with a larger board, which is not efficient in term of space usage and allocation. There is no ‘clear’ rule governing the component placement. However, there are few pointers, which can be useful for laying out a complete board.

First, the electrical parameters must always take priority over a nicely lined up components. Second, the schematic must be analyzed and explored the possibility of breaking the components into functional blocks. An example of functional block is the voltage regulator IC having an input and output line, combines with other components such as resistors, capacitors and LEDs to provide a steady Direct Current ("DC") voltage to other different functional blocks. Last but not least, the analog circuit should not mix with digital, as well as high frequency with low frequency circuit. Each of these circuits has their own unique set of electrical parameters. For example, digital grounds are perpetually noisier than analog because of the switching noise produced during the digital chips state transition. If both circuits shared the same grounds, the inherent noise of digital would impose to the analog signal paths. Where necessary, use a different ground each of these circuits for combination.

In high frequency circuit, the effects of parasitic inductance, capacitance and impedance of the layout become dominant. When the signal is too rapid and the track is too lengthy, the track can take on transmission line and may cause interference signals if it is not well taken care of. However, there is no such issue when dealing with low frequency of less than 10MHz circuit.

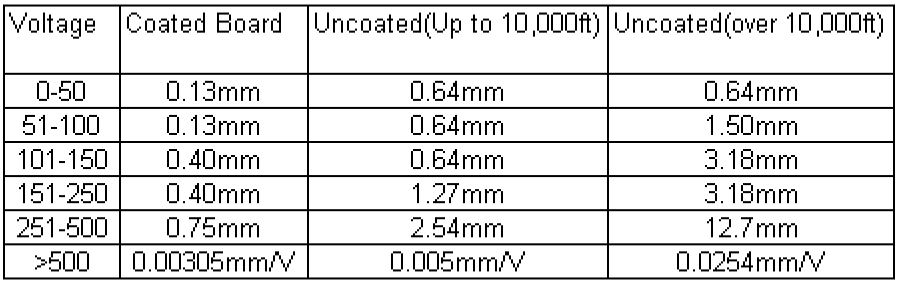
After laying the components and routing the tracks, the next will be finding the track width. Theoretically, the width is proportional to the maximum current that the track is designed to carry. However, a wider track would yield a better DC resistance, a lower inductance and is easier to inspect or rework. One should select the appropriate track width without compromising the minimum electrical requirement (refers to Table 6.1A).



Current/A	Track Width(mil)	Track Width(mm)
1	10	0.25
2	30	0.76
3	50	1.27
4	80	2.03
5	110	2.79
6	150	3.81
7	180	4.57
8	220	5.59
9	260	6.60
10	300	7.62

Table 6.1A – IPC recommended Track Width for 1 oz Copper PCB and 10 deg Temperature rises

Once the track widths have been established, the final consideration will be the electrical clearance between tracks. The potential voltage differences between tracks are used to determine minimum clearance (refer to Table 6.1B). If the clearance between each track is insufficient, it may cause sparks and impair functional failure to the design. Alternatively, the PCB can be coated to reduce the requirements between track clearances. Then again, the qualities of the coating, in addition to the material used, are critical to ascertain that these requirements are met.



Voltage	Coated Board	Uncoated(Up to 10,000ft)	Uncoated(over 10,000ft)
0-50	0.13mm	0.64mm	0.64mm
51-100	0.13mm	0.64mm	1.50mm
101-150	0.40mm	0.64mm	3.18mm
151-250	0.40mm	1.27mm	3.18mm
251-500	0.75mm	2.54mm	12.7mm
>500	0.00305mm/V	0.005mm/V	0.0254mm/V

Table 6.1B – IPC recommended Electrical Clearance

The use of different types of PCB can be an essential element to be considered. Currently, there are three major types of PCB construction in the market: single-sided, double-sided, and multi-layered. In single-sided board, components are only allowed to place one side of the substrate, usually on the side without the copper foil. For double-sided and multi-layered, components are placed on either sides and on multi-layer respectively.

In single-side design, when the number of components becomes too much, jumper links are usually employed to reduce the board size. Hence, it is certainty more demanding in the single-side design as compared to the rest, and it is all about balancing and minimizing the number of jumper links used against the board size.

The last phase is the fabrication of the PCB, where the chemical processes take place and components are soldered to complete all phases. In fact, this phase can be totally subcontracted to a PCB design house or manufacturer if one is willing to pay the high costs. However, to develop a prototype or engage in a one-off project, it will be greatly beneficial for one to undertake the fabrication, to enhance the one's design knowledge through practical experience.

Importantly, individual must be able to decide on the most suitable options based on the practicability of fabrication. For one-off case production, the THT would be definitely preferred over the SMT, as the THT components are easier to handle and to solder due to its larger dimension. Although, the components placement is crucial on a single-sided PCB, but in term of fabrication, the technique employed is rather straightforward as compared to the other boards. The following steps demonstrate the PCB fabrication using the THT on a single-sided PCB:

6.2 Printing Design

The PCB design layout can be printed from a normal home printer onto paper or transparency (refer to Diagram 6.2A), depending on the type of transferring method used. The two main methods are the tone transfer using paper and photo exposure using transparency, which will be explained later. A laser printer is usually preferred to catch the fine details of the design.

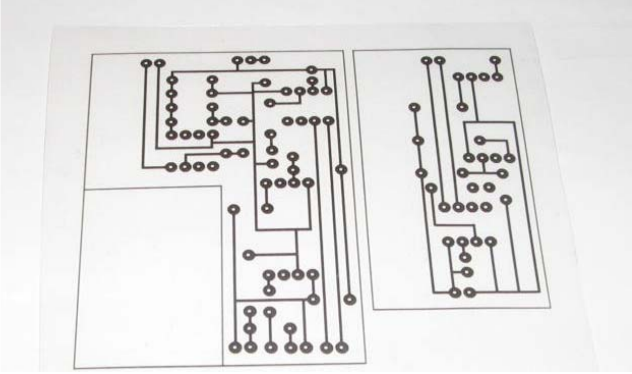


Diagram 6.2A – Design on Transparency

6.3 Transferring Design

The main difference between the two methods is that; one uses heat and the other uses ultra-violet light. The paper printout will be transferred onto the copper plated board using a heated iron. Once the design is begin transferred, it can immediately send for etching process, which explains for its simplicity using this method. To obtain better tracks quality, the latter method using photo exposure will be a better choice but the photo-sensitive PCB is more costly, in addition, there is a step for developing process.

A photo-sensitive PCB can be purchased from the market and it usually come with a minimum size of 10 cm x 15 cm. The photo-sensitive PCB is cut into the desirable size, preferably bigger than the actual required size, before tearing off the white protective film (refer to Diagram 6.2B). Next, place the transparency on top of the PCB and position with scotch tape (refer to Diagram 6.2C).

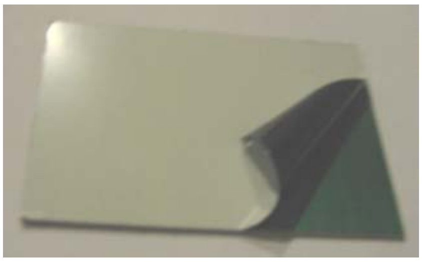


Diagram 6.2B – PCB with the Protective Film

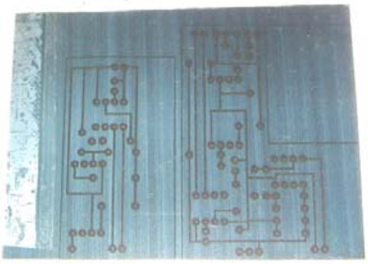


Diagram 6.2C – Printed Transparency positioned on PCB

The PCB is then placed under a fluorescent lamp for 8 to 10 minutes with a distance of 5 cm (refer to Diagram 6.2D). For a better result, a piece of flat glass will be used as a top layer to make a good contact between the transparency and surface of the PCB. The distance between the light source and the PCB also play an important role, as double the distance will tripled the exposure time.

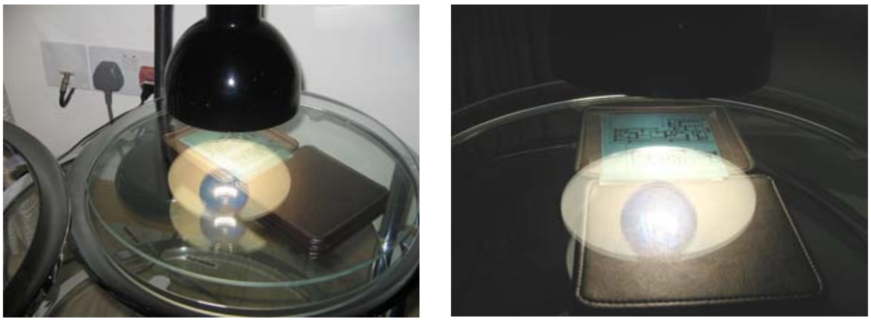


Diagram 6.2D – Photo Developing Process

6.4 Developing

After exposed, the design printout will be transferred onto the PCB and it can be observed with a fade yellowish colour tracks on top of the photo-sensitive layer. The PCB can now proceed to the developing stage. A universal developer in the form of powder is mixed with 50g per litre water, in a suitable container (refer to Diagram 6.4A). The powder must be completely dissolved in the water before cooling down to 20ºC to 25ºC, which is the most effective temperature for developing. After which, the PCB must be fully immersed into the container with the design facing upward and agitated until the design is appears to be clear (refer to Diagram 6.4B). Finally, the PCB is rinsed with running water.

Diagram 6.4A – Universal Developer with the Container

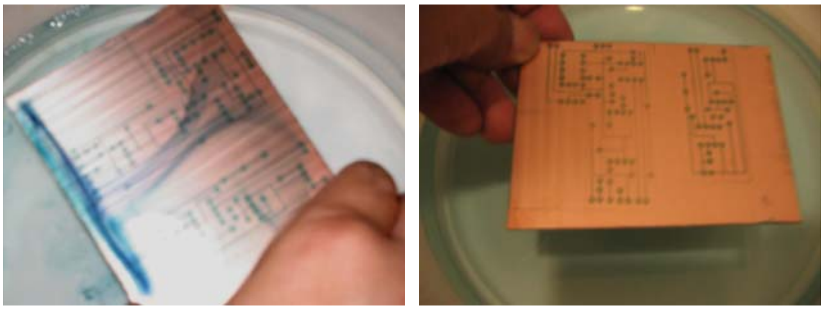


Diagram 6.4B – Developing Process

6.5 Etching

Before the PCB is ready for etching, any small breaks on the design can be still corrected by using oil-based permanent marker. Ferric Chloride, a toxin chemical, will be used to etch away the copper foil, leaving behind the desired design layout. As usual, the Ferric Chloride must be totally dissolved in the water and the amount to be used is solely depending on the size of the PCB. The etching process is most effective when the solution is kept at a temperature of about 50ºC to 60ºC. The PCB must be fully immersed into the etching solution with the design facing upward (refer to Diagram 6.5A) and agitated until the unwanted copper foil etched away. Subsequently, a household detergent can be used to wash out the chemical solution without removing the photo-sensitive coating.

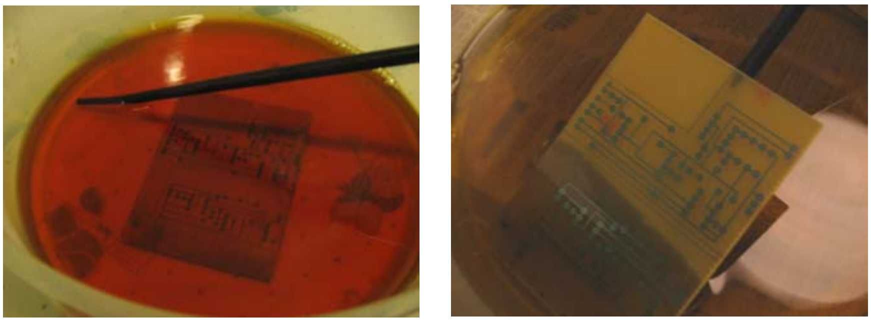


Diagram 6.5A – Etching Process

6.6 Cutting and Drilling

Once the etching is completed, the next step is to cut or trim the PCB to the actual size required. The photo-sensitive coating should not be removed before the hole drilling process, as it served as a protection to the tracks. Before drilling, it is prudent to have a dot punch to mark a shallow guide hole for the drill bit alignment while drilling (refer to Diagram 6.6A). The nominal drill bit size should be 0.8mm, which is sufficient for majority of the components. However, the size will need to increase to 1.0mm with input and output connectors. Every drill action will create sharp edges along the circumference, and these edges should be de-bur by a small file when possible. After the drilling is completed, the photo-sensitive coating can then be removed, using a dish-washer green sponge. The PCB (refer to Diagram 6.6B) is now considered completed and is ready for soldering of the components.

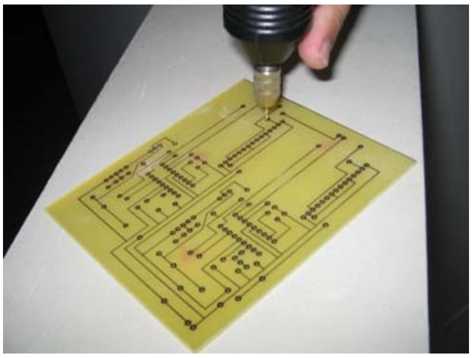


Diagram 6.6A – Drilling Process

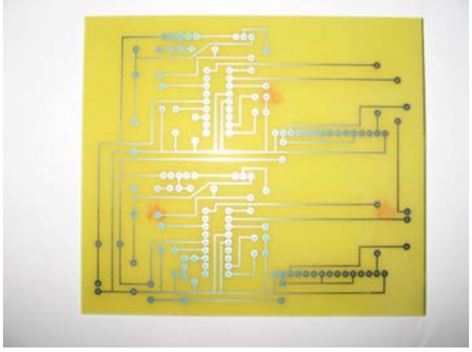


Diagram 6.6B – Completed PCB

7. Conclusion and Recommendations

7.1 Conclusion

To conclude this final report has been a strain because of 2 key issues encountered:

- Substantial delays during the prototype development and testing caused the insufficient time to conduct final flying test to finalize the success of sensing system integration. At the moment, success is only determined at static position with propeller running.
- Late pulled out from the project by my course mate due to his work commitments has resulted the inability to conduct testing from the software perspective.

At every deployment of action plans, the resources available in order to ensure successful completion of the project are vital. From information exchanges with tutor, including information gathered from literatures and websites, they are imperative to the project development. Obtaining required information is uncomplicated. Complexity sets in when involving the actual construction of the prototype and ensuring its success.

The actual involvement on working on and testing the prototypes has undoubtedly enriched my technical experience. If outsourced to contractors to execute the task will rob away valuable practice and know-how. Diagram 7. 1 shows the completed installation of sensing system onto the UAV

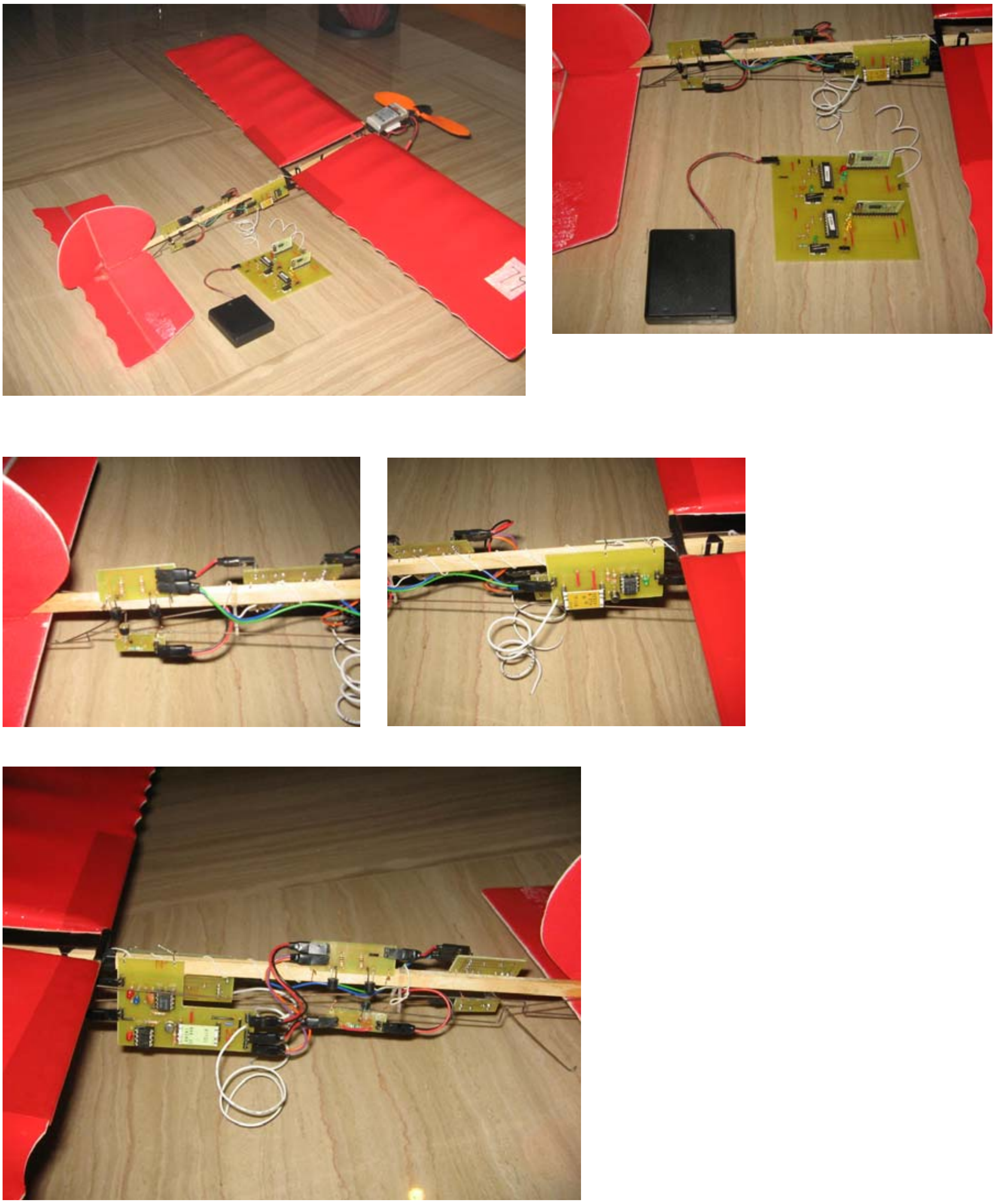


Diagram 7. 1 – Completed Installation

7.2 Recommendations

Given that the UAV has incorporated the flight control system, it mainly focuses on the surfaces movement detection. Propose to measure the speed of the propellers can help to determine the speed of the aircraft when in airborne. The sensing system can further improve to indicate the angles of deflection; and feedback the aircraft movement about its axes. This can be done by using angular displacement sensor.

Certainly, to integrate the surveillance camera on UAV undercarriage will enhance visual effects onboard to capture maximum airborne view. I reckon that it is useful and worth to have this project continues to work on the visual aspects of enhancement.

This project has been very demanding and an individual effort can be very stretched and limited, let alone an individual has to deal with work and project concurrently. I propose that the project be a group attempt, for instance, work can be distributed amongst team members and each member can focus his / her effort on their respective area of responsibility; an individual has limited ideas, in some case, being partial and if it is in a group, frequent discussion or even arguments can perk up new ideas.

(11,036 words)

8. Acknowledgements

I like to thank Singapore Polytechnic, Aerospace Engineering faculty, in loaning the UAV for project development. Secondly, I like to thank Mr Toh S. K. and Mr Chaganti for all the valuable advices and suggestions on how to improve and progress with my project. Last but not least, to my lovely wife, Joanna Chee, who has been very accommodating to all those late nights engaged on the project.

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10. Appendixes

Appendix 1 – Accurate Linear Measurement Using LVDTs

Appendix 2 – Using Decoupling Capacitors

Appendix 3 – GaAlAs Plastic Infrared Emitting Diodes Types OP293 & OP298 Series

Appendix 4 – NPN Plastic Silicon Phototransistors Types OP593, OP598 Series

Appendix 5 – RF / IR Encoder / Decoder Chipset

Appendix 6 – FM Transmitter & Receiver Hybrid Modules

Appendix 7 – Series of Adjustable Micropower Voltage Regulators

11. Glossary

Aerodynanic – the motion of air when it interacts with a moving object

Aerodynamic force – the force created by a object's movement through the motion of air

Aileron – the movable part at the back of the wing

Alternating current – an electric current that reverses direction at regular intervals

Amplitude Modulation – the amplitude of a carrier voltage is varied with the frequency of the modulating voltage

Angle of attack – describing the angle between the chord line of an airfoil and the the relative motion between the airfoil and the air

Axis – a straight line through a body / figure that conforms to certain conditions

Bandwidth – the width of the range of frequencies that use on a transmission medium

Bernoulli's Principle – study of wings that produce lift of an aircraft

Capacitance – the property of storing an electrical charge

Dielectric constant – the ability of an insulator to store electrical energy

Direct current – an electric current flows only in one direction.

Drag – opposes an object's motion through the air

Electro-optics – the modification of the optical properties of a material by an electric field

Elevator – the moveable part at the tail horizontal airfoil of an aircraft

Force – a pull or push acting on an object causes that body to accelerate and change its velocity

Frequency Modulation - the frequency of a carrier voltage is varied with the frequency of the modulating voltage

Global Positioning System – allow the pinpoint location in earth through use of satellite constellation

Inductance – the ratio magnetic flux to the current

Interfacing – a simple input or output devices connected to the standalone circuitry

Lateral axis – a geometrical definition of an axis of pitching

Lift – directly opposes the weight of an object and holds the object in the air

Longitudinal axis – a geometrical definition of an axis of rotation

Mutual inductance – ability of one inductor forcing link with another inductor

Processing – conversion of received signal into an suitable form for use

Propeller – an object with two or more twisted blades that is designed to propel through air or water

Radio frequency – any frequency within the electromagnetic spectrum related with radio wave propagation

Rudder – the moveable part at the tail vertical airfoil of an aircraft

Servo – an electromechanical device that has an output shaft operated when a coded signal is received

Thrust – the force that moves an object through the air

Vertical axis - a geometrical definition of an axis of yawing

Part 2: Critical Review and Reflections

In every project engaged, it is critical to institute an organized procedure in executing every project stages, so as to ensure the project progress in the right direction and systematic way.

To reinforce the importance of proper plan, the project plan emphasized and employed 6 stages (refer to Diagram 2).

Diagram 2 – Project Plan Stages

Stage	**Description**	**Brief Explanation**
1:	Topic Selection	- Explore topics to engage
2:	Project Proposal	- Work out the project details
3:	Discussion	- To re-affirm the topic by discussing with tutor and course mate
4:	Project Revision / Decision	- Amendments / improvements to be made after discussion
5:	Project Development	- Actual work to be carried out to
6:	Testing and Validation	- To confirm the project feasibility with hypothetical tests
7:	Project Finalization	- Launch

At every stage, specific tasks were established with estimated date line to accomplish. This creates an orderly approach to facilitate proper appraisal of the project progress and to address any obstacles during the course of action.

A brief but concise feedback / comments have been tabulated during the implementation of the project (refer to Table 2).

The project progressed smoothly at initial stages until stage 5 where complexity sets in when involving the actual construction of the prototype. This prototype development is distinctively segmented 3 main categories: Sensing, encoding / decoding and transmitting / receiving, after that are developed and tested individually. Many obstacles encountered during the testing at every category. It was even more challenging when trying to integrate all the 3 categories' components because many times, the circuit interface failed to perform to expectation. A lot of efforts and time spent to study the malfunctions and resolving them.

Next, the prototype testing using bread board creates long tracks and introduces large capacitance / inductance to the circuit which can badly distort / detune RF signals. Therefore, whenever possible, avoid using the bread-board with RF modules; the use of PCB is preferred. With that, this give rise to extra time spent on developing prototype on PCB as it requires soldering and component placement.

There is a massive time delay at the stage where 3 categories prototypes are integrated to achieve certain performance; this is unanticipated and in some ways, bewildering. With reference to theory, the set up and integration suppose to work out, unfortunately, when in practical testing, it does not happen as expected at times. It is mainly due to human error, example during installation of the components, there are some lose connection. Careful study of the schematic design of the system helps better understanding of signal flow in order to rectify the issues and attain results.

Table 2 – Project Plan Review and Feedback / Comments

Stage	ACTION	TIMING	Feedback / Comments (project work-in-progress)
1	a. Review project available b. Evaluate project viability / practicability	Mid Sep 07	a. Have selected the topic on developing sensor to control aircraft surface movement.
2	a. Determine the importance of the project b. Assess possible project problems/obstacles c. Build up case study / project proposal	Mid Oct 07	a. Set clear objectives on how to approach the project. b. Identified obstacles, i.e. limited knowledge and skills on sensor designs on aircraft.
3	a. Present project proposal with key points b. Discuss with Tutor and Course Mate to improve the project development	End Oct 07	a. Completed first proposal of project and improved on it after discussion with Tutor and Course Mate. b. Able to grasp the concept of the project engaged.
4	a. Modify and improve on the project proposal b. Appraise project assumptions	End Nov 07	a. Obtained the UAV from Singapore Polytechnic (“SP”). b. Critically assessed the project limitation and set assumptions. - Completed and submitted the project initial report.
5	a. Outline the requirements to commence the making of a prototype / model	Early Feb 08	a. List the components necessary for designing and building the sensor on the aircraft. c. Difficulty: deemed suitable components may not be ideal to incorporate onboard the UAV. d. Examples: LVDT sensor has power source issue; Decoder without DIP package; Multiplexer/Demultiplexer requires special logic control addressing input.
	b. Use facilities and/or equipment		b. Have had basic equipments to conduct the testing hence did not make use of any specialized equipments or program available at the aerospace laboratory in SP.
	c. Start working on the prototype / model		c. Problems faced when: - Developing prototype testing using bread board - A lot of efforts required to develop prototype on PCB - Circuit interface failed when incorporating all the segments prototypes - Additional time spent on rectifying and resolving

Stage	ACTION	TIMING	**Feedback / Comments** **(project work-in-progress)**
	d. Conduct regular progress check; record development e. Seek Tutor's comment and advice on develop		d. Consciousness assess the progress and tracking against time line set - Failed to accomplish the prototype in stipulated time; has delayed completion in mid-March. e. Tutor periodically calls to check progress.
6	a. Experiment the prototype / model b. Analyze the testing hypothetically c. Confirm the feasibility of the project d. Build-up final assembly	Mid Mar 08	a. Prototype complete and the sensor incorporated onboard the aircraft works. b. Hypothetical testing through the indication of the surface movements via wireless system. c. Confirmed the success of incorporating the sensing system using wireless technology works in accordance to expectation / plan. d. All components have been assembled onboard and on ground; the sensing perfect when aircraft is static, have not testing the liability when aircraft in airborne. e. The intent to build a camera surveillance onboard aircraft has been abandon because: - No suitable camera found for a narrow and light body UAV - Limited space constraints the mounting of camera, together with the sensing system. - Insufficient time to resolve the issues faced and explores further improvement on this aspect.
7	a. Final report b. Ready to launch!	Early Apr 08	a. Due to the delay in prototyping stage till 1st week of April, this creates tremendous pressure in developing the final report. b. Will only be ready to launch after first flying test, which expected to be end of April, before the final presentation.

The initial project proposal includes a “spying” capability in addition to ground surveying capability, i.e. incorporation of surveillance camera onboard aircraft. However, there is no suitable surveillance camera that can meet the minimum payloads requirements on the narrow and light-bodied UAV. Moreover, my counterpart Jimmy is suppose to develop the software for displaying the image and the flight control movement using micro-controller, has pull out the project in March due to his work commitments. With all the mentioned constraints, the inclusion of surveillance camera is aborted.

Whilst all these confronting issues surfaced throughout the project execution, it has immensely sharpened my focus and positively ‘aggravates’ (i.e. motivates) me to want to perfect the project. I discover that in any project management, it is important to set smart objectives that have proper planning with identifiable actions. My weakness is in time management. Being organized and stay positively objective at all circumstances will alleviate aspirations to pursue the overall purpose of the project.

The final flying test has yet to be conducted. There is final touch to the aircraft to conclude the project. I am confident the outcome will be pleasing.

(1,222 words)