ROGUE
AVIONICS
"Tomorrow's Innovations Today" ™
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March 5, 2009

Dr. Patrick Leung
School of Engineering Science
Simon Fraser University
Burnaby, B.C. V5A 1S6

Re: ENSC 440 Design Specification for a Virtual Piloting System

Dear Dr. Leung:

Attached is the design specification for Rogue Avionics' Virtual Piloting System (VPS). The main objective of our project design is to improve flight safety by removing the pilot from the risks of being inside the aircraft. The system incorporates video, telemetry, and controls to fully simulate an "in-cockpit" experience, therefore, realizing true flight from the safety of the ground.

The design specification is written to provide a set of technical design guidelines for the VPS. The document is to mainly focus on the proof-of-concept phase of the project and is to be used by Rogue Avionics' design engineers and testers to ensure that the prototype is conforms to all design requirements.

Our company, Rogue Avionics, consists of a team of four members: Jyh-Yuan Yeh, Isaac Chang, David Guo, and Xiaofeng Jin. Through our aspiration, creativity, and skill, we are committed in bringing *Tomorrow's Innovations, Today*. If you have any questions or concerns about our design specification, please feel free to contact the team at *Rogue.Avionics@gmail.com*.

Sincerely,

JyhYuan Yeh

Jyh-Yuan Yeh
Chief Executive Officer
Rogue Avionics

Enclosed: Virtual Piloting System: The Design Specification

VIRTUAL PILOTING SYSTEM

Source: NASA Image EL-1997-00111

THE PROJECT PROPOSAL

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Issued Date: March 5, 2009

ROGUE AVIONICS

EXECUTIVE SUMMARY

Modern advances in today's aviation technology boast more fuel efficient engines, new lightweight body material, and improved comfort for airline passengers. However, no significant strides were taken in ensuring the safety of the pilot's operating the aerial vehicle. The aftermath of the September 11, 2001 attacks has opened a new chapter in the world of terrorism. Increased airport security measures are still not able to completely suppress the fearful reality airline pilots must face each day on the job. The requirement of a pilot onboard a plane's cockpit brings about certain security repercussions itself.

Rogue Avionics' Virtual Piloting System (VPS) has proposed a revolutionary design that allows a pilot to maneuver an aerial vehicle from the safety of ground station. The first developmental prototype will be design for the flight control of a helicopter. The system is designed to be flexible enough to be retrofitted for an airplane without many modifications. The idea itself presents a cost effective solution and economic design to flight control.

This document gives an outline for Rogue Avionics' highly effective VPS design with features that are efficient, cost-effective and safe. Our design includes an on-board camera on the helicopter that will provide the pilot, stationed on the ground, with visual information of the helicopter's surroundings. The camera is manipulated by the servo motors that respond to a gyroscope located on the video display goggles. A data link between the helicopter and ground station is established using wireless ZigBee technology. The control of the helicopter is actuated by two joysticks that mimic the typical design of a helicopter's cockpit.

The design of our prototype includes two phases. The proof-of-concept phase will involve designing features present above. This phase is expected to be completed by April 2009. Adaptability of the concept to other platforms will be investigated in the second phase. Eventually, our final mission is to allow trained professionals in the airline, military, and aerospace industries to use our VPS system.

The VPS design specification is intended to act as guidance for manufacturers in mass production, or third party standard organization such as FDA in evaluating the device for marketability. Also, this document is used by the Research and Development team to make necessary changes to any design in the prototype for upcoming phases.

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1 INTRODUCTION

As an integrate part of our lives, air flight is something we take for granted everyday. The importance of air flight is undeniable whether it is for transportation, military, or aerospace. Despite its glory, air travel is dangerous and accidents occur frequently. Among the fatalities are pilots, who fly these aircrafts through treacherous terrain, frigid conditions, and death-defying maneuvers. The VPS is designed to remove the pilot from these risky situations and put them safely on the ground. Using an integrate system of controls, displays, and telemetry, trained pilots will be able to fly any aircraft from the ground just as if they were inside the cockpit. By not having the pilot in the cockpit, pilots are no longer required to risk their lives to satisfy society's needs. This document will describe the design specifications and requirements of the prototype VPS.

1.1 Scope

The primary focus of the design specification is to provide a set of guidelines for the design process of the VPS. As a follow up document to the functional specification, the design specification will specify how the proof-of-concept system, and to some extent the final product, will conform to the pre-defined functional requirements. Detailed illustrations and explanation of each component of the system is presented in a way to allow users to gain a full perspective of the VPS project.

1.2 Intended Audience

The user of this design specification consists of Rogue Avionics' design engineers and testers of the VPS project. The document will provide detailed technical design guidelines for design engineers to follow and address during the development process. Testers can then use these guidelines to determine whether the proof-of-concept and later prototypes conform to the requirements presented.

2 General System Design Specifications

2.1 Computing Specification

All the computational requirements needed for the VPS are completed using a Microchip 16F88 PIC MCU. A signal chip make was chosen to ensure easy integration of components and cost considerations for mass production. This 8-bit, 18-pin package PIC is able to process data at a crystal-oscillated rate of 20 MHz with over 7K of programming memory. The serial port interface allow for communication with serial devices, as well. The built-in 10-bit Analog-to-Digital convertor (ADC) also makes data conversion of analog signals easy and convenient. This 16F88 PIC MCU satisfies the overall computational requirements of the VPS. A total of 5 PICs will be used for the various components of the system.

2.2 Electrical Design

All devices used on the VPS will be regulated to either a 5V or 3.3V power supply. On-board the helicopter, the camera and video transmitter will use a 5V DC supply. The accelerometer and data transmitter will use a 3.3V DC supply. Corresponding voltage regulators will allow a single 7.4V battery, used to power the helicopter, to power the different devices. Similarly, on the ground, the control and video system will use a 5V supply while the gyro and receivers use a 3.3V supply. These will also be regulated with corresponding voltage regulators. All PICs will use a 5V supply. By regulating all source powers, voltage fluctuation from the supply will be protected from the devices. This is an important feature required for the VPS's electrical design because any electrical failure can result in potentially fatal consequences if the aircraft is to carry human lives.

2.3 Vibration Considerations

During flight, heavy vibrations are constantly acting on the on-board electronics. The camera and video and data transmitters are especially venerable to such vibrations. The camera needs to record a clear and smooth picture for the pilot to safety fly the aircraft. Strong vibration, therefore, needs to be avoided to maintain a high level of video quality. Both the video and data transmitters are also affected by vibration. Testing of the transmitter under heavy vibration has resulted in loss of data, distortion of data, or overall device malfunctions. Since the information transmitted to and from the helicopter is vital for safe and precise flight, all on-board electronics are dampened from vibration using specially designed foam padding.

2.4 Safety Considerations

As a prototype, the VPS, like any other experimental devices, is venerable to unexpected failures. To prevent in-flight failures from damaging the proof-of-concept helicopter in the event of a crash, a specially design shock absorbing landing mechanism is mounted on the bottom of the aircraft. Special crash resistant propellers are also used to prevent airborne object from damaging the blades. Electronically, a master power switch is also integrated into all component designs. In the case of chronic electrical failure, all systems can be turned off with a single switch. This feature is mainly designed to protect the pilot and other on-ground users from electrical shock dangers.

3 Joystick Control System

3.1 Physical and Mechanical Design

3.1.1 Joystick Layout

To ensure that the VPS proof-of-concept system has "true" helicopter control, a two-joystick layout was used. This layout can be found in most commercial helicopters where two control sticks are used in a similar fashion. *Figure 3.1* illustrates our control layout.

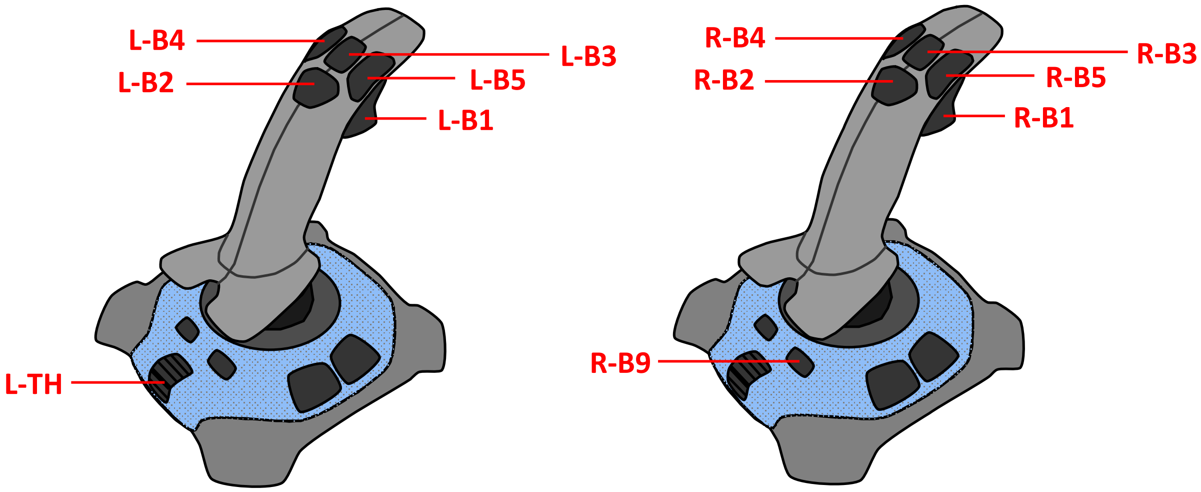


Figure 3.1: *VPS Joystick Layout*

Stick motion and button features were designed to incorporate all the major functionality of a typical helicopter during flight. This includes calibration buttons that are needed when the helicopter is required to fly under varying degrees of constant imbalance. *Table 3.1* summarizes the various button features of the VPS control system.

Inputs	Functions	Inputs	Functions
L-B1	Throttle Up Amplifier	R-B1	Throttle Up
L-B2	Throttle Down Amplifier	R-B2	Throttle Down
L-B3	Calibrate Backward	R-B3	Calibrate Forward
L-B4	Calibrate Rotation CCW	R-B4	Calibrate Left
L-B5	Calibrate Rotation CW	R-B5	Calibrate Right
L-TH	User Defined	R-B9	Motor On/Off

Table 3.1: *VPS Joystick Button Features*

3.1.2 Flight Control Operation

The control mechanics of the VPS is designed to minimize the learning curve for a professional helicopter pilot. Control mechanics such as forward, backward, left, right, and throttle mimic those found in a typical helicopter. The operation details of the joysticks are shown in *Figures 3.2a to 3.2c*.

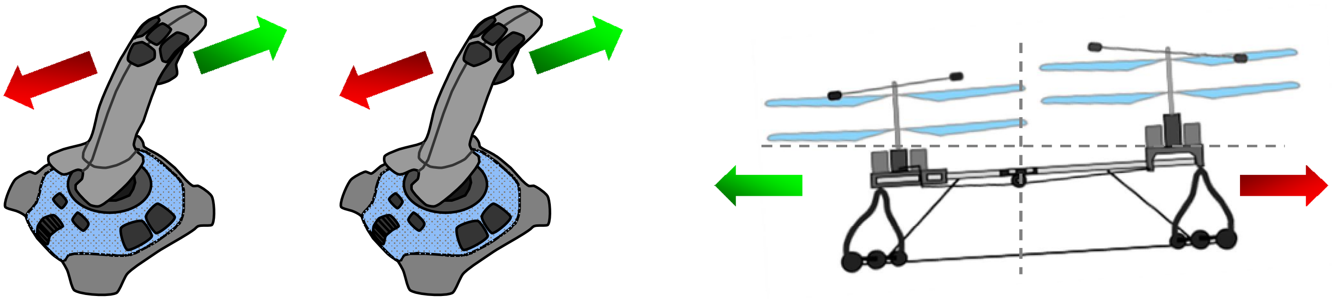


Figure 3.2a: *Forward and Backward Operation*

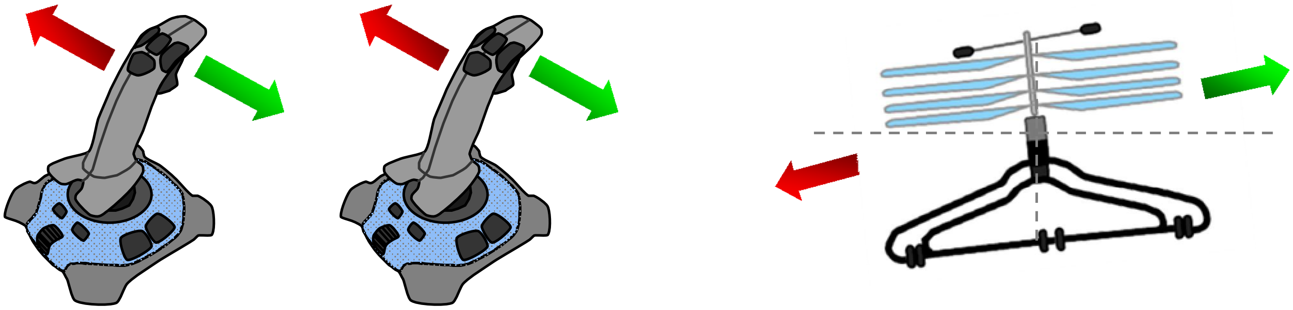


Figure 3.2b: *Left and Right Aileron Operation*

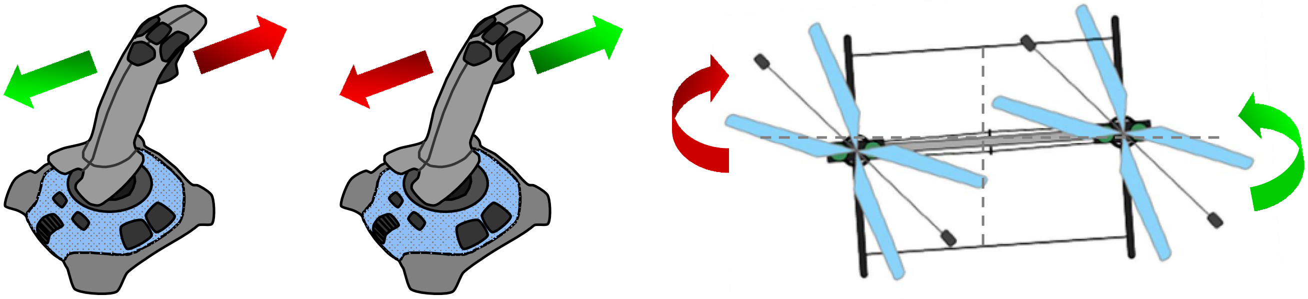


***Figure 3.2c:** CW and CCW Rudder Operation*

Throttle control is completed using R-B1 or R-B2, for slow throttling actions, and L-B1 or L-B2 as throttling amplifiers, for faster throttling actions. Operation diagram is shown in *Figure 3.3*.

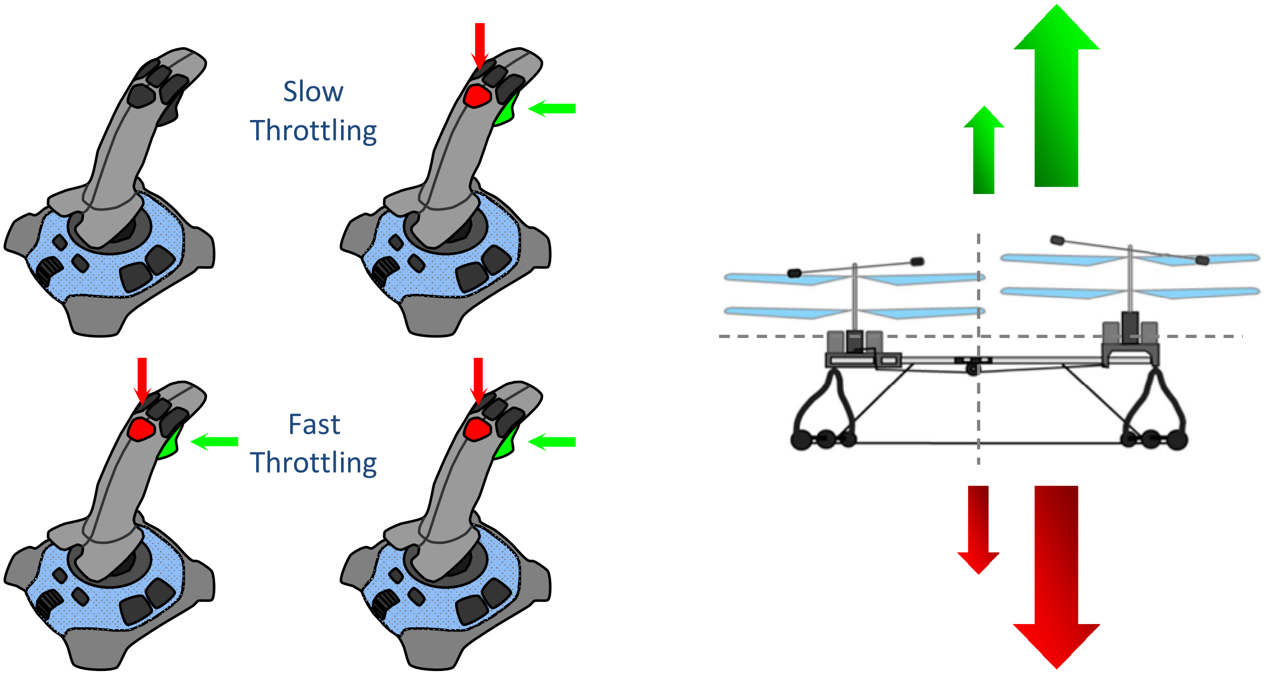


***Figure 3.3:** Throttle Operation*

By pressing L-B1 or L-B2 with the corresponding throttling, R-B1, or de-throttling, R-B2, will cause the helicopter to throttle at an amplified power. This is useful for fast takeoff or emergency landing, which may be required during normal flight.

3.2 Electronic Design

A total of 12 buttons and 4 analog signals were extracted from the two joysticks to fully utilize the various control features of the prototype helicopter. To minimize port usage on the PIC MCU and accommodate the various signals, a 16-Channel Multiplexer was used to feed to signals to the PIC input port. The general electronic layout of this apparatus is shown in *Figure 3.4*.

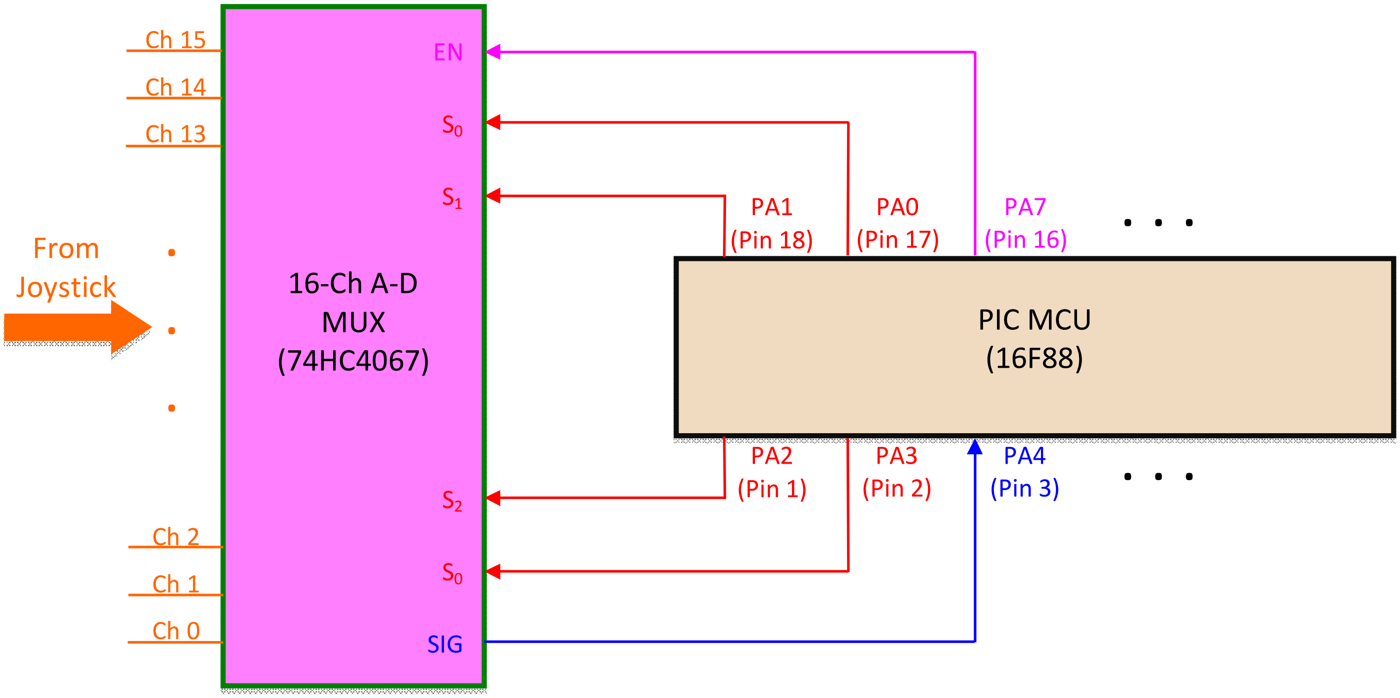


Figure 3.4: *MUX to PIC Electronic Layout*

Without the MUX, the 16 signals from the joysticks will have to occupy 16 different ports from the PIC. To make this possible, either a larger PIC package or more than one 16F88 PIC will have to be used. With the MUX, only 6 ports are needed as illustrated in *Figure 3.4*. A single input port, PA4, can process all 16 analog signals while the 5 other ports output the channel select signals and enable signal to the MUX. *Table 3.2* show the channel select logic for the MUX.

S$_3$	S2	S1	S0	EN	SIG
Unk.	Unk.	Unk.	Unk.	0	Unk.
0	0	0	0	1	Ch 0
0	0	0	1	0	Ch 1
0	0	0	1	1	Ch 2
. . .	. . .	. . .	. . .	. . .	. . .
1	1	1	0	1	Ch 13
1	1	1	1	0	Ch 14
1	1	1	1	1	Ch 15

***Table 3.2:** MUX Channel Select Logic*

The entire joystick system (controllers, MUX, and PIC) is powered with a single 5V regulated source.

3.3 Algorithm Design

The PIC MCU is programmed to sample and covert the analog signals into digital signals, used for processing, with the algorithm show in *Figure 3.5* of the following page. The MUX is first enable using an ON enable signal. The first channel is then selected following the channel select logic defined in *Table 3.2*. The channel signal is then samples and sent to the build-in Analog-to-Digital converter (ADC). The algorithm will begin the conversion process once the proper registers are initiated. Once conversion is complete, the converted digital value is stored as a global variance. This process is complete for each of the 16 channels from the two joysticks.

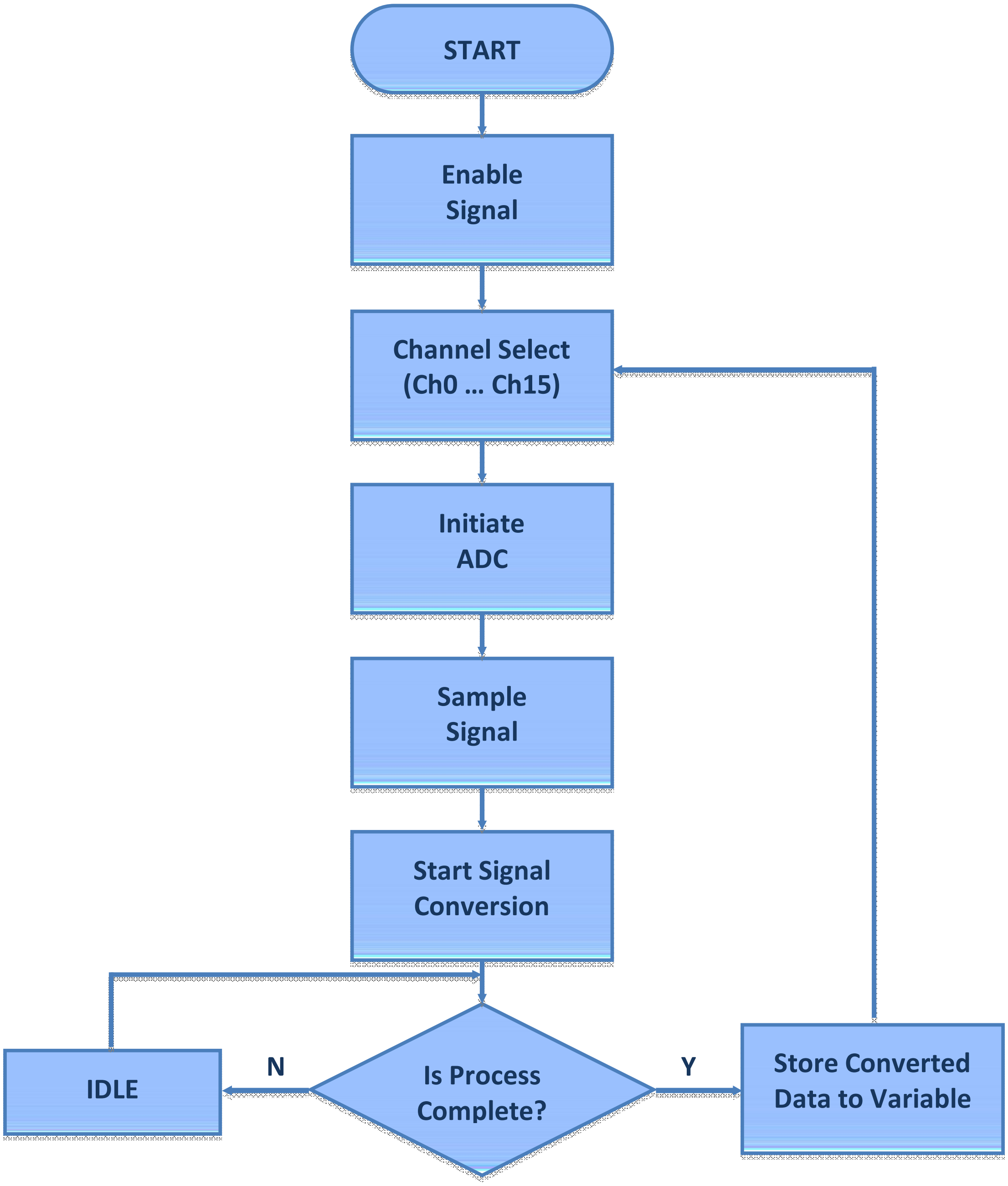


Figure 3.5: *Joystick Sampling Algorithm*

The stored channel values are then processed in one of three ways to create useful information to transmit to the helicopter's motors. *Figure 3.6* illustrates the various processing methods.

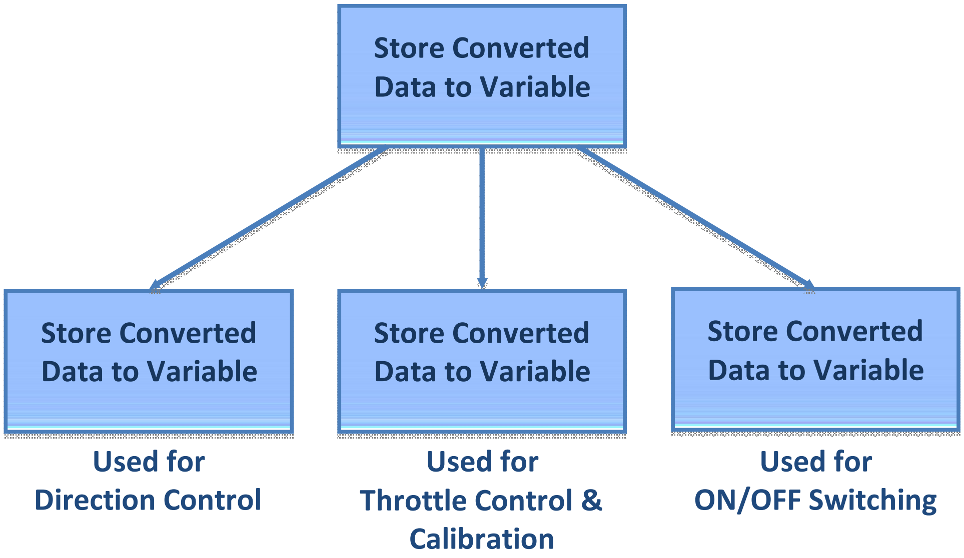


Figure 3.6: *Joystick Signal Processing Methods*

4 Motion Detection System

A major drawback to remote flight is the inability to “feel” the orientation of the aircraft. Inside a typical cockpit, measurement devices can help pilots determine the pitch, yaw, and roll of the aircraft during flight but ground systems may lack these instrumentations. Using an on-board accelerometer, the VPS is able to determine helicopter tilt. This information is visually relayed to the pilot using the camera display to help the pilot determine the helicopter’s orientation to ground during flight.

4.1 Physical and Mechanical Design

Helicopter tilt indicator shown in *Figure 4.1* utilizes Three Axis Micromachined low-g Accelerometer, MMA7260Q, to display the orientation of the helicopter with respect to the horizon. The tilt indicator is designed to provide the pilot with an effective way of understanding the orientation of the aircraft so that he or she can have as much information about the behavior of the helicopter as those found in a cockpit. This information about the orientation of the helicopter allows the pilot to determine the horizontal direction of the helicopter.

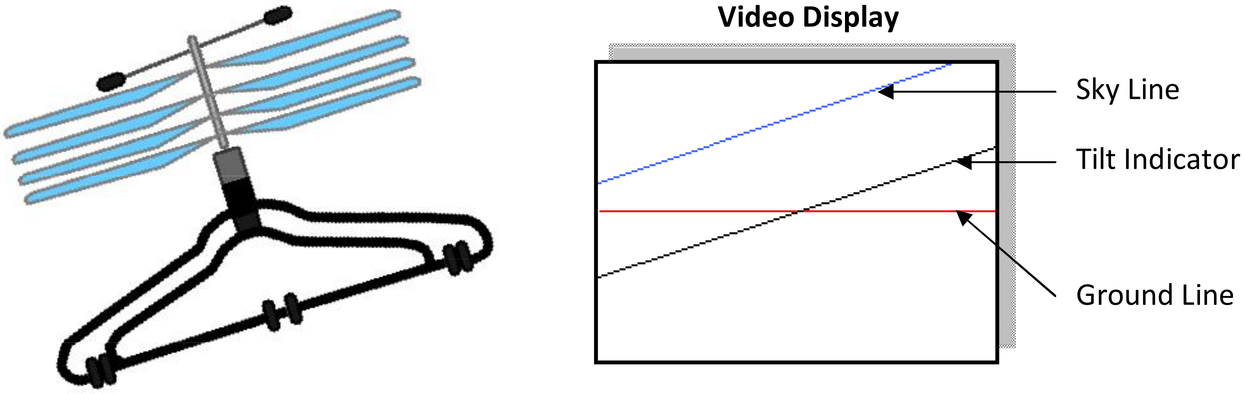
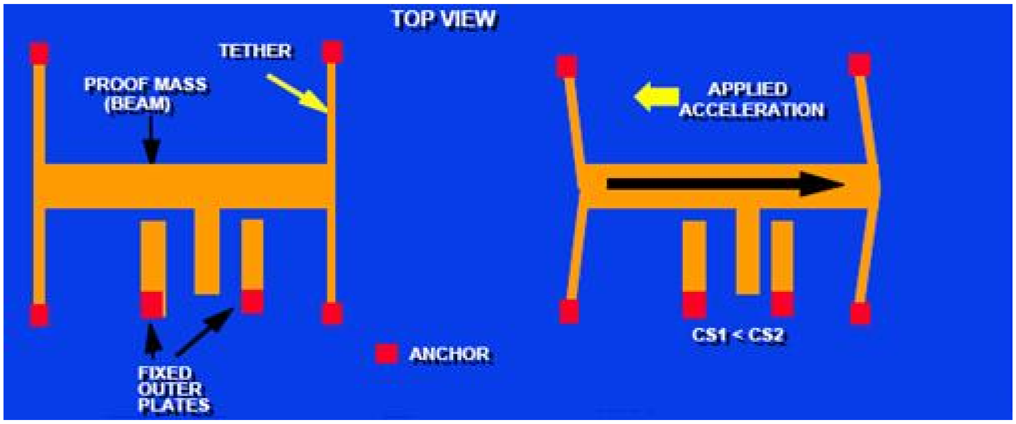


Figure 4.1: *Helicopter Tilt Indicator Characteristics*

Basic operation of the Micro-Machined Mechanical Structure (MEMS) accelerometer depends on differential capacitance. As the built-in proof mass experiences acceleration, differential capacitance changes, resulting in change of output voltage. *Figure 4.2* shows a simplified MEMS-based configuration for one axis of the accelerometer.



(Source: 2008 ENSC 387 Lab 2 Manual. Accredited to Dr. Patrick Leung)

Figure 4.1: *MEMS-Based Configuration of Accelerometer in One Axis*

Once the accelerometer is turned on with a 3.3V supply voltage, three separate voltages are outputted at three different pins for three Cartesian axes. When a particular axis experiences zero acceleration, the output voltage has a typical offset of 1.65V. As there is acceleration present in one axis, the output voltage either increases or decreases from the typical offset voltage. The output will increase if the acceleration is in the positive (defined in the manufacturing process) direction and decrease if it is in negative direction. In normal operation, Z-axis will experience gravitational acceleration and its typical value is higher than other axes (about 2.4V). In determining the tilt amount, only the Z and Y-axis are used.

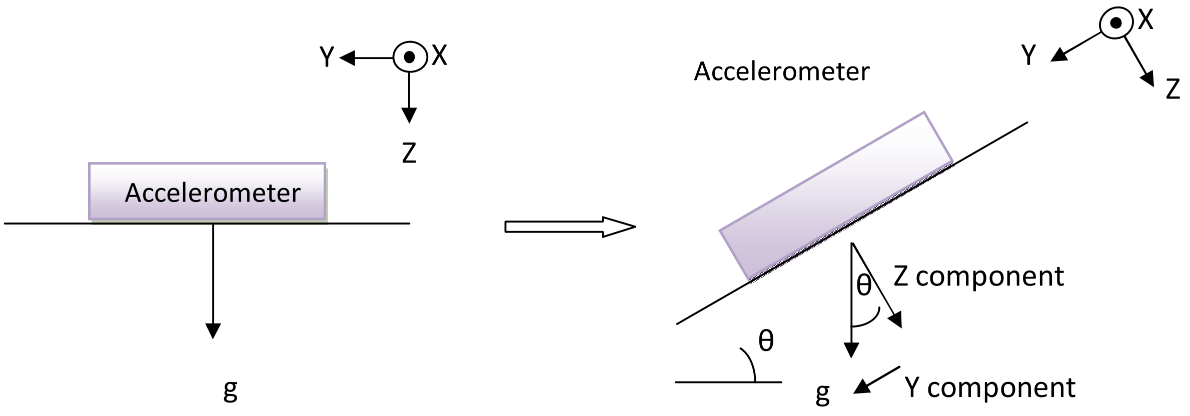


Figure 4.3: *Basic Mechanics Used for Tilt Indicator*

Figure 4.3 shows basic mechanics used in the tilt indicator. When the accelerometer is stable, all of the gravitational acceleration is reflected in the Z-axis. However, as the helicopter rotates the vector components of the gravity are divided into Z and Y-axis. This principle can be used to draw the tilt indicator line on the video display.

4.2 Interface Design

The method of drawing a line on the video display requires the user to designate two coordinates within invisible grid superimposed on the display. The tilt indicator line is drawn such a way that the line extends towards the left and right ends. An example is shown in *Figure 4.1*. *Figure 4.4* below shows the grid configuration on the video display.

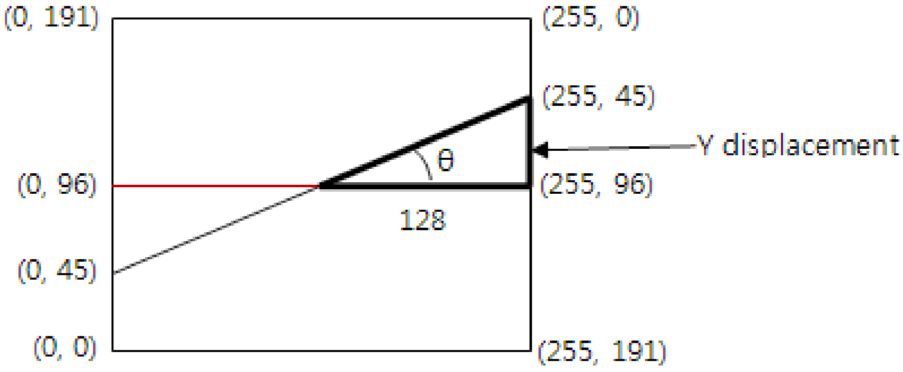


Figure 4.4: *Grid Configuration on the Video Display*

One important fact to point out from *Figure 4.4* is that Y coordinate is literally flipped as the grid system crosses the midline of X coordinate. For example, on the left side of the screen, the Y coordinate starts from the bottom but on the right side of the screen, Y coordinate actually starts from the top. This may be confusing at the beginning, but it resulted in simplification of code, which will be explained later.

4.3 Algorithm Design

As mentioned, the developer is required to give two coordinates to draw a line on the video display. As it can be noticed from *Figure 4.4*, X coordinates are always consistent such that 0 is the starting position and 255 is the end position. As far as Y coordinate is concerned, the derivation below shows how the Y coordinates can be determined.

From *Figure 4.3*,

$$\tan(\theta) = \frac{Ymagnitude}{Zmagnitude}.$$

Thus,

$$\theta = \tan^{-1}\left(\frac{Ymagnitude}{Zmagnitude}\right)$$

From *Figure 4.4*, Y displacement can be determined as

$$Ydisplacment = 128 \times \tan(\theta),$$

where 128 is the half way point of the X coordinate range. By substituting θ into the above equation, we can arrive to a simple equation below.

$$Ydisplacment = 128 \times \left(\frac{Ymagnitude}{Zmagnitude}\right)$$

Once Y displacement is determined, Y coordinate value can be calculated by subtracting Y displacement from the midpoint of Y coordinate range. As θ goes to negative value, $Y_{magnitude}$ will become negative producing negative Y displacement. By simple mathematical equation, the Y coordinate can be calculated accordingly. Because multiplication and division are considered complex operations for microprocessor, especially when the multiplier or divisor is large, few tricks are applied as the algorithm proceeds to minimize the processing requirements. Because of the complexity in calculations, X coordinates are not modified in drawing a line. This limits the angle of the line that can be drawn.

$$\tan^{-1}\left(\frac{96}{128}\right) = 36.9°$$

Thus, the angular range of the line is ±36.9º. Detailed algorithm is described in Figure 4.5 below.

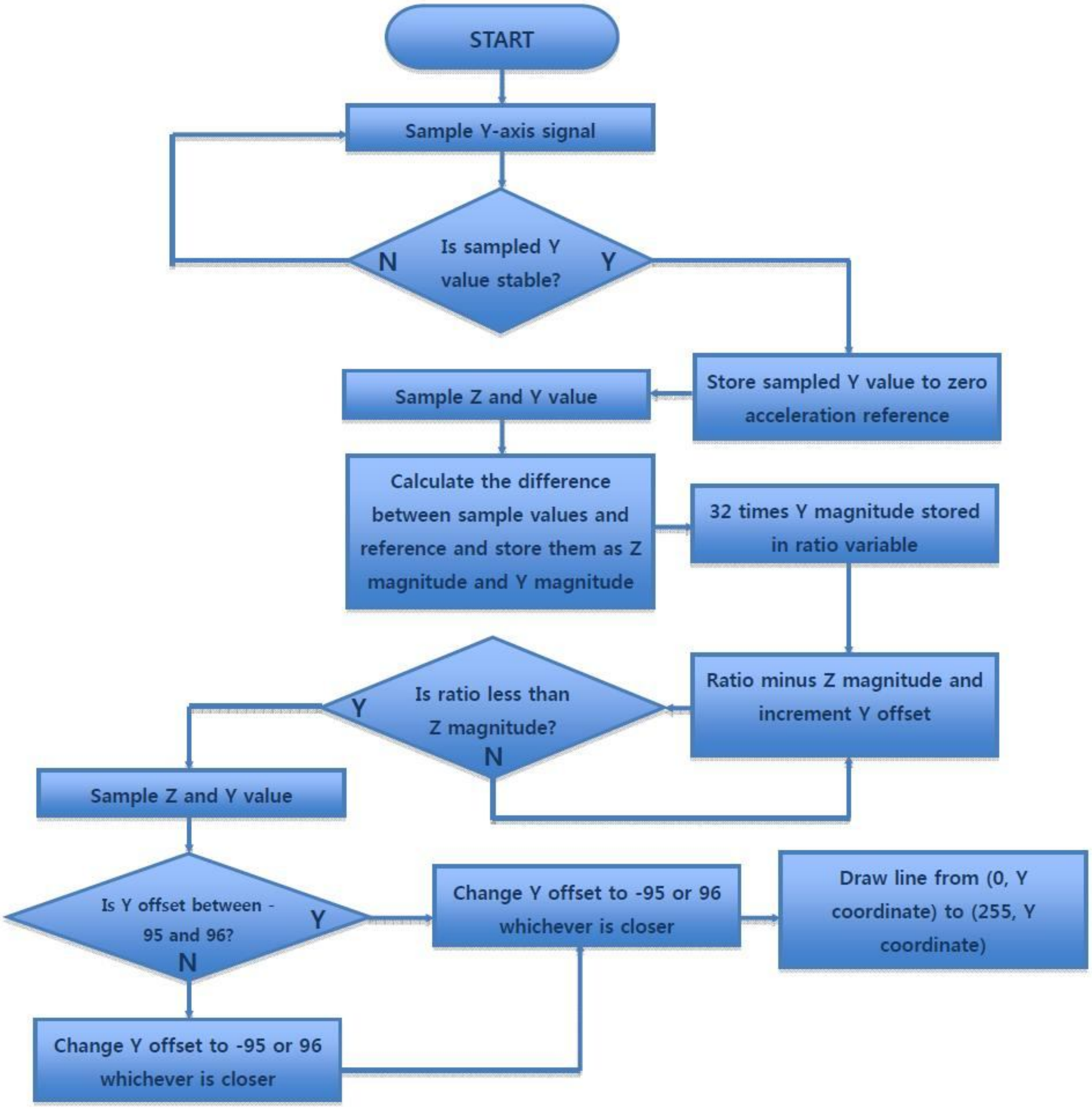
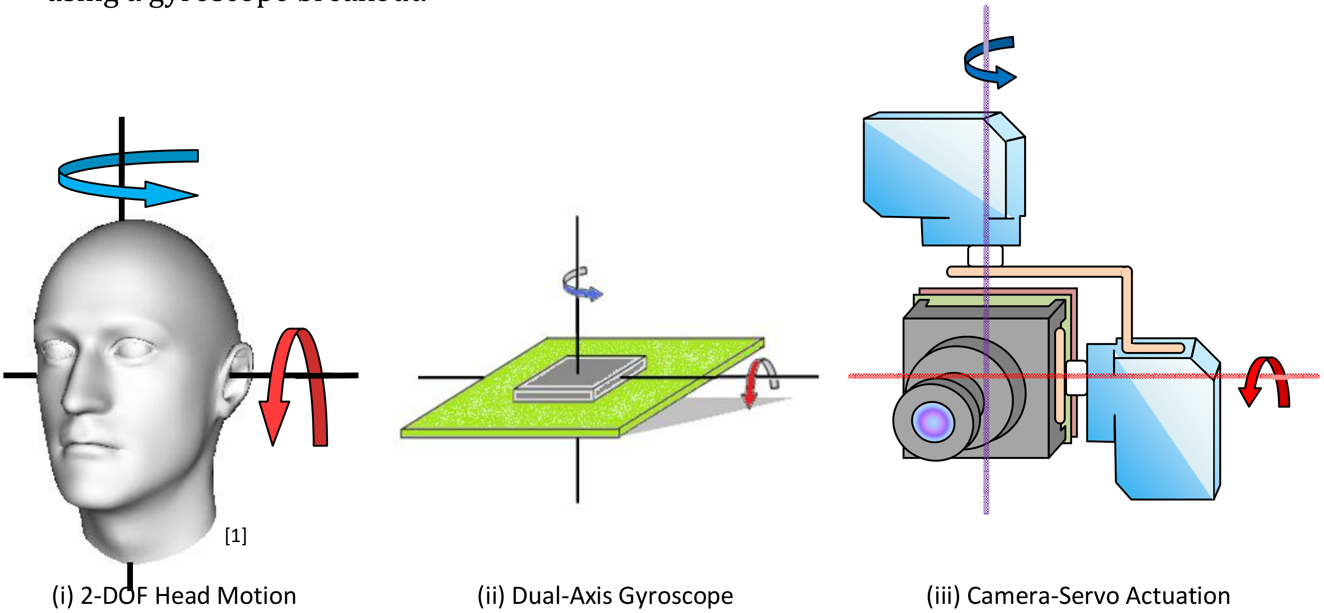


***Figure 4.5**: Accelerometer Tilt Detection Algorithm*

5 Video Interface Design

One of the objectives for the development team is to match a camera’s line of sight with the pilot’s head motion. In other words, when the pilot turns his head left, right, up or down, the camera must adjust its angular position accordingly. The camera will be stationed at the helm of the helicopter while the video feed transmitted back to base where it will be displayed on the pilot’s goggles. This feature brings the full perspective view from the cockpit to the pilot, while sitting at the comfort and safety of a base station. *Figure 5.1* illustrates how the virtual system transforms a user’s head motion to camera rotations using a gyroscope breakout.



(i) 2-DOF Head Motion (ii) Dual-Axis Gyroscope (iii) Camera-Servo Actuation

Figure 5.1: *Pilot Vision Control Methodology*

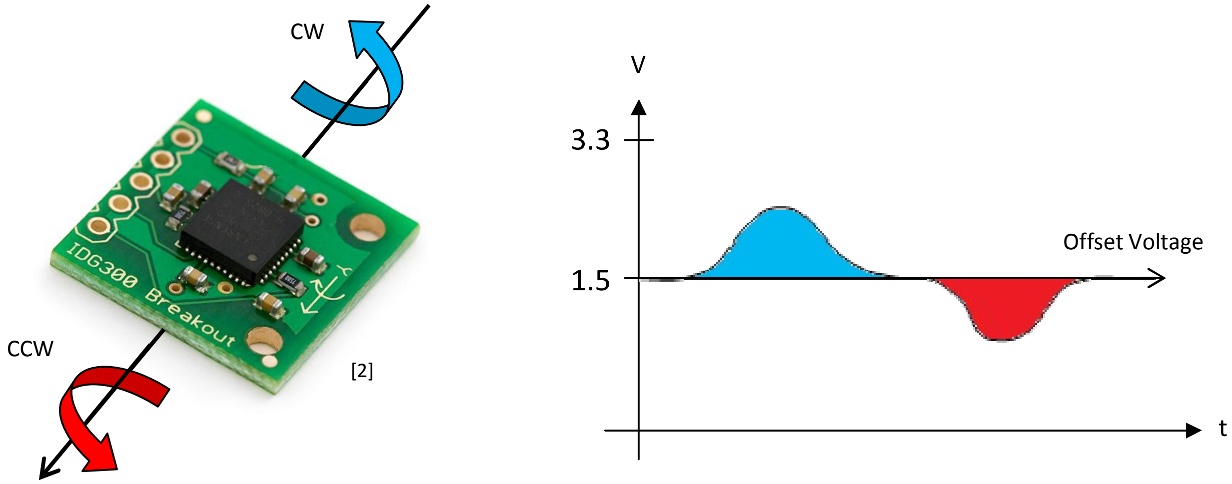
[1] Prof. Horace H.S Ip, University of Hong Kong, Department of Computing Science

5.1 Gyroscope Sensor

The IDG-300 gyroscope module integrates dual Micro-Electro-Mechanical System (MEMS) onto a single substrate to give higher precision angular velocity readings on two axis. The dual axis gyroscope will be mounted on top of the goggles between the two video eye-pieces. As soon as the module receives power from a 3.3V supply line, measurements from the dual axis will automatically be outputted from two breakout pins as varying analog voltages.

5.2 Signal Comprehension and Processing

The analog outputs for each axis have a constant DC offset voltage at approximately 1.5 volts. Whenever the module is left stationary, both output signals should remain stable at 1.5V. A clockwise (CW) or counter-clockwise (CCW) rotation about an axis will cause the corresponding axis pin to rise or fall. *Figure 5.2* depicts the typical operation and signal output from the gyro’s output pin.



(i) Rotation about a single axis

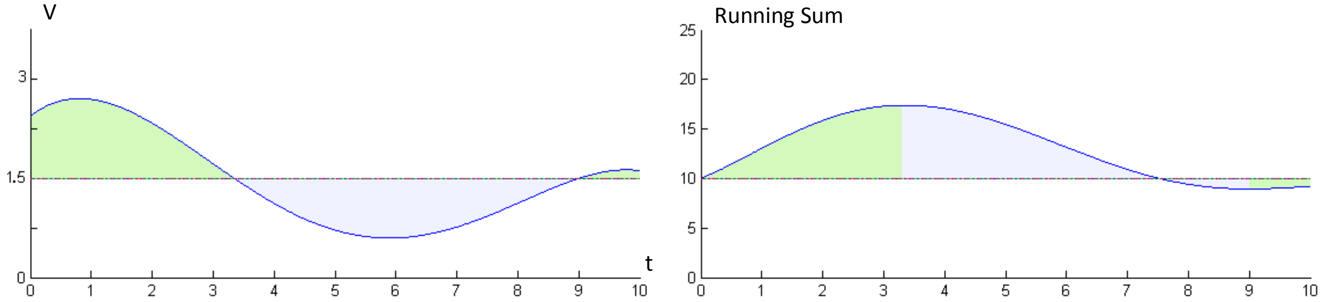
(ii) Analog voltage on corresponding axis pin

Figure 5.2: IDG300 Gyroscope Signal Output
[2] SparkFun Electronics - IMU Sensors

The voltage swing of an axis output signal is directly proportional to the *angular velocity* of the module about that axis. So, for example, if the module were to be angularly displaced around the y-axis amount θ, then the y-axis output would vary as the module is rotating. The signal will then return to its offset voltage once the module comes to a halt, after being displaced by angle θ. For the purpose of the pilot vision system, the angular displacement, θ, is of more interest than the module’s output of angular velocity. By intuition and simple calculus, an angular displacement can be extracted by integrating the angular velocity output signal.

5.2.1 Signal Integral

Figure 5.3 demonstrates how the signal integrator would work in theory. Voltage from the gyroscope’s output pin is periodically sampled, and the offset voltage value is subtracted from the sample. The result is multiplied by the sampling period, and added to a running sum. The running sum can be given an initial value to depict any initial angular position for the camera.



(i) Angular velocity output from gyroscope

(ii) Angular displacement calculated result

Figure 5.3: *Extraction of Angular Displacement Using Integration*

The running sum is a float number that only represents the voltage area of the function in *Figure 5.3i*. The running sum must be linearly scaled to give a meaningful representation of angular displacement of the gyroscope around an axis. The coefficients for the linear conversion can be determined systematically or through experimental trial and error. Excessive growth of the running sum is a non-issue, because the running sum is limited by the amount a user can turn his/her head.

5.2.2 Discrete Time Integration

A real-time analog integrator can be assembled using an active Op-amp circuitry, however, there is an operational flaw with this technique. Outputs of Op-amp integrators tend to drift or shake even in the presence of a near constant voltage. This is unacceptable because we cannot have the pilot's camera vision drift or vibrate uncontrollably in a steady environment. The source of the signal drift or vibration was traced back to the noise embedded within the gyroscope's dual axis output. *Figure 5.4* show the typical noise fluctuations from a gyroscope's output plaguing what is supposed to be a simple constant voltage. Real time integration of this noise can easily cause an integrator's running sum to vary unreliably.

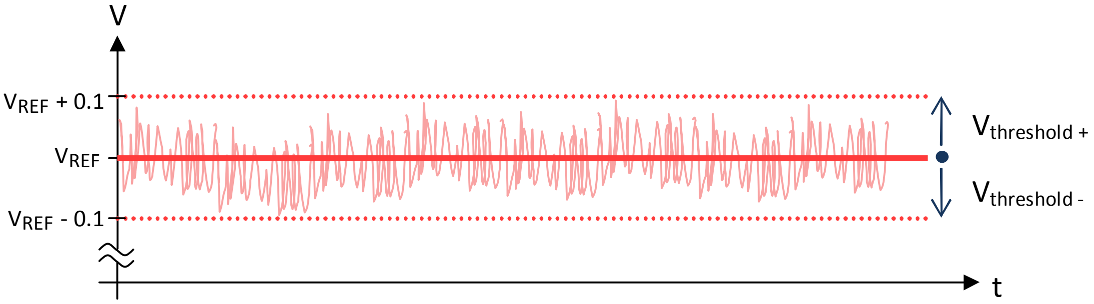


Figure 5.4: *Noise Fluctuation for Gyroscope*

The solution is to use the PIC 16F88 to perform discrete time integration along with some form of signal processing algorithm. During initialization of the PIC, the offset voltage is determined by averaging 10 samples when the gyroscope module is stationary. The averaged value is stored as a voltage reference against all other future samples. A threshold voltage, shown in *Figure 5.4*, has been determined experimentally to be approximately around ±0.1V.

Any sample value falling within the threshold range will be ignored, thus adding zero to the running sum. Any sample falling outside the threshold range will have the reference voltage subtracted from its value before being added to the running sum. Sampling is to happen in a precise periodic manner using the PIC's onboard high-speed timer and A-D converter. We do not anticipate any violent or drastic head movement from the pilot, so the signal outputs from the gyroscope are relatively low frequency functions. A timer sampling period of < 1ms *(1000 samples per second)* was deemed sufficient enough to model the slow varying signal. *Figure 5.5* illustrates a scenario of a PIC sampling a typical slow varying signal that is expected from the gyroscope.

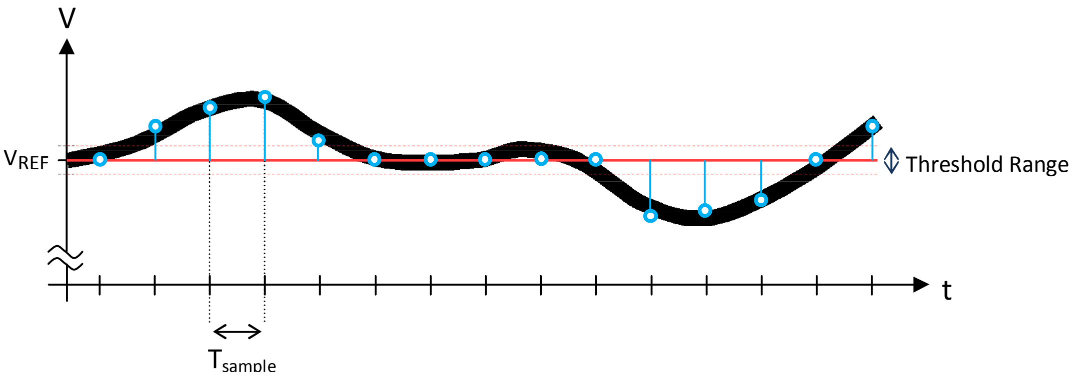


Figure 5.5: *Periodic PIC Sampling of Slow Varying Gyroscope Signal*

A true integrator calculates the area, *A(t)*, under a curve by multiplying the sample value with the sample period as outlined in the equation below.

$$A(t) = \sum_{-\infty}^{t} f(t) * \Delta t = \sum_{-\infty}^{t} V(t) * T_{sample} \qquad \text{EQU.5.1}$$

However, as mention in section 2.1, the running sum will eventually be scaled linearly to an effective angular displacement value as shown in *Figure 5.6*. Since a linear transform will be done, then the value of true area is not of significance.

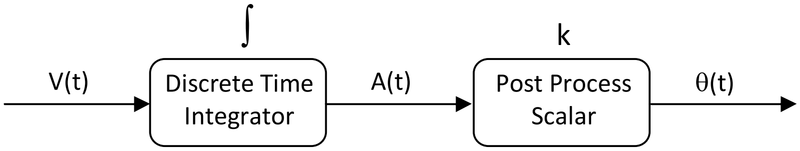


Figure 5.6: *Calculation of θ(t) with True Integrator*

If the integrator were to be scaled by a time scalar equivalent to $1/T_{sample}$, then the effective integration technique can be simplified to just a running sum of the voltage swing with respect to V_{REF}. The effect is exemplified below in *Figure 5.7*.

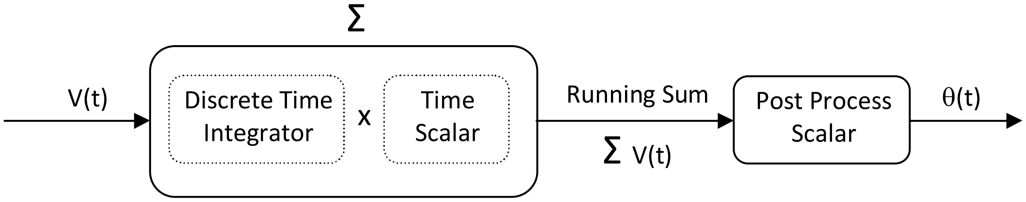


Figure 5.7: *Calculation of θ(t) with Simplified Running Sum Integrator*

Once the angular displacement has been calculated from the running sum, it is converted to a duty cycle integer than can be used by a servo motor. The duty cycle integer is packaged within a data packet and sent to the helicopter for further camera servo control. Data packet packaging is described in the next section.

6 Wireless Transmission

All communication between the helicopter and the ground is done so wirelessly. Data, for controls and telemetry, is communicated separately from the video feed to minimize transmission conflicts. The overall wireless setup of the VPS is illustrated in *Figure 6.1*. Details regarding each communication channel are explained in the following sections.

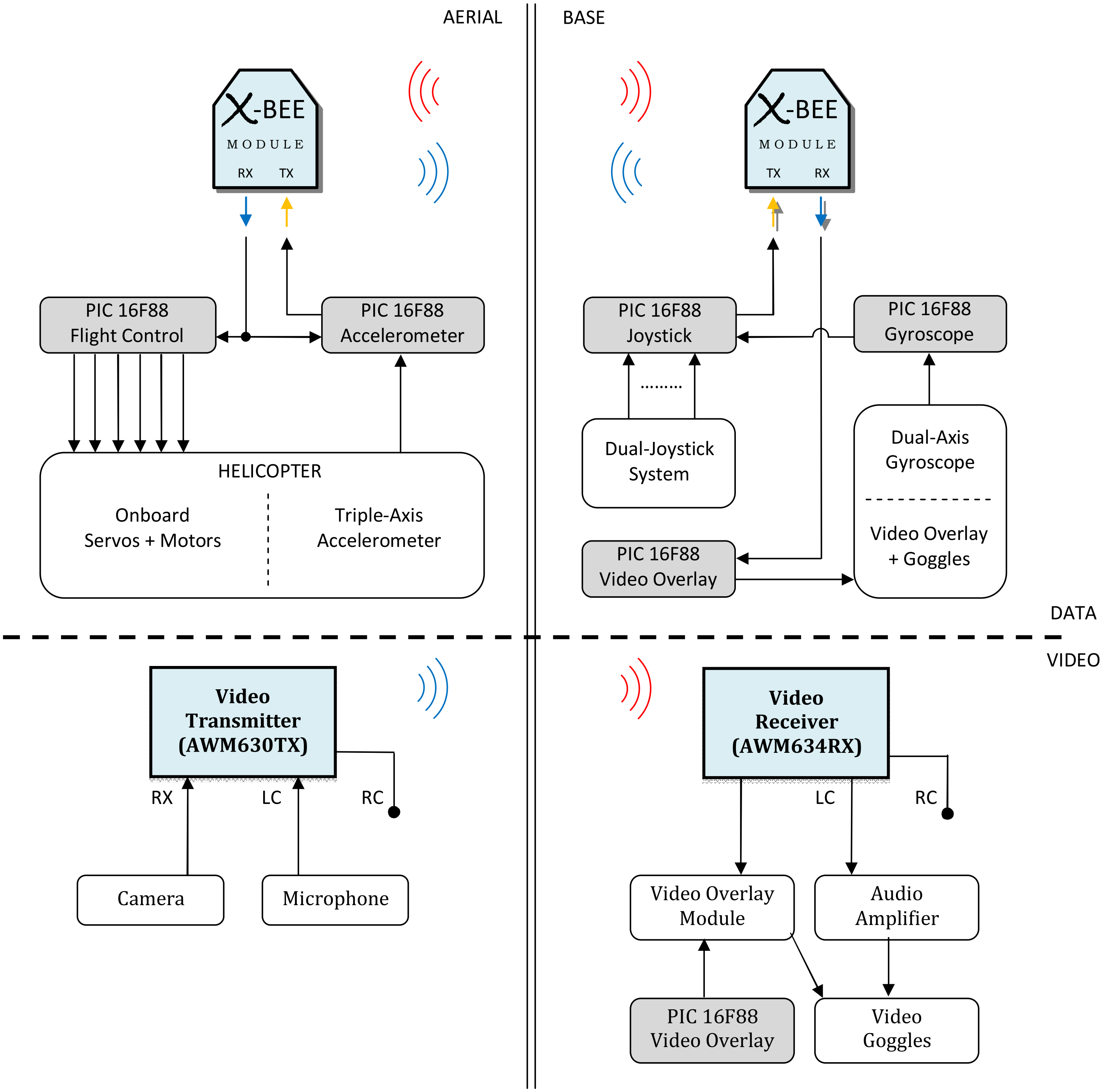


Figure 6.1: *VPS Wireless Transmission Schematic*

6.1 Data Communication Specification

6.1.1 Transceiver Module Design

(Source: Sparksfun.com)
Figure 6.2: *Zigbee Wireless Transceiver*

During the helicopter operation, Zigbee wireless technology is utilized to transmit and receive information between the helicopter and the ground station. The device used to achieve the wireless communication is 2.4GHz XBee module. XBee module requires 3.3V supply voltage and provides Baud Rate of 9600 kbps. The range of the device extends to 100m. This range is sufficient for our prototype development since video transmitter module is also limited to 100m.

The module is equipped with built in 128-bit encryption. This is may be crucial in situations where multiple modules are within the range. When operating, XBee module operates in transparent mode where the user is not required to give extra command to the module to send the transmitting byte. The user provides the XBee module with the data to transmit and the module stores it in a 3 byte buffer. Once the buffer is filled, the module transmits burst of 3 bytes to the opposite end and the bytes are automatically received. Transmission occurs when the PIC utilizes it serial peripheral to generate an asynchronous data stream. The PIC must initialize itself to a baud rate of 9600 kbps in order to match the configurations of the XBee module.

Zigbee technology is a powerful and well-established platform outlined by the IEEE and various features are available in the module. The full extent of Zigbee features, however, will not be explored during the developmental phase of our project.

6.1.2. Algorithm Design

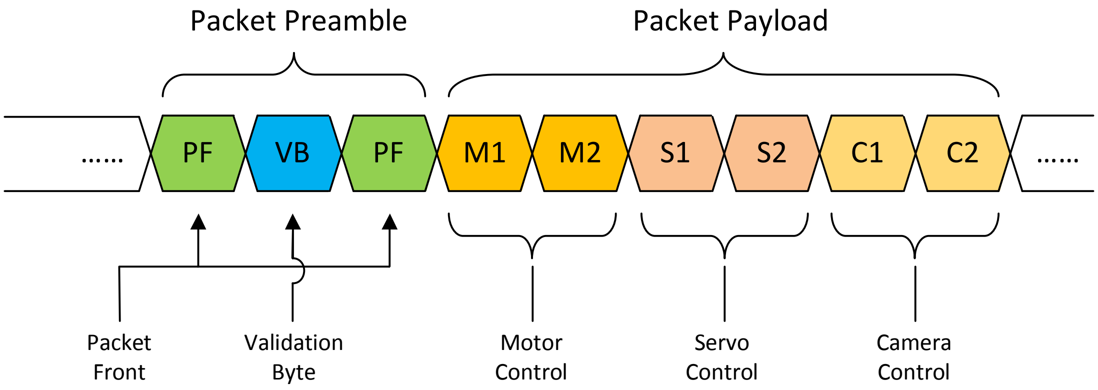


Figure 6.3: *Command Packet Configuration for Helicopter*

During the communication between the helicopter and the ground station, important information is constantly sent and received wirelessly. A particularly important process is sending commands from the ground station to the helicopter to control the helicopter during flight. These commands are composed of 6 bytes where 2 bytes are allocated for motor control, 2 bytes allocated for servo motor control and the last 2 bytes reserved for camera control. Because the bytes are transmitted wirelessly, there is the possibility of noise being present. This may hinder the proper conveyance of the command bytes to the helicopter. In order to prevent any undesired reception from the helicopter, the 6 bytes of the commands are preceded by 3 recognition bytes. The first and third bytes of recognition sequence are constant values indicating the start of the commands transmission. The middle byte is used to validate whether the 6 commands bytes contain significant meaning in them. The 3 recognition sequences must be checked by the microprocessor on the helicopter before receiving the actual 6 bytes following the packet preamble. The sequence of bytes is shown in *Figure 6.3*.

At the time rcByte() is called, there can be junk data stored in the received byte stack. Received byte stack is a stack with size 2 and it stores any previously received bytes until the program reads them. The stack is cleared when all of the items are read. As rcByte() executes, its first task is to clear the stack to aid desired data to arrive without hindrance since whenever there is information contained in stack, the unknown information must be taken out of the stack before the useful information is extracted.

After the stack is cleared, stream of bits start to come in from the transmitter. As continuous bits are received, the rcByte() function must distinguish the correct starting position of the byte and must not start sampling bits in the middle of the byte transmission. Fortunately, PIC16F88 contains features that aid the programmer to discard any wrong information. For example, byte information is surrounded by start bit and stop bit at either ends. The receiver initiates sampling when start bit is received while the receiver is idle. However, it is possible to misinterpret other bits as the starting bit and start taking wrong information. In this case, it is highly probable that the stop bit, 9 bits after start bit is wrong and PIC indicates that the byte that was just received contains wrong information. In this case, the byte received is ignored.

After first few false receptions, the receiver will be able to synchronize itself with the transmitter because after a packet of bytes is sent, there is certain delay before another packet is transferred. Once proper bytes are starting to be received, the bytes are must go through the validation process described in *Figure 6.4* on the following page. The ultimate goal of the algorithm is to validate first three bytes and if they are correct, store the next 6 bytes received. The requirement is that the first and third bytes in the packet preamble section must equal to hexadecimal number of CC. Another requirement is that the two CC's must be apart by one byte which is not CC. The probability that this exact sequence appears within other section of the packet is highly improbable and after this sequence of check-up, it is almost definite that the commands received are proper.

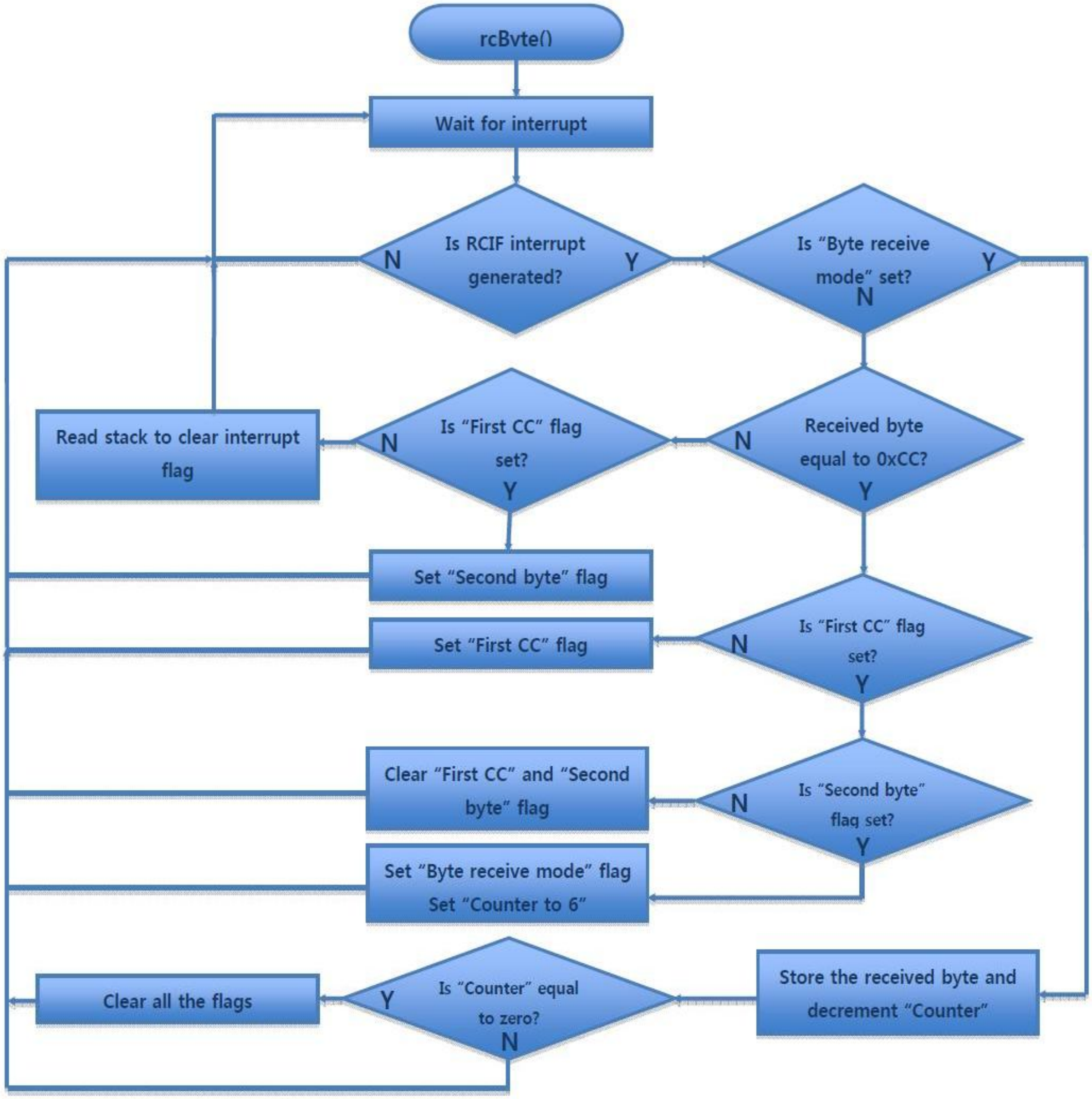


Figure 6.4: *rcByte Function Algorithm*

6.2 Video Communication Specification

6.2.1 Video Overview

The video display system for the VPS consists of 4 main components: Camera, Video Transmitter/Receiver, Video Overlay, and Video Display. The overall video system layout is shown in the bottom half of *Figure 6.1*. On board the helicopter, the video transmitter transmits video and audio input from the camera and microphone, respectively, to the receiver on the ground. The matching receiver then sends the video and audio signals, separately, to the video overlay module and audio amplifier. The video overlay PIC will program the video overlay to superimpose the necessary telemetry to the main video feed. The finalized video feed is then displayed on the video display goggles along with the amplified audio signal. All components of the system are powered by a signal 5V regulated source. On-board devices are protected against vibration by mounting them on dampening foam padding.

6.2.2 Camera Design

A DPC-161 Color CCD camera is used for acquiring an aerial view for the pilot. A wide-view, 512x492 effective pixel lens enables the pilot to observe a 72° horizontal view. The output of the camera is in standard NTSC format and has an equivalent of 380 horizontal TV lines of resolution. Details regarding the camera's mounting and movement interaction with the pilot are explained in the Gyroscope section. *Table 6.1* summarized the electronic and physical specifications of the camera device.

Property	**Specification**
Lens	Wide view f2.9mm glass optic lens with 72° horizontal view
Pixilation	512 x 492 effective pixel format
Resolution	380 horizontal TV lines of resolution
Output	Standard NTSC color composite video
Supply Voltage	5V DC from on board voltage regulator
Supply Current	160mA (approximately)
Cable	3-wire A/V cable (5V, Ground, Video)
Weight	23 grams
Dimension	26mm (W) x 22mm (H) x 32mm(D)

(Source: Panasonic DPC-161 Datasheet)

Table 6.1: *CCD Camera Specifications*

6.2.3 Video Transmitter/Receiver Design

An Airewave AWM630TX video transmitter is used for transmitting both the video signal, from the camera, and audio signal, from the microphone, to the ground station. The electronic layout of the video transmitter circuit is shown in *Figure 6.5.*

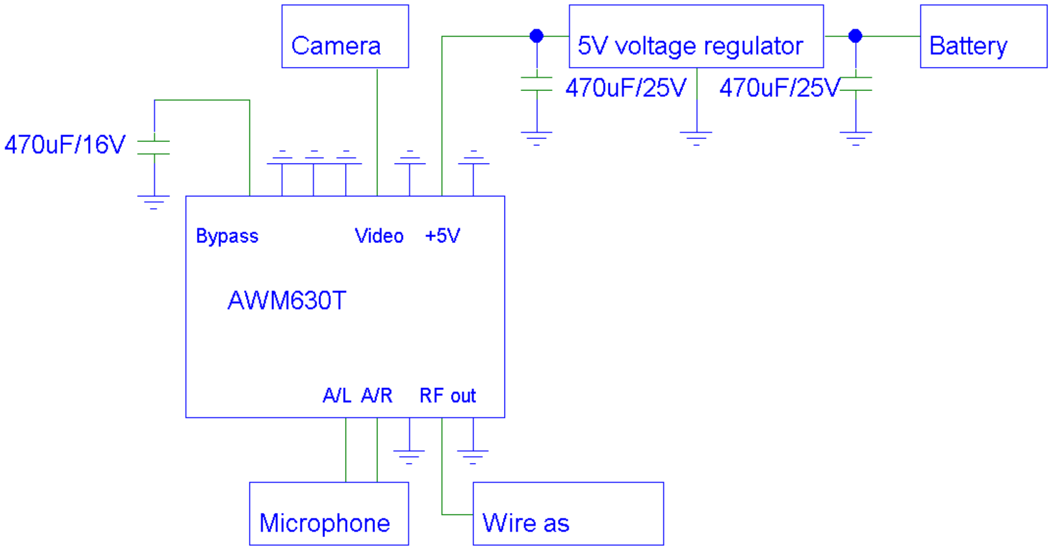


Figure 6.5: *Video Transmitter Circuit Layout*

Signal relay to base is done so using 2.4GHz wireless RF transmission. Other specification for the video transmitter is summarized in *Table 6.2.*

Property	Specification
Operation Frequency Range	2400 – 2483 MHz
Channel Selection	PLL Synthesizer 4CH
Max. Operating Attitude	91.44 m (300 ft)
Operating Ambient Temp.	-10°C – 60°C
Supply Voltage	5V DC from on board voltage regulator
Supply Current	55mA (Approximately)
Antenna Port Impedance	50Ω
Video Input Impedance	75Ω
Video Input Level	$1V_{p-p}$
Audio input Level	$3V_{p-p}$

(Source: Airewave AWM630TX Datasheet)

Table 6.2: *Video Transmitter Specification*

On the ground, Airewave AWM634RX video receiver receives the transmitted signal. The receiver operates in the same frequency band as the transmitter. The circuit schematic of the receiver is shown in *Figure 6.6*.

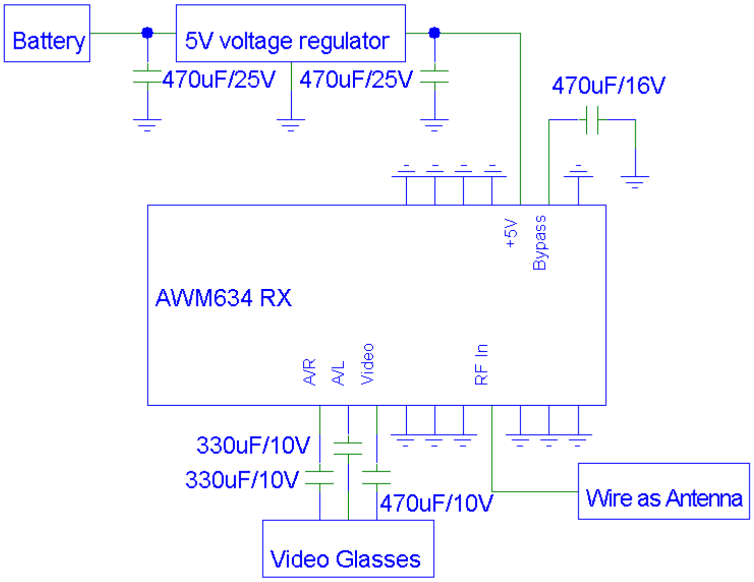


Figure 6.6. *Video Receiver Circuit Schematic*

In terms of specifications, the receiver shares many common properties as the transmitter. These specifications are summarized in *Table 6.3*.

Property	**Specification**
Operation Frequency Range	2400 – 2483 MHz
Channel Selection	PLL Synthesizer 4CH
Max. Operating Attitude	91.44 m (300 feet)
Operating Ambient Temp.	-10°C – 60°C
Supply Voltage	5V DC from voltage regulator at base station
Supply Current	140mA – 180mA (Approximately)
Video	
Output Signal Level	$1V_{p-p}$
Frequency Response	+/-5 dB, max. 50Hz – 5.5 MHz
S/N Ratio (100KHz, $1V_{p-p}$ Sine Wave)	40dB, min.
Audio	
Output Frequency Range	50Hz – 20KHz
Output Signal Level	$3V_{p-p}$
S/N Ratio (50Hz – 15KHz)	50dB

(Source: Airewave AWM634RX Datasheet)

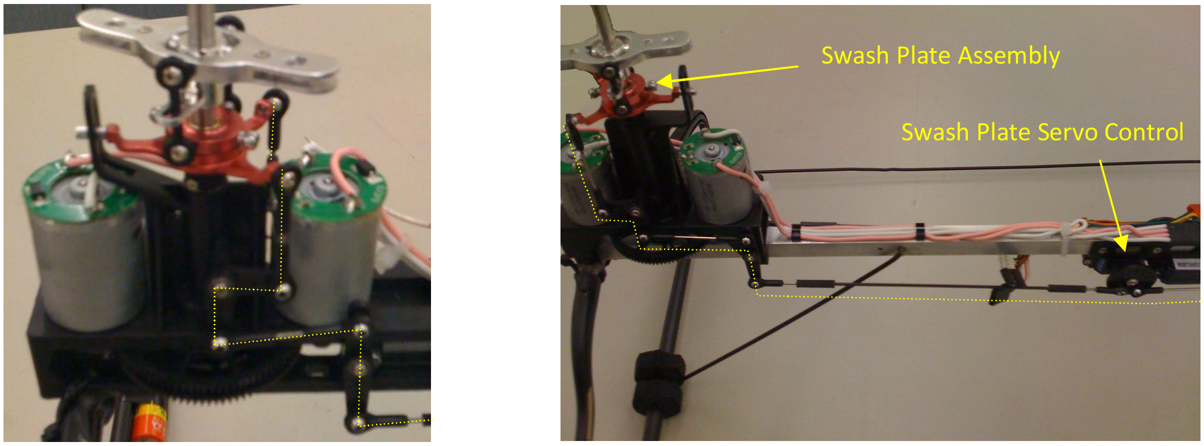
Table 6.3. *Video Receiver Specification*

7. Helicopter Dynamics

Helicopter flight control and stability can be acquired by controlling the *power output of the main rotors* and the *directional tilt of the rotor blades*. Control of motor power output and blade directional tilt can be controlled with the understanding of the *Swash Plate Assembly* and *Electronic Speed Controller*. Both of these control mechanisms are described with more detail in the sections below.

7.1 Swash Plate Assembly Design

Figure 7.1i below shows swash plate assembly used onboard the Walkera tandem rotor helicopter for this project. The yellow dotted line shown in *Figure 7.1ii* traces the mechanical control lines used by the a servo motor to control the tilt angle of the swash plate.



(i) (ii)

Figure 7.1: *Walkera’s Onboard Swash Plate Assembly and Control Mechanism*

Figure 7.2 below demonstrates the mechanics of the swash plate assembly.

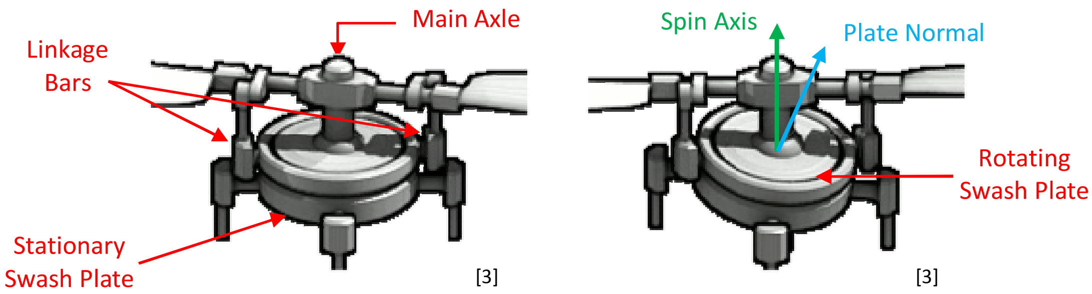


Figure 7.2: Mechanically operation of swash plate
[3] Wikipedia – Swash Plate Assembly

The swash plate assembly is comprised of two main components; the stationary swash plate, and the rotating swash plate. The stationary swash plate does not rotate with the main axle. It is only able to adjust its tilt with the help of a servo, as seen in *Figure 7.1ii*. The rotating swash plate rests on top of the stationary plate, as shown in the right diagram of *Figure 7.2*. The rotating plate has the ability to spin around an axis parallel to the main axle, while maintaining a normal parallel to the stationary's plate normal. As the rotating plate spins on the surface of the stationary plate, two linkage bars will either pull down or lift the rotor blades to create directional tilting. *Figure 7.3* illustrates how directional tilting of rotor blades can be used to translate the helicopter in straight vectors *(elevator and aileron control)*.

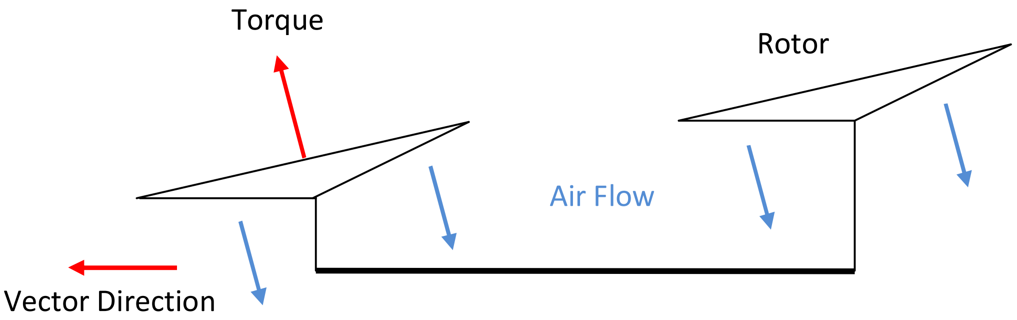


***Figure 7.3:** Directional Blade Tilting to Move Helicopter Forward*

7.2 Electronic Speed Controller Design

Figure 7.4 shows the electronic speed controller used onboard the Walkera tandem rotor helicopter for this project. The electronic speed controller is responsible for supplying the correct power to the four main motors in order to control motor speeds of up to 28,000 RPM.

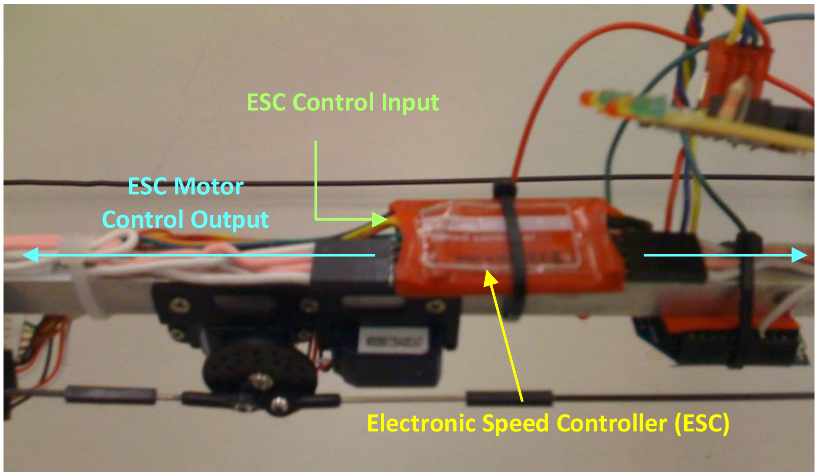


Figure 7.4: *Electronic Speed Controller Module*

The electronic speed controller is a special module capable of pushing up to a total of 40 amps of current to the low resistance brushless motors. Even in times of high vibration and operational noise, the ESC is capable of outputting a constant voltage.

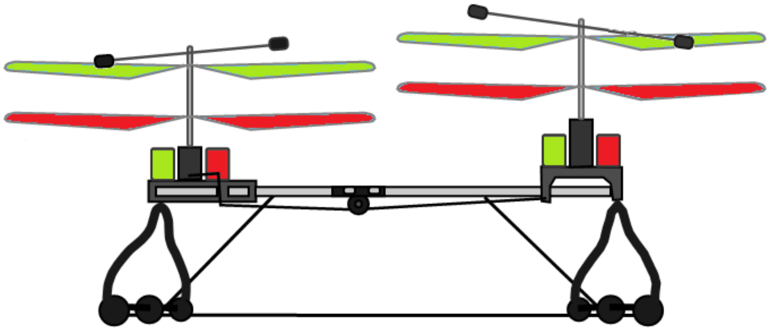
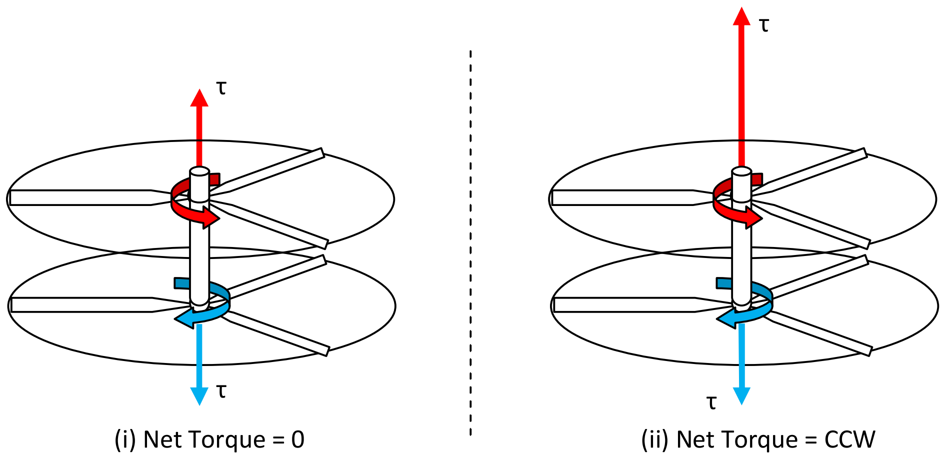


Figure 7.5: *Motor-Blade Set Correlation*

The ESC is able to control the four brushless motors by using two input signals to generate two different output voltages, as illustrated in *Figure 7.5*. Varying the speed of the two sets of motor pair allows to the helicopter to rotor clockwise or counter-clockwise in the air *(Rudder Trim Control)*.

The physics behind how helicopter rudder control is achieved simply by varying motor speed can be understood by analyzing the torque produced by the quick rotating blades. The top and bottom blades are rotating in opposite directions. So if the blades were to rotate at constant speed, the torque generated from the top blades will cancel out with the bottom blades, as shown in *Figure 7.6i* below.



(i) Net Torque = 0
(ii) Net Torque = CCW

Figure 7.6: *Net Torque Spawning from a Single Axle*

If there are there is a net torque along the axle generated by two different motor blade speeds, as shown in Figure Xxii, then that net torque will also appear on the other axle of the helicopter, since both axles are controlled by the same two motor signals. *Figure 7.7* on the next page illustrates how controlling motor speed, thus control net torque, can effectively rotate a helicopter CW and CCW.

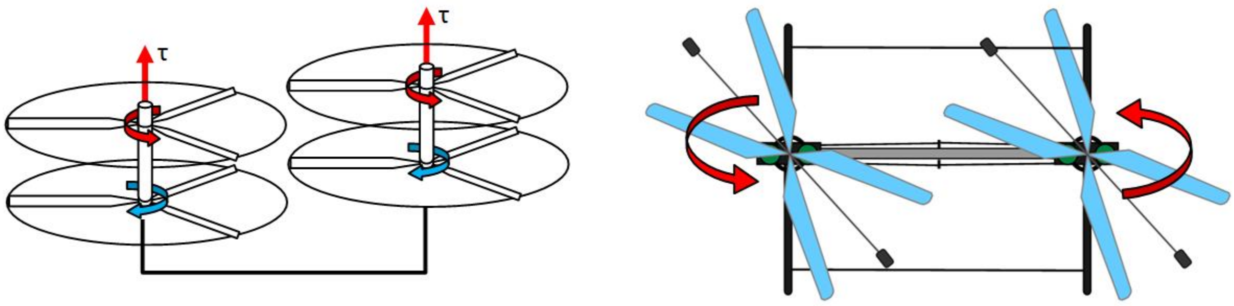


Figure 7.7: *Helicopter Rudder Trim Control*

7.3 Flight Motor Control

All motors are directly controlled by speed controller. The speed controller will generate desired DC current based on the rectangular signal duty cycles, which are generated from a dedicated motor controller on board. The controller uses received control signals from joy stick to generate specific rectangular duty cycle signals. The logic of generating such signal is shown in *Figure 7.8*. The control signals received from the ground station are integers with a range typically from 0 to 100. The number 0 indicates minimum power, and number 100 indicates maximum power. A counter is used to specify duty cycles for each signal and the counter is set up according to the integer control signals. When the counter starts or restarts, controller will output logic high which is between 3.16 V to 3.44 V depending on the individual motor. As the counter starts counting, it will be used to compare the desired length of logic high signal to the actual length. When the counter is larger than the length of the logic high, then the output turns to low. If the counter is larger than the length of the period, the output will change to high, and counter restarts.

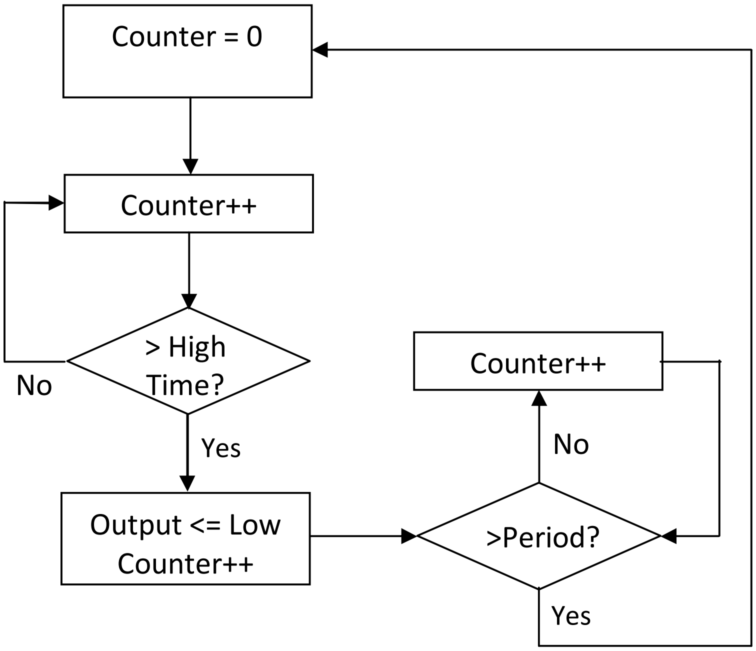


Figure 7.8: *Duty Cycle Generation Algorithm*

Figure 7.9 also shows the generation logic for specific duty cycle signal. The horizontal axis is time for output signals and counter. Vertical axis is voltage for output signal and counted number for counter. The thicker signal is the specific rectangular duty cycle output, and the thin climbing signal is the counter. As counter increases, it will reach the time for terminating the high signal and as it reaches the point, the output changes to low.

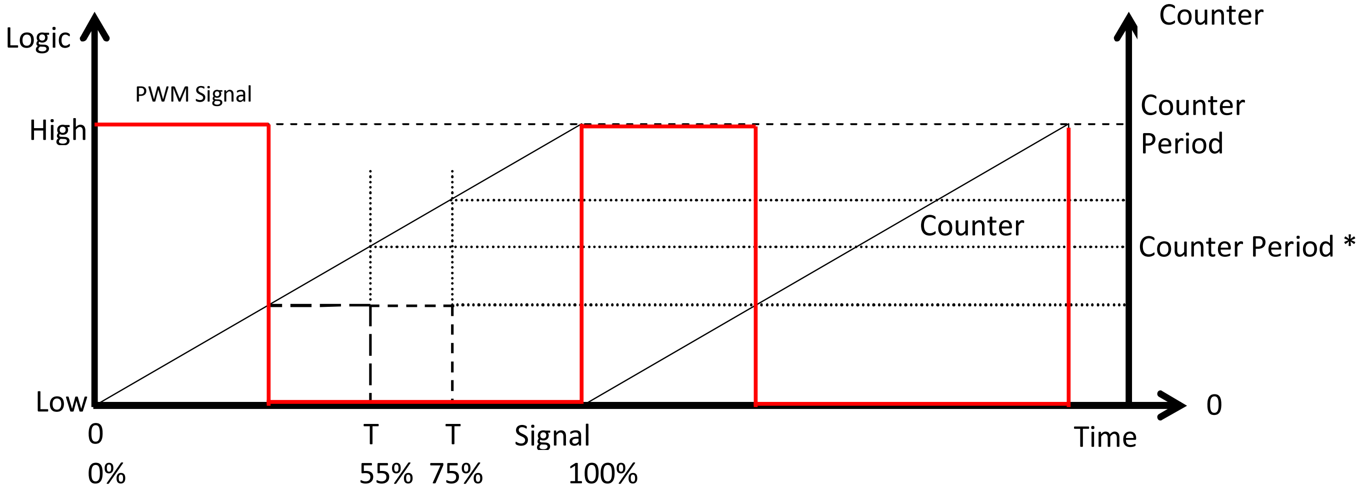


Figure 7.9: *Generation of PWM Signal*

The helicopter uses two sets of counter-rotating rotor blades. Each set of blades has two coaxial blades turning in opposite direction which cancel out the torque produced by each individual. All of the power from motors is used for lifting, when rotation control signal is at 50 percent duty cycle, which both top and bottom blades spin in same speed.

Lift control signal controls the power delivered from motors. The signal duty cycle is from 0 to 100 percent which corresponding to zero to full power for all blades. The rotation control signal duty cycle also varies from 0 to 100 percent which scale down the power delivered to the top or bottom blades. This will cause the unbalance of the torque produce by top and bottom blades which eventually produce rotation of the helicopter.

8 System Test Plan

As the project development is entering integration stage, the system testing also becomes more focused on integration system testing. There are four integration systems of concern.

1. Video transmission and display system
2. Helicopter control system
3. Pilot head movement detection and camera response system
4. Helicopter status feedback system

Each system can be tested individually without dependence on the other systems. For the systems, which share common sub-components, simultaneous testing for both systems will also be performed to ensure compatibility. Full system testing will be held as the final stage.

8.1 Video Transmission and Display System

1. Testing of video display with static helicopter and manually movement of camera
   Expectation: Clear, non-noisy, stable images with arbitrary movement of camera
2. Testing of video display with distance variation
   Expectation: Functional with clear images at distance range of 50m
3. Testing of video display with speed variation
   Expectation: Functional with clear images at maximum flying speed

8.2 Helicopter Control System

1. Stability with default settings
    Expectation: Floating statically and stably in the air at default lift setting
2. Full control testing
    Expectation: Functional with basic movement including elevation, forward movement, backward movement, turning, and rotation
3. Performance testing
    Expectation: Skilled flight with routing flight and barrier avoiding
4. Crash prevention testing
    Expectation: Detection of inappropriate operating and automatic safe landing response
5. Fully functional testing with load and different environment
    Expectation: Fully functional with 100 gram load and all regular environment conditions, such as minor turbulence

8.3 Pilot Head Movement Detection and Camera Response System

1. Functional testing with Static helicopter
    Expectation: Response properly with helicopter static on the ground
2. Irregular movement and response testing
    Expectation: Proper response with violate and over-limit movement
3. Performance testing with helicopter in motion
    Expectation: Fully functional with helicopter in motion

8.4 Helicopter Status Feedback System

1. Manual movement testing with full test plan
    Expectation: correct measurement display with pre-designed test plan, such as specific speed and acceleration measurement
2. Functional testing with full flight
    Expectation: reasonable measurement response with helicopter in motion
3. Precision adjustment
    Expectation: Improvement in measurement precision

9 CONCLUSION

Rogue Avionics is committed to designing an alternative aircraft control system that will allow pilots to operate any aircraft without physically being inside the cockpit. The VPS will not only eliminate the entailed risks of being a pilot but should also revolutionize the current concept of aviation. This design specification should have given readers a better understanding of the requirements involved in building such a system and the various features that can be found in the VPS. Our development team is expecting completion of Phase I (Proof-of-Concept) by April 2009 with its success determining the continual development of future prototypes.

10 GLOSSARY

ADC: Analog-to-Digital Converter
CCD: Charged-Coupled Device
CW: Clockwise
CCW: Counter-Clockwise
DOF: Degrees Of Freedom
EEPROM: Electrically Erasable Programmable Read-Only Memory
ESC: Electronic Speed Controller
FCC: Federal Communications Commission
MCU: Microcontroller Unit
MEMS: Micro-Electro-Mechanical System
OOD: Object-Oriented Design
OpAmp: Operational Amplifier
OSD: On Screen Display
PWM: Pulse Width Modulation
RPM: Rounds Per Minute
QA: Quality Assurance
UAV: Unmanned Aerial Vehicle
VOM: Video Overlay Module
VPS: Virtual Piloting System

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[3] Wikipedia (2009). Swash Plate Assembly [Online] Wikipedia.com. Available from: http://en.wikipedia.org/wiki/Swashplate_(helicopter). (Accessed: 5 March 2009).