VIDEO TRACKING SYSTEM FOR UNMANNED AERIAL VEHICLE

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ABSTRACT

Surveillance and tracking using unmanned aerial vehicles (UAVs) is a growing field and to visually track an object independent of a flight path requires a video transmission and control system. Applications utilizing UAVs to track a stationary or moving target are plentiful, from military to local law enforcement; every application introduces an alternative to placing a human into an aircraft and increases the usefulness over a fixed position recorded video. Here we have introduced a cost effective video tracking system that will provide a constant video transmission, manual control for tracking, and further implement an automatic control system to automatically correct for the UAV's roll and yaw. The video tracking system has been designed to be cost friendly while constrained to be applicable for small UAV applications. We have detailed the successful design of our system that overcomes the imposed constraints in great detail in the sections that follow.

1. INTRODUCTION

Modern tracking and surveillance with a UAV has become more prevalent and valuable by reducing the risk of sending a human into a potentially dangerous area while still collecting valuable information. The benefit of using a completely automated aircraft is the removal of the human element from related risks and by implementing a video tracking system; detailed information can be surveyed and collected real time while target acquisition is available from a secure ground station. In this paper we present the design of the video system:

- We design the system from the ground up to be implemented on a 40% YAK 54 UAV. The complete system design is decoupled (section 3) to ensure the video transmission is constant while a joystick can adjust what the camera is looking at.
- To improve the video transmission's distance of operation a custom antenna was researched, designed, and fabricated. We discuss the need for this custom antenna and its associated challenges in section 3.2.
- We engineer an automatic control system to compensate for flight deviation from the UAV's roll and yaw. Section 3.2 details this in addition to the rest of the onboard components.
- We establish our maximum budget of $1200 and compose purchasing accordingly to ensure a cost efficient design (section 4).
- We design a versatile and adaptable system to easily incorporate future revisions and upgrades.

2. BACKGROUND

To set the scene for this paper, we begin with a brief overview of current UAV video tracking systems. Suppose you are in need of implementing a video tracking system to your own UAV, where do you start? Does the local UAV shop have a video tracking system available to pick up? Probably not, and unfortunately your task has suddenly increased in difficulty. Your task has drastically changed from simply picking one out and buying it to designing it and ensuring it doesn't affect your UAV adversely. While more companies tailor to UAV video customization, the cost of simply buying a complete video system with tracking controls is astronomical. Here we look at how to implement a low cost video system that can track an object all while being lightweight and small enough to be placed in most modern day UAVs.

3. METHODLGY

Our video tracking project was first divided into three subsystems: the on-board subsystem, the transmission subsystem, and the ground station subsystem as shown in Figure 1. These are further divided up into separate systems later in the design. All the components chosen were selected from available sources that anyone can purchase online. The emphasis for selecting off the shelf components is to ensure that this project is reproducible and also to keep costs at a minimum. Using commercially available components and using open operating frequencies further enables this design to be versatile.

3.1 OVERVIEW

With a twelve foot wingspan the 40% YAK 54 is just the right size to implement a video tracking system. The mid-size UAV is large enough to handle a prototype tracking system but small enough to ensure this application can be implemented into various UAV sizes. Trying to fit the onboard components into the 5”x 5” x 6” package while weighing less than five pounds was difficult but this was the limited space and maximum weight allowed inside the YAK 54. Additionally, finding components that would meet the requirements on a limited budget was intimidating.

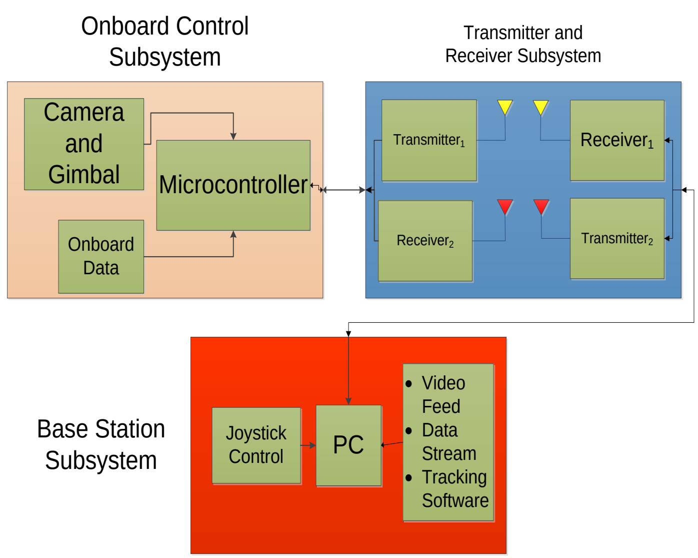

Figure 1: Block diagram of three sub-systems.

Size, weight, and cost were constant design constraints that required careful planning. We successfully met these constraints through preparing a full design review to account for the onboard weight and size while not going over budget.

Our full design review analyzed every component, physical interconnect, and purpose to ensure the component did its job and did not interfere with other components or constraints.

3.2 ON-BOARD SUBSYTEM

The on-board subsystem faced more physical design challenges than the other two subsystems due to the imposed size and weight constraints only imposed on this section. The first hurdle to pass was the selection of the camera and gimbal. A light weight HD Go Pro mini camera was chosen to provide the live video output. The gimbal system controlling the camera's view is a simple two axis, pan and tilt gimbal. The gimbal is only a few ounces and can support the camera's adjustments by using two servo motors. Both the gimbal and two servo motors were lightweight and cost effective.

The video transmitter was the most expensive off the shelf component and takes up the majority of the space of the onboard package. It receives a component video feed and transmits the footage digitally using Quadrature Phase Shift Keying (QPSK) modulation at an operating frequency of 2.4 GHz. The camera and the video transmitter provide a constant video stream down to the base station. This separates the video transmission from the control link which simplifies troubleshooting and ensures a constant video feed is always available.

The battery selected for the onboard system is a 2 cell Lithium Polymer battery capable of providing 3300 mAh at 7.4V. All components receive power from a linear regulator to provide a constant DC source. Four linear regulators were used in parallel to handle the amount of current being sourced to all the onboard devices. Both servo-motors, the Mega 2650, and the video transmitter all used their own regulator.

The primary goal of the Arduino Mega 2650 was to control the camera's position and perform the automatic control compensation. The manual controls are received from the XBee Pro 900 as a digital signal and sent to the Arduino to decipher how much change was sent in the X and Y directions. After the signal was decoded the Arduino adjusted the servo motors to make the appropriate adjustments and move the camera. Encoding the onboard Arduino to account for the manual controls was fairly straight forward with an iterative coding approach to ensure each section performed its specific task. To create an automatic control compensation system the Arduino interfaces with a two axis gyroscope to acquire rate of change with respect to roll and yaw. The gyroscope interfaced with the Mega 2650 using I2C communications. Registry values in the ITG-3200 gyroscope contained rates of change for each of the 3-axis were sent to the Arduino Mega2560. The following shows a pseudo flow for the program:

1. Each axis value was sampled every 15 milliseconds.
2. A simple arithmetic conversion was made to turn the value to a degree rate of change.
3. The acquired degree rate of change was then integrated by multiplying it with the sample time (Riemann sum integration)
4. The degree displacement was then written to the respective servo (pan or tilt) for compensation
5. Loop back

The XBee Pro 900 transceiver has the capability of receiving the manual control signals and sending data at the same time. While this version of the design did not implement data transmission from the UAV to the ground station, the design was intentionally left open for transmission. Valuable data like GPS, telemetry, or other can easily be integrated with this system thus adding value to a customizable application. A detailed block diagram is shown below in Figure 2, showing all components and interconnects of the on board subsystem.

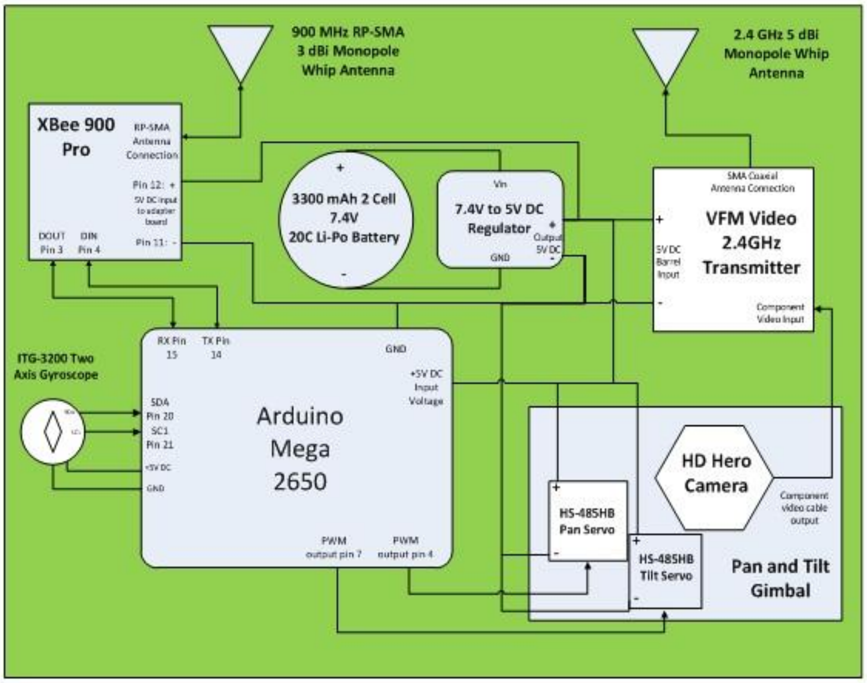

Figure 2: Level 2 block diagram of on board system.

3.3 TRANSMISSION SUBSYTEM

The video transmitter sends the video signal wirelessly at a center frequency of 2.4 GHz across four 20 MHz bands. Each band is changed dynamically through frequency hopping spread spectrum which helps reduce interference with other 2.4GHz signals. The modulation technique of our digital video transmitter is Quadrature Phase Shift Keying (QPSK) which further helps reduce signal interference. Implementing QPSK modulation utilizes the channel bands more efficiently and can allow for higher data transfer rates. The transmitter is directly connected to the camera via component video cable. This transmitter pairs with a receiver on the ground station to complete the video transmission link. Both the transmitter and receiver come with stock 5 dBi omni-directional antennas; however an 18 dBi helical antenna was designed for the receiver to increase the range of the system. Without this custom antenna the operating distance would have been limited to 500 feet and greatly reduce the functionality of the system. The XBee Pro 900 was chosen as the on board transceiver, which receives control data from the ground station and has the capability to transmit data back to the ground station. Another XBee Pro 900 completes the data transmission pair at the ground station. Both of the XBee transceivers use 3 dBi omni-directional antennas. To determine the physical distance the communication links will work the Friis Transmission equation must be satisfied. Equation 1 is the logarithmic Friis Transmission equation.

$$P_{RX} = P_{TX} + G_{TX} - L_{TX} - L_{FS} - L_M + G_{RX} - L_{RX} \quad (1)$$

Using equation 1, specifications from the components, and imposing a minimum overlap margin of 15 dB the maximum theoretical distance for the 2.4GHz video transmission link is 1.35 miles. This exceeds our initial operating distance of one mile from initial panning estimations. To ensure this distance is met, a custom antenna was designed and built. A helical end-fire antenna was designed to produce the necessary forward gain while not limiting the operating view. Figure 3 is the custom built helical antenna. The research and design of this antenna was prepared prior to a final design review.

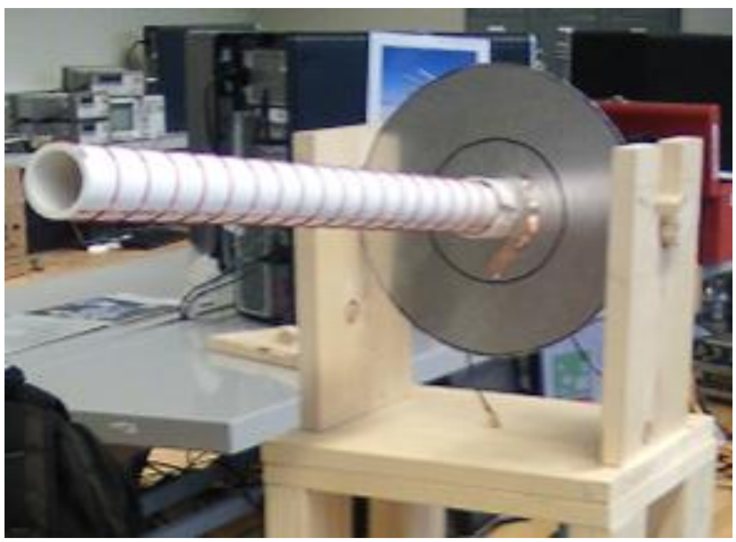

Figure 3: 18 dBi helical receiver antenna.

The Helix antenna required large forward gain, wide beam width, and could be built out of available parts. The antenna's design was calculated to have 20 turns and be 600 mm long with a large reflecting backplane. This antenna ensures the 2.4 GHz video link has sufficient overlap margin at the operating range the UAV will be flying at. While the helix antenna does have 18 dBi of gain, there is a polarization loss of 3 dB due to the circular polarization of the helix and vertical polarization of the onboard antenna. The loss is accounted for in the link budget calculations and an acceptable loss due to the overall gain of the transmission link. Researching and designing a key component that will drastically improve the system is very rewarding. This has been one of the best rewards of this project; applying a new concept to improve functionality. Researching, learning, and designing the helical antenna to our specific requirements was difficult. Many parameters were accounted for to ensure the correct operating frequency, gain, beam width, and frequency response. These challenges were met with proper design planning.

The data link between the XBee Pro 900 transceivers was calculated using the Friis transmission equation and by imposing a 15 dB overlap margin. The maximum theoretical distance with these impositions is calculated to be 2 miles. This link will easily remain constant at a one mile maximum flight distance.

3.4 BASE STATION SUBSYSTEM

The base station, or ground station, subsystem is comprised of only a few components. First is the power supply; a 7.4V, 2100 mAh battery that is regulated to 5V and 3.3V with linear power regulators. The next component is the Arduino Mega 2650 microcontroller. The purpose of the ground station microcontroller is to interpret data from the joystick and send the information to the on board subsystem via the control uplink. As previously mentioned, this uplink is created by two XBee Pro 900 transceivers operating at 900 MHz.

The joystick functioned as a 2 axis potentiometer (left-right, up-down), with movement of the joystick determining a voltage value (between 0V to 5V) sampled by the Mega 2650. Simple comparisons were made to determine if the voltage was above or below a specific value, which corresponded to position on the joystick. After determining the position of the joystick, the microcontroller sent corresponding data to the XBee to be transmitted to the onboard unit.

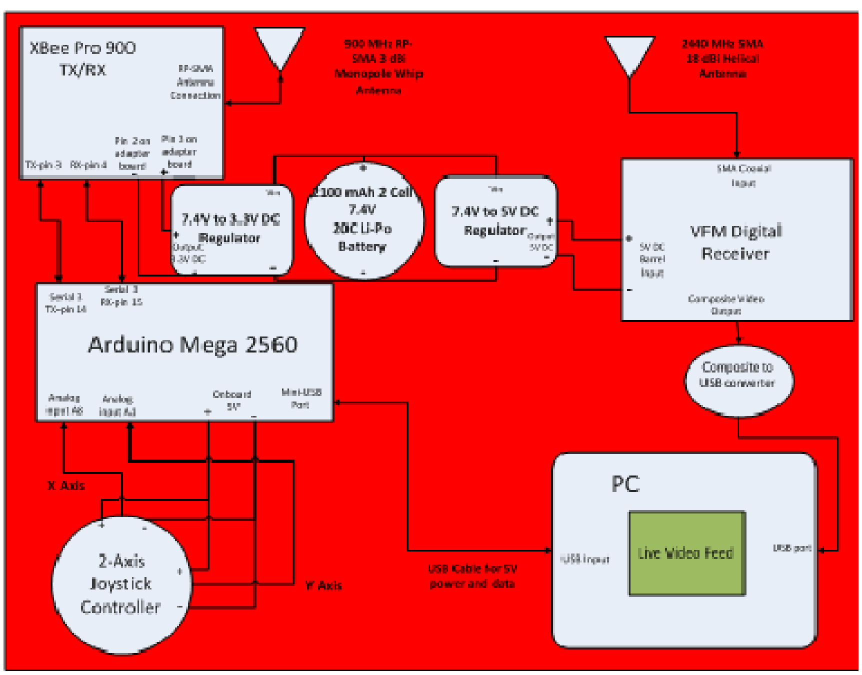

Figure 4: Level 2 block diagram of ground station subsystem.

The ground station also includes the video display system, a laptop PC was used. The helical antenna is connected to the video receiver with SMA connectors and a coaxial cable, and the video receiver output is a standard component video signal. Using a simple component-to-USB converter the video receiver easily connects to any computer. Future iterations will implement automatic tracking software on a computer; while this was not implemented in our design, we designed our system to be open to incorporate revisions and upgrades. By designing with the intention to be expanded upon, the system becomes flexible and adaptable to many applications. Figure 4 is a detailed block diagram, indicating all components and connections for the ground station subsystem.

With the components and interconnections established all that remains is building the physical packages.

4. RESULTS

With very careful planning established, purchasing the components was an easy task. Every component was already accounted for and specifications were cross referenced to ensure each part performed its selected task. The total cost of this project came to $1,176, coming in just under the established $1,200 budget. All the components selected were chosen in particular due to their availability to the average consumer; no parts were purchased exclusively or required any additional purchasing power (i.e. government clearance or credentials).

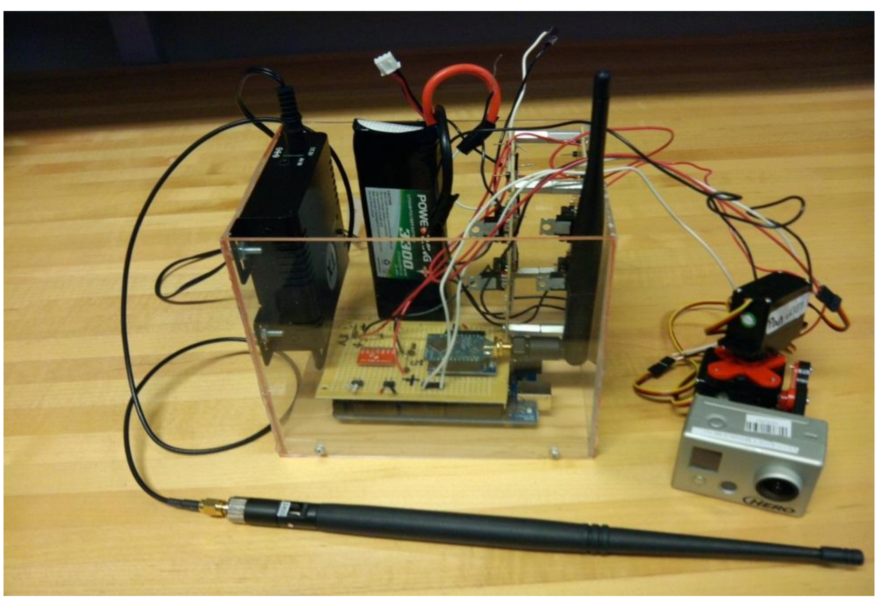

Figure 5: On board subsystem physical package.

Figure 5 shows the physical onboard package that contains the onboard components and wiring all enclosed in a plexiglass box. The box served as a size constraint reference as well as multiple walls to mount the devices too. A base station was constructed using a 12 inch square piece of wood one inch thick. With the base all the components are screwed into place to have a secure home.

The onboard subsystem was tested in two ways: the first was to ensure the camera and video transmitter were providing a constant video stream and the second was to ensure the sensor, XBee, and Arduino were working together. The video transmitter was easily tested using DC power supplies and transmitted video immediately upon receiving the components. The XBee's and sensors were tested by implementing each individually to ensure they were working before combining them both physically and within the Arduino software.

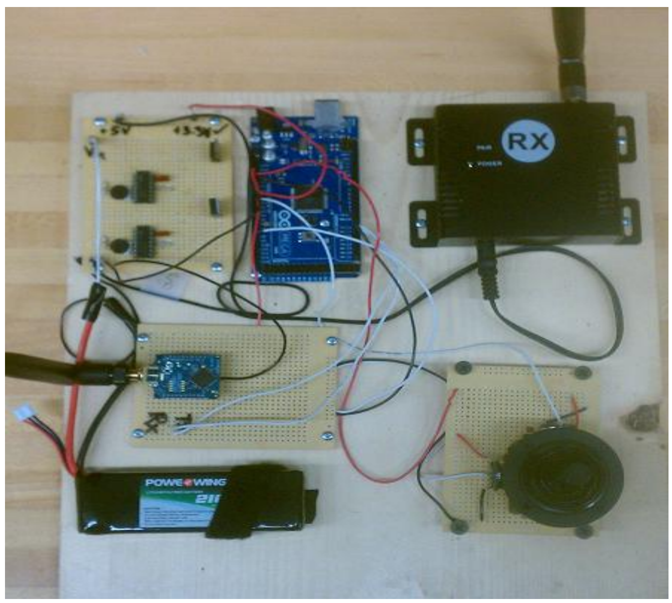

Figure 8: The base station package.

The base station was tested similar to the onboard by splitting up the video reception and the data link. The video reception and output to a PC was tested independently of the joystick, XBee, and Arduino. To ensure the manual control was being sent wirelessly to the onboard station the joystick was integrated with the Arduino first and then the XBee was added to transmit the movements. By ensuring each part of the design worked before the subsystem was complete; the final design testing became much easier to troubleshoot and setup.

A range test was performed with two 7 dBi monopole antennas for the video transmission link and a distance of over a ¼ mile was achieved with direct line of sight. With the 18 dBi helical antenna, distances over 1 mile can be easily attained with direct line of sight. Since the 900 MHz data signal can be transmitted farther than the 2.4 GHz video signal, only the video system was tested for range to ensure the limiting wavelength could withstand long range distances.

5 CONCLUSION AND RECOMMENDATIONS

Overall the project was a success, as each primary objective (manual control, automatic compensation, and live video) were achieved. Through careful planning and research each objective was established as a milestone and precise execution was required to surpass them. Planning in advance gave clarity to the entire design process and gave structure for direction.

The results of testing verified that all the primary objectives in the design were achieved. Manual tracking with a joystick ensures a UAV can easily monitor an object while flying. The automatic control system was engineered to provide a smooth but responsive correction to the UAV's flight dynamics. The custom built helical antenna guarantees the video transmission link will work at a distance of one mile. The budget costs were minimized by careful component selection and through building what could have been bought. The system was designed to be versatile and welcome future upgrades.

One main goal of the project is to keep the project open-ended for further advancement. Listed below are a few suggestions for improving on our design:

- Custom milled circuit boards
- Improve upon power regulation
- Lighter weight components
- Better video resolution
- Camera capable of zooming in on target
- Automatic control of position for base station receiver antenna
- More robust packaging for onboard and base station
- Smaller physical package
- Implementation of auto-tracking software
- Secure transmitting frequencies and encode/decode data
- Integration with Auto-Pilot to adapt flight pattern

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