Unmanned Aerial Vehicle with Autonomous Control Capability

E90 Senior Design Project Proposal
Department of Engineering
Swarthmore College

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Abstract

The goal of this project is to design and build an autonomous flight control system for a scaled model unmanned aerial vehicle. The system would essentially be an autopilot that would fly the airplane on a preset course. The objectives of the project will be to establish a sturdy radio frequency data link between a ground station and the aircraft and to allow the microcontroller to control servo motors which in turn will steer the aircraft via push rods to the control surfaces. This system is meant to be used alongside the typical RC manual control system. We will have to build a switch to disengage the aircraft from manual control to autonomous and vice versa. This will involve simply overriding the inputs to the onboard signal decoder for each required case. Initial testing of the airplane's control system will take place on the bench top by observing the movement of the control surfaces such as the ailerons and rudder. A second test will later be done with actual flight after a sturdy data link is implemented. Autonomous flight testing will be the last task in this project. Additional minor projects may include a rudimentary on board camera with a cockpit view to make manual control of the aircraft easier. The overall project will involve significant control theory and communication systems theory.

Figure 1 – Scaled Model of the United States Air Force (hunter/killer) MQ-9 Reaper UAV

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Introduction

Unmanned aerial vehicles are becoming highly utilized by search and rescue teams, the military and other branches of law enforcement. This is a result of its relatively low human and collateral costs, long mission endurance and increased terrain accessibility. Autonomous aircraft technology is still a highly researched field, and while relatively simple systems already exist such as in commercial aircraft autopilots, the capability of the system to adjust to certain changes such as in dynamic path planning remains quite difficult to build.

The purpose of this project is to design a simple autonomous control system for a scaled model UAV or radio controlled hobby airplane. Our objectives are very rudimentary and will be described later. Furthermore, the system we plan to implement will work alongside the standard manual control transmitter which comes as a standard accessory with the model airplane kit.

The remainder of this proposal provides detailed discussion of this project and is organized into the following sections: Technical Discussion, Project Plan, Critical Path Method, Project Qualifications and Project Cost. The technical discussion highlights the tools and technology that is required to develop and build the communications and control system; the project plan presents the tasks to be accomplished and the timeframe within which to complete them; the qualifications section discussed the reasons why we are qualified to do this project and finally the project cost section will present the project budget.

Technical Discussion

System Overview:

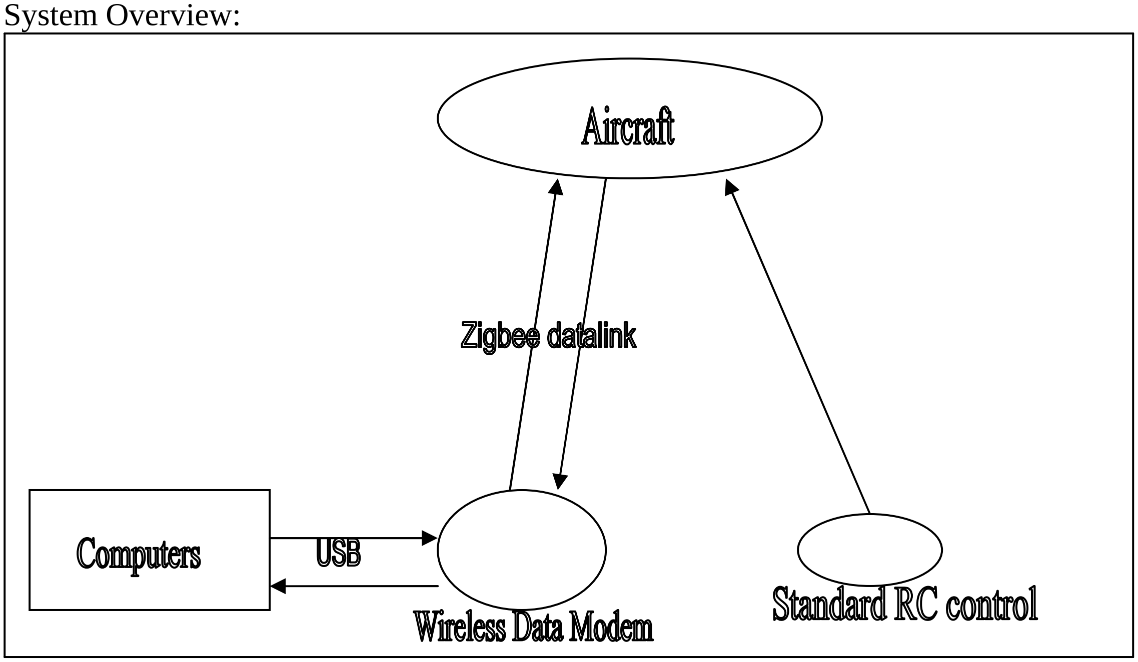

Figure 2 – Overview of Communications System

Main Objectives

The 3 main objectives of this project will be as follows (in autonomous operation):

1) Maintaining level flight
2) Executing controlled changes in altitude
3) Executing controlled inflight turns

Communication and Physical Control

We are going to design a complete system of hardware and software for autonomous flight as well as complete ground station for task planning and flight monitoring using a bi-directional data link for telemetry and control. The ground control will receive telemetry through the ground-based wireless Zigbee modem.

The planned system will include 2 main communication systems
1) Zigbee based Communications System with Ground Station
2) Standard Shipped Manual Radio Control Link

Zigbee Datalink
This involves using a bidirectional wireless modem which supports both telemetry (downlink) and telecontrol (uplink). This datalink will enable flight parameters to be available in real time and allow full control of the aircraft from the ground station. We plan to use one of each of the following modems to implement the datalink.

1) XBee-PRO™ Zigbee/802.15.4 USB RF Modem
2) XBee-PRO™ ZigBee OEM Module

The flight data to be communicated via the data link is as follows:
1) Pitch
2) Roll
3) Yaw
4) Altitude
5) Heading

Standard Manual Radio Control Link
The avionics and ground station setup will support the typical RF connection between the aircraft and a standard radio-control transmitter. While this link is not required for actual autonomous flights, it is usually considered to be an important safety control in the case of failure of the flight computer.

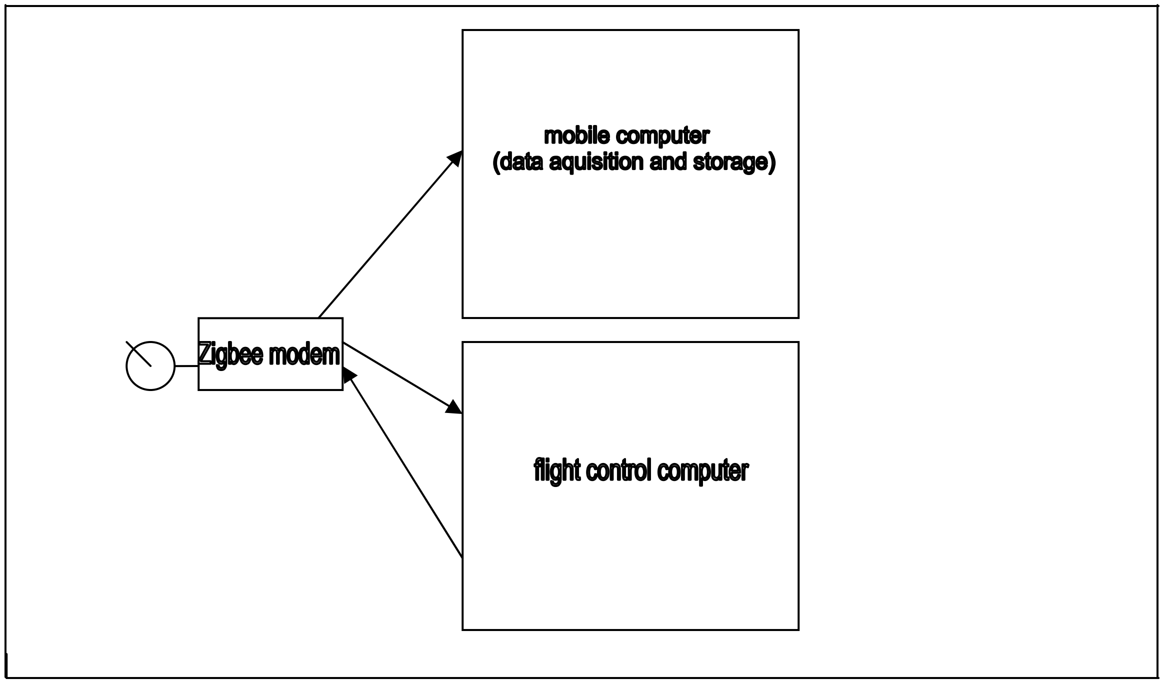

Figure 3 – Ground Station Flight Computer and Peripherals Outline Showing Data Paths

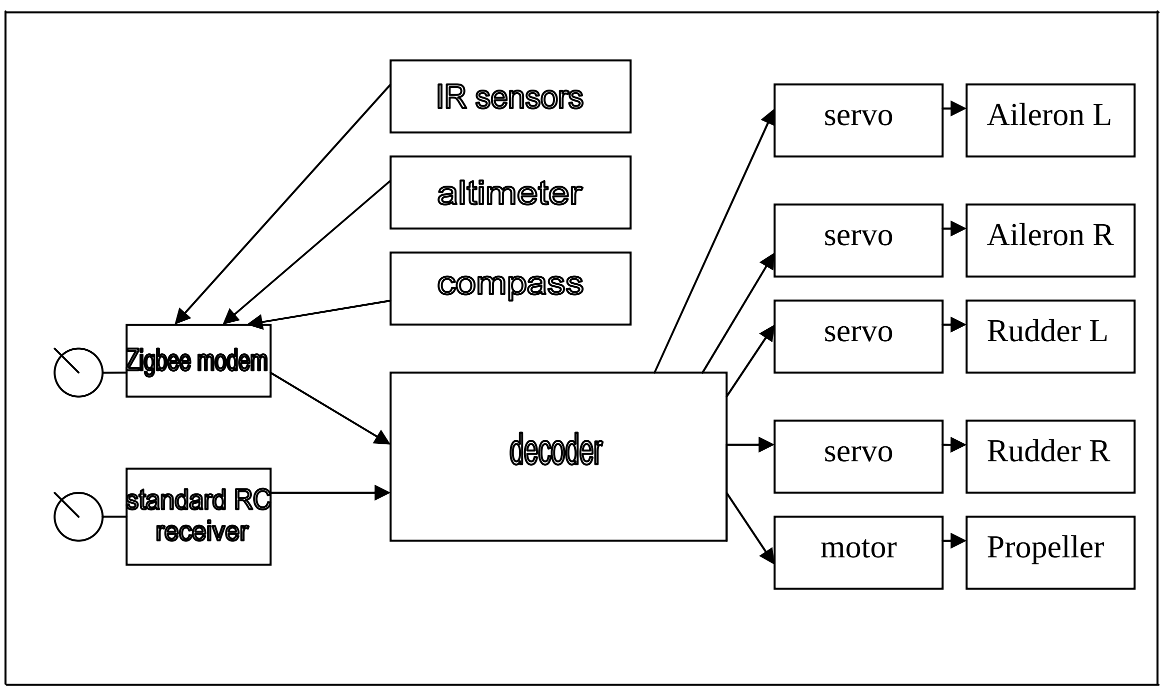

Figure 4 – Outline of Path from RF Link to Control Surfaces Onboard Aircraft

Main Avionics Components

Sensors
The avionics sensors will include:
1) Infrared sensors for flight stability.
2) A barometer to measure altitude.
3) A compass for heading information.

Communications
The airborne hardware will include the following communications devices:
1) Zigbee Radio Modem for datalink for telemetry and telecontrol.
2) Traditional RC Receiver for manual control.

Airborne control system components
For manual and autonomous control, the onboard hardware will include:
1) Standard RC receiver
2) Zigbee receiver
3) Signal decoder
4) Servos and motor controller

Ground Station Components

Grounded (flight control) Computer: We may use either of the Atmel AVR or Philips ARM7 LPC micro-controllers or any suitable substitute. These boards include one or two microcontrollers and the required connectors to handle the servos, motor controllers, sensors, RC receiver, radio modem, and a variety of payloads. The autopilot code will be written in C and will be derived from the PID control models in MATLAB and Simulink. The code will then be downloaded to the flight computer. Having capability for manual and autonomous control of the airplane will require some device to switch between the two options. Consequently we will use potentiometers to switch between manual and autonomous control of the aircraft. Some literal system identification will have to be performed with regards to switching input of the decoder (on the aircraft) between that of the standard RC link and the Zigbee system.

Ground Station Software: Time permitting, we will develop a GUI to control and interact with the UAV during flight.

System Identification - Control System Modeling

The autonomous control of the aircraft will require controllers for each of the pitch, roll and yaw attitudes. A PID controller will have to be designed for each. From the PID models, we will be able to derive transfer functions for each of the three required subsystems.

We have already begun research into the possible state space equations for the control systems. For example of a generic pitch attitude controller, the state space equations can be represented as follows:

$$\begin{bmatrix} \Delta \dot{w} \\ \Delta \dot{q} \end{bmatrix} = \begin{bmatrix} \frac{Z_w}{m} & u_o \\ \frac{1}{I_y}\left[M_w + M_{\dot{w}} \frac{Z_w}{m} \right] & \frac{1}{I_y}\left[M_q + M_{\dot{w}} u_o \right] \end{bmatrix} \begin{bmatrix} \Delta w \\ \Delta q \end{bmatrix} + \begin{bmatrix} \frac{Z_{\delta_e}}{m} \\ \frac{1}{I_y}\left[M_{\delta_e} + M_{\dot{w}} \frac{Z_{\delta_e}}{m} \right] \end{bmatrix} \left[\Delta \delta_e \right]$$

Figure 5: State-Space Matrices For Short Period Motion

$$\begin{bmatrix} \Delta \dot{u} \\ \Delta \dot{w} \\ 0 \\ \Delta \dot{\theta} \end{bmatrix} = \begin{bmatrix} \frac{X_u}{m} & \frac{X_w}{m} & 0 & -g \\ \frac{Z_u}{m} & \frac{Z_w}{m} & u_o & 0 \\ \frac{M_u}{I_y} & \frac{M_w}{I_y} & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} \Delta u \\ \Delta w \\ \Delta q \\ \Delta \theta \end{bmatrix} + \begin{bmatrix} \frac{X_{\delta_e}}{m} \\ \frac{Z_{\delta_e}}{m} \\ \frac{M_{\delta_e}}{I_y} \\ 0 \end{bmatrix} \left[\Delta \delta_e \right]$$

Figure 6: State-Space Matrices for Long Period Motion

Similar systems will have to be developed for the roll and yaw attitudes and some of the parameters of the system will ultimately have to come from actual flight testing of the aircraft.

Project Plan

List of Tasks

Preliminary Tasks: (Fall 2007)
Task A: *Research UAV autonomous control and communication systems*
Task B: *Determine materials needed for projects*
Task C: *Order the agreed upon materials for the project*

<u>Main Tasks</u>: (Spring 2008)

Task D: *Ground test of aircraft's control surfaces*

Task E: *Air-Ground Zigbee data link implementation*

Task F: *Control System Identification and MATLAB/Simulink F-14 control demo*

Task G: *Programming the microcontroller*

Task H: *PCB Design*

Task I: *PCB Manufacture*

Task J: *Mechanical assembly*

Task K: *Bench testing*

Task L: *Flight testing*

Task M: *Presentation and report write up*

Task	**Needs**	**Feeds**	**Duration**	**Effort (hrs/week)**
A	-	B	3wks	10
B	A	C	2wks	8
C	B	D	1wk	3
D	-	F	1d	2
E	A	F	4wks	30
F	A,E	-	5wks	15
M	E,F	-	1wk	10

Table 1 – Summary of Required Tasks, Their Duration, and Effort Needed

Tasks G through L will be undertaken time permitting.

Critical Path Method

Project Duration - Jan 21st 2008 – May 8th 2008 (excluding March 7th -15th) – 14 Weeks

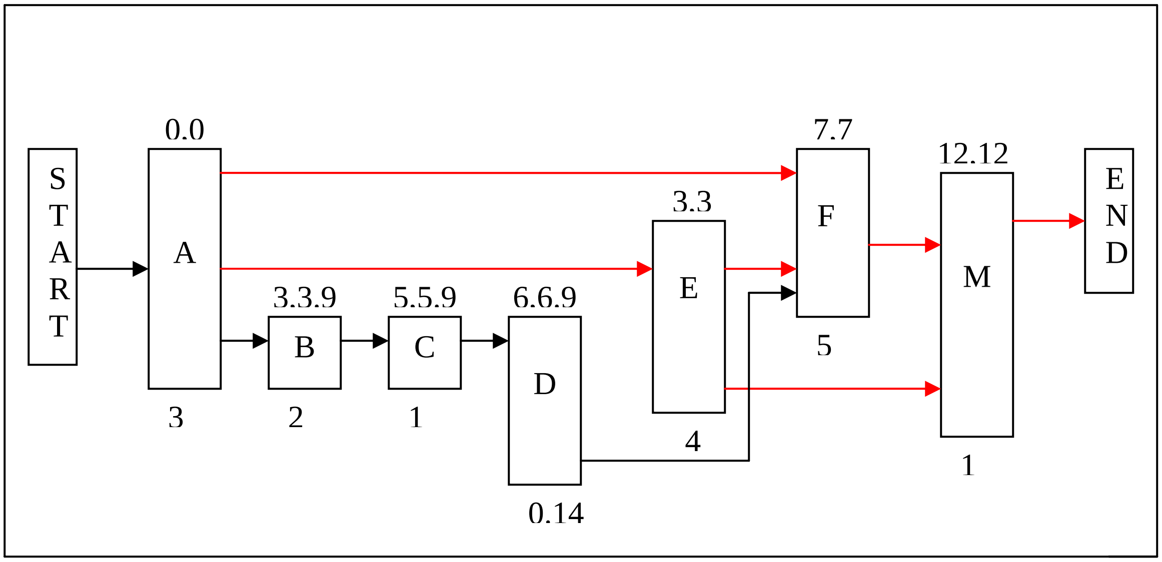

Figure 7 - A CPM Diagram for Our Project. The Critical Path(s) is Shown in Red.

GANTT Chart

sk Name	Days	Start	Finish
Engineering Phase	**136**	**11/1/07**	**5/8/08**
Research UAV systems	16	11/1/07	11/22/07
Determine materials needed for projects	11	11/22/07	12/6/07
Order the agreed upon materials for the project	7	12/6/07	12/14/07
Ground test of aircraft's control surfaces	2	1/22/08	1/23/08
Air-Ground Zigbee data link implementation	28	1/23/08	2/29/08
Control System Identification	35	2/29/08	4/17/08
Presentation and report write up	5	5/2/08	5/8/08

Figure 8 – A GANTT Chart For Our Project

Project Qualifications

As senior engineering students at Swarthmore College, we have taken and participated in many relevant courses, projects, and labs that would help in developing this aircraft control system. We have background in Control Systems, Electronic Circuit Applications and Communications Systems Theory that would allow us to gain substantial ground in the task. Also, Paul's coursework on Digital Systems Design and Tristan's work on embedded systems would assist in use of the microcontroller which would be the core of the autopilot for the aircraft.

Additionally, we have acquired significant experience with various computer software programs such as MatLab and Multisim. This software will certainly be used during this project, especially in simulating the aircraft's feedback control system and laying out a PCB for microcontroller integration. With regards to the air-ground communications system, we plan to reference the work done in the 2005 E90 Senior Design Project by B. Park and S. Realov on a ZigBee based wireless network.

Finally, Tristan has adequate flight experience from his semester abroad in Fall 2006 in Adelaide, Australia where he spent significant time training in Polish made Puchatek and German made Bergfalk glider aircraft and had a brief introduction to Cessna turboprop aircraft.

Project Costs

Item	**Cost**
Model Aircraft kit	$90.00
Microcontroller	$10.00
DC motor	$30.00
Altimeter (barometer)	$40.00
Battery	$25.00
Micro servos	$5.00 each
XBee USB Ground Modem	$109.00
XBee Air Modem	$32.00
Infrared sensors	$50.00
PCB	$50.00
4 Channel Standard RC Transmitter	$45.00
Total	**~ $500.00**

Table 2 – Bill of Materials. This Caters For Possible Extensions To The Project.

References

[1] B.Park, S. Realov, Solar *Powered Wireless Sensor Network*, E90 Final Project, Swarthmore College. May 4, 2006.
http://engin/academics/courses/e90/2005_6/E90Reports/BP_SR_Final.pdf

[2] UAV Flight Test Programs at Georgia Tech
http://www.ae.gatech.edu/people/ejohnson/uav2004_ftest.pdf

[3] UVS CANADA – UAV COMPETITION
http://pages.cpsc.ucalgary.ca/~hanlen/uav/UAVcompetition_phaseI.pdf

Appendices

XBee-PRO™ Zigbee/802.15.4 USB RF Modem

http://www.maxstream.net/products/xbee/xbee-pro-pkg-u-modem-zigbee.php

XBee-PRO™ ZigBee OEM Module
http://www.maxstream.net/products/xbee/xbee-pro-oem-rf-module-zigbee.php

RC Model Kit
http://www.nitroplanes.com/4eluavrqprra.html