Development of a Digital Flight Data Recorder/Controller System for a Radio-Controlled Helicopter

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Abstract

A digital flight data recorder/controller system for a radio-controlled helicopter has been built to demonstrate the basic requirements necessary to build a flight control system. The system utilizes the standard radio control system augmented with an extra micro controller and other circuitry to utilize rate gyro feedback in the control loop. The system is able to record flight data, perform programmed flight maneuvers such as frequency sweeps, and record flight data. The data that has been recorded can be now be used to develop a closed loop control system.

Introduction

A radio controlled (RC) helicopter is one of the most difficult hobbies to master. It is a very complicated machine with many control actuators. It has a complicated model of motion. The control inputs are coupled with one another. How could one be made easier to fly? Add a stability augmentation flight control system! This would require some electronics able to use the radio to servo control signal to sense the pilot input and the rate gyro feedback signal to generate a control signal that will control the helicopter in such a way that the motion of the helicopter will match the pilot's input. Since the motion of a helicopter is very difficult to analyze, the system would be designed so that it could record flight data, which is used to identify the system. Since the electronics recording the flight data would be in the loop of control (without altering the control signal, just passing it through), the dynamics of the controller would be included in the identification, which would lessen the chances of a system adding an adverse effect to the plant. Once the data is gathered, it can be analyzed to identify the plant, and a control law can be put into the control system to stabilize the helicopter.

With a system like this built, it can be used in many ways to enhance the learning process at Cal Poly: Some of the uses include demonstrating the effects of changing the control gains, performing lab exercises to design a control system with the given architecture, or adding even more functionality. Since it was designed for expandability, adding more functionality or even hardware would be a relatively simple process. More sensors, such as accelerometers, level indicators, or possibly a GPS receiver (weight permitting) could be connected to the hardware. Also, the firmware could be modified to add functionality, change the control laws, or a variety of other applications.

System Description

The project began with a standard radio controlled helicopter, which included a gas engine and radio controller. Several pieces of hardware were needed for the control system: rate feedback devices, control system electronics, input/output devices, and mounting hardware. The choice for the feedback devices was made simpler because most of today's RC helicopters come equipped with a rate gyro to help control the yaw of the helicopter, which is very tightly coupled to the power setting. The yaw gyro, developed by the radio manufacturer, was developed to sense the yaw motion and send a rudder servo command to stop the unwanted yaw motion. This same device was determined to be adequate for the roll and pitch feedback as well. This choice also made sense since the electronic interface was already existing, and the units are inexpensive, lightweight, and available. Two of these gyros were added for the roll and pitch feedback.

The main flight requirements on the electronics were forced by the existing radio electronics. The radio controller generated a Pulse Width Modulated (PWM) signal to control the position of the servos (control actuators), while the rate gyros generated an analog differential voltage signal. These two facts required a system that could interpret PWM and analog signals to generate a PWM signal. Also, the system needed to record flight data and have some means of downloading that to a personal computer (PC). These things pointed to the use of a micro controller, which has built in PWM generators, analog to digital converters (A/D) and serial communications capabilities. A micro controller also adds flexibility since it can be reprogrammed to change the functionality of the system. The Motorola MC68HC711K4 (K4) micro controller chip was chosen to meet these needs. The K4 has two 16-bit PWM generators, an 8-bit A/D, serial communications lines, 24K bytes of EPROM (electrically programmable read only memory) storage, several I/O and address lines, and a Serial Peripheral Interface used to communicate at a high rate with the external 12-bit A/D for the analog feedback. The 12-bit A/D was added to system to have better resolution of the feedback signal. To prepare the signal for the A/D, there are a few stages of amplification and a low pass filter. The filter is a very important item, which is used to filter out any high frequency noise. The initial cut-off frequency was set at about 70 Hz, and the implications of this value will be discussed later in the Data Collection Section. The system also needed a way to store data collected in flight, so a 512K byte Static RAM (random access memory) chip was added. A static RAM chip was chosen since it can retain its contents with very low power consumption. Finally, a power supply was added which used battery power when the system was turned on, and switched to a capacitor to maintain the Static RAM's contents. There are also comparators and buffers for the PWM inputs and outputs and a serial line driver to interface with a PC via an RS232 connection.

This system also needs any easy to use interface to check internal parameters in the processor or activate different modes of operation. A keypad and LCD display were added to the system to allow the user to change settings and modes of operation quickly and easily. The keypad has eighteen keys and is similar to the number keypad on some computer keyboards. The LCD displays two lines of data with sixteen characters per line. Since these items would not be necessary in flight, they were assembled separately from the controller circuitry and simply plug in when needed. In addition to the hardware, firmware needed to be written to utilize the LCD and keypad to allow the user to change parameters and modes with the keypad.

Data Collection

With the electronics assembled and tested, the next phase of the project began: flight-testing. In order to identify the helicopter system, the firmware was written to provide a means to input a known control input into the system and record the response. Two types of inputs were chosen: step inputs, and sinusoids. The step inputs are necessary to calibrate the feedback signal level with the servo PWM signal. By comparing the feedback voltage recorded at steady state with a known input, the output to input ratio can be found and utilized in the closed loop control. The frequency sweeps are necessary to identify the dynamic response of the system.

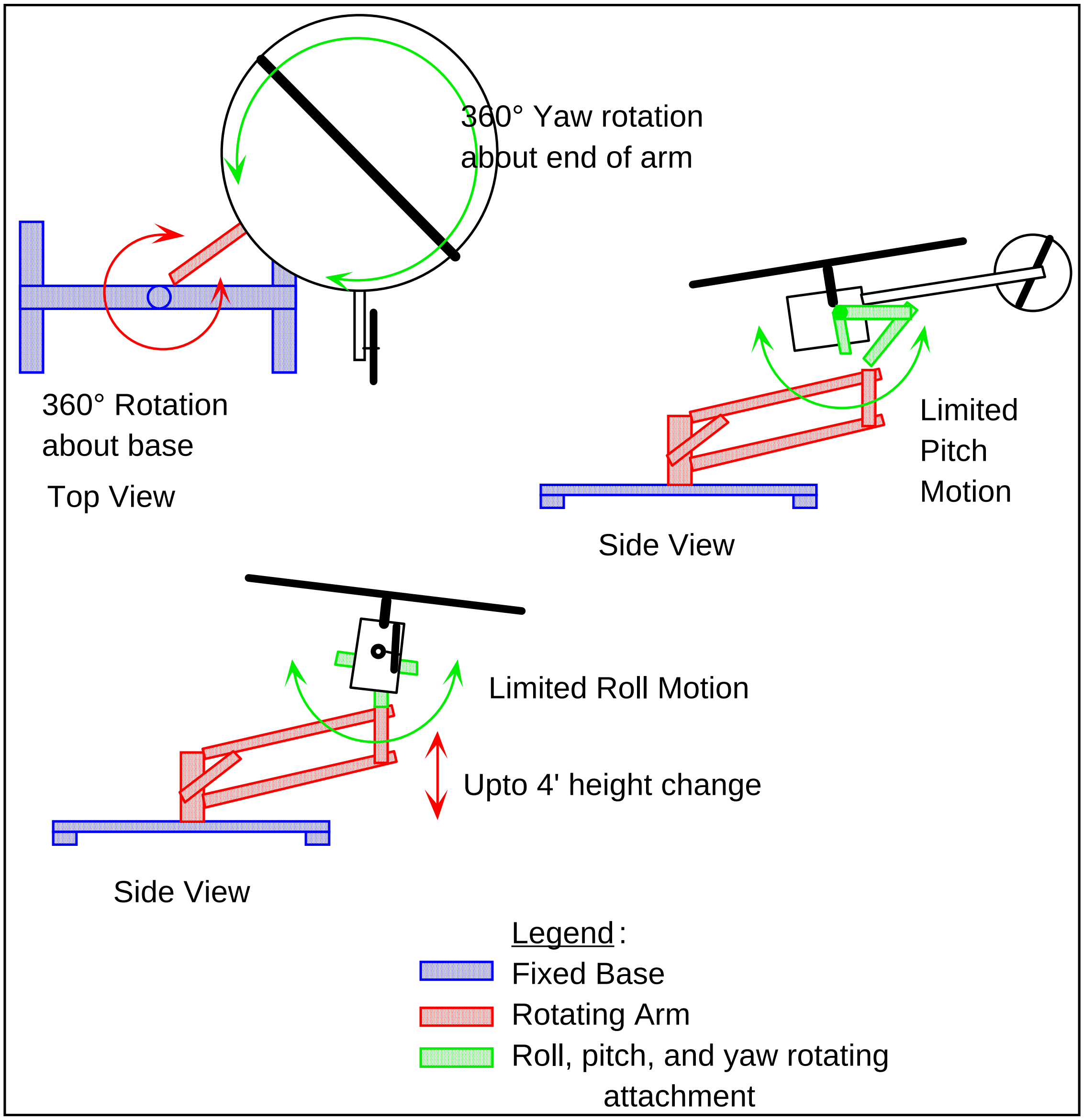
The steady state flight mode allows the user to output a precise step to the servo of a selected channel. The steps increase in size in 10% of maximum output incrementally by pilot control. Also, the pilot at startup defines the duration of the steps. The steps begin in one direction and increase to the maximum output, then start again in the opposite direction at 10% and work up to the maximum again.

In the frequency sweep flight mode, the micro controller generates a sinusoid output to the servo. The sinusoids begin at a low amplitude and frequency, approximately 1/8 of the maximum output and about 1/6 Hz. The pilot controls when the frequencies change. The frequencies are 1/6 Hz, 1/5 Hz, 1/4 Hz, 1/3 Hz, 1/2 Hz, 1 Hz, and 2 Hz. After the 2 Hz frequency has been reached, the cycle repeats with higher amplitude of about 1/4 of the maximum, then 1/2 of the maximum, and finally the maximum output.

For safety and repeatability, the flight tests were performed on a training stand. This stand allows the helicopter to roll, pitch, yaw, and translate forward and backward to some extent. See Figure 1. As can be seen in the figure, the translational motion is altered by the mechanics of the stand. For example, if the helicopter pitched forward while in the configuration shown in the top view, the helicopter would only translate forward until the arm of the stand was vertical (in the drawing). Also, the stand would cause the helicopter to move sideways.

The initial flight tests did not limit the motion of the helicopter any more than the normal limits on roll and pitch. However, as the tests proceeded, it was observed that the mechanics of the stand were affecting the true motion of the helicopter. A roll or pitch motion would cause translational motion laterally and longitudinally, as well as the entire assembly rotating around the base, which could show up in the rate feedback. It was determined that the stand must be fixed by setting two cinder blocks on either side of the arm and lashing it to the blocks with rope so that the arm cannot swing. This reduced the motion of the helicopter to pure roll, pitch and yaw.

After several tests were completed, the data was checked for validity. A plot of the roll step inputs was made showing the pilot's input (nothing), the signal to the servo (step inputs), and the rate feedback for roll, pitch, and yaw. The plot showed large amplitude, high frequency noise on the signal. See Figures 2-4.



The figures display data that was recorded at 35 Hz. It appears that there is a high frequency signal on the input. Notice that the high frequency noise exists regardless of pilot input or

Figure 1. Helicopter Training Stand

servo signal. The areas where the output is different from the pilot show the step generated automatically. The main cause of the noise is probably a slight rotor head imbalance because the noise has higher amplitude on the roll and pitch channels. Since the roll and pitch rate gyros are mounted at the top of the helicopter frame just aft of the rotor mast, they will pick up the oscillations caused by the imbalance. The yaw gyro is mounted near the center of the helicopter and is oriented to pick up the yaw motion, which would not be affected as strongly by a rotor imbalance.

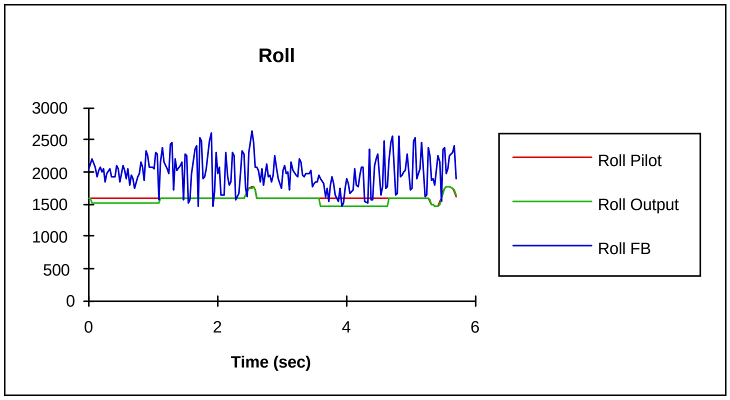


Figure 2. Roll Time Response Plot (70Hz filter corner frequency)

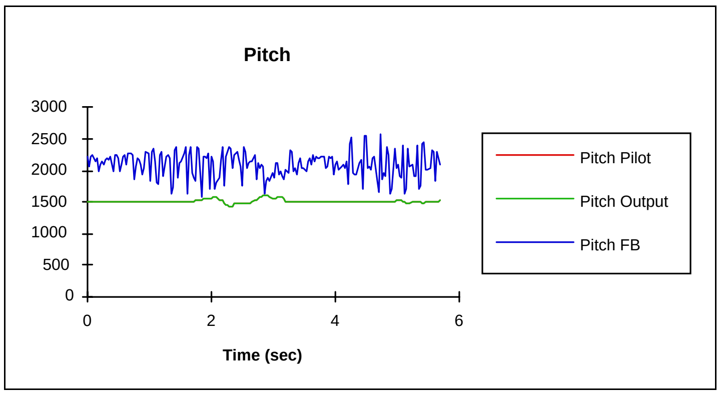


Figure 3. Pitch Time Response Plot (70Hz filter corner frequency)

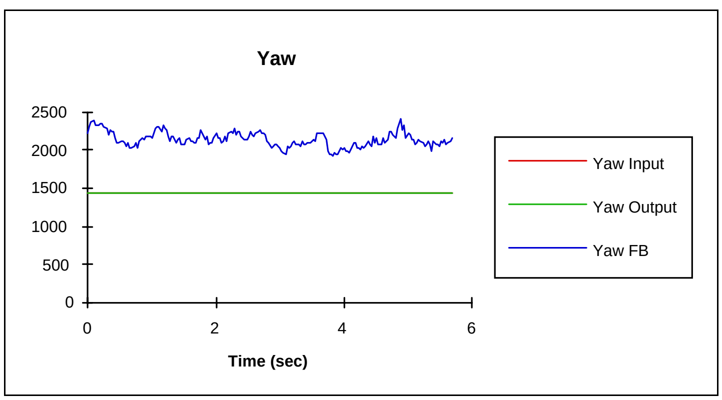


Figure 4. Yaw Time Response Plot (70Hz filter corner frequency)

By re-evaluating what frequency range is of interest, namely 1/4 to 2 Hz, it was determined that changing the cut off frequency of the low pass filter in the feedback loop could help alleviate the noise problem. Changing a capacitor on the circuit board changed the cut off frequency to about 10 Hz. 10 Hz was chosen according to a rule of thumb that states that you should sample at about 2 - 5 times the frequency range of interest to avoid aliasing. Also, the recording frequency was set to 23.3 Hz to be sure not to miss any important data (23.3 because it is a multiple of 70). See Figures 5-7 for the data showing the use of the new filter frequency.

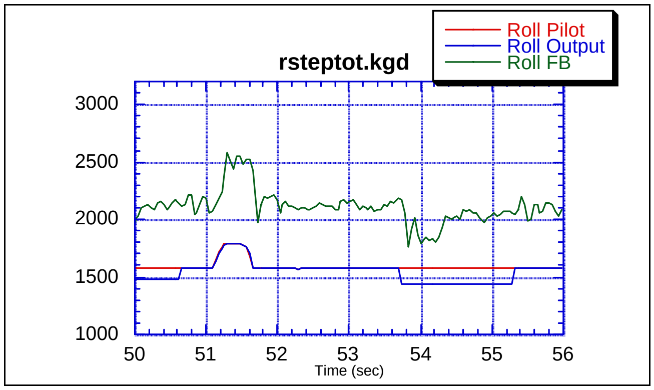


Figure 5. Roll Time Response Plot (10Hz filter corner frequency)

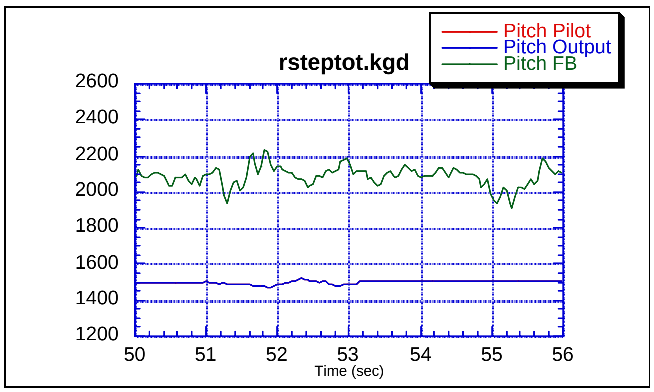


Figure 6. Pitch Time Response Plot (10Hz filter corner frequency)

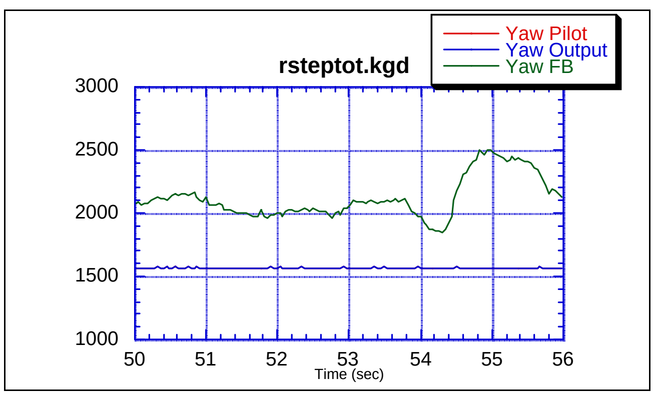


Figure 7. Yaw Time Response Plot (10Hz filter corner frequency)

With the noise problem fixed, the flight tests were repeated. After the first tests, the firmware was altered so that the frequency sweep algorithm would automatically increment the amplitude, which made the testing go much faster. The step input and frequency sweep tests were performed for roll, pitch and yaw.

Discussion and Results

The flight data clearly showed what the response of the helicopter is to certain inputs (Figures 4-7 are just a sampling of the data collected). A detailed analysis can now be performed to truly identify the system, which is left to another project. Following is a brief discussion of what can be seen in the data.

The step response data for all axes showed that the response is rapid and proportional to the input. As the steps are input, there is an instant spike in the feedback, which returns to the null point when the helicopter reached the mechanical stop of the stand. For the larger inputs, a small coupling effect between roll and pitch can be seen. It is hard to see in the plots, but it seems that the coupling occurs when the helicopter reached the mechanical stop, creating a sort of ‘bounce’. Something that seems very odd is the coupling of the roll step inputs with a yaw response. This also appears to be the helicopter yawing after is reaches the stops. For example, the helicopter rolls right, then being at that sharp bank angle, the moment arm of the tail pulls the tail down, causing the yaw. This effect is not observed in pitch because the yaw axis remains in the vertical plane as the helicopter pitches forward or aft. Since there is not a mechanical stop for the yaw axis, the step inputs resulted in saturating the rate gyros when yawing left. This is because of the torque created by the engine helps the helicopter yaw left, but opposes right yaws.

The frequency sweep data shows similar results. The roll and pitch data show only slightly diminished magnitude at the higher frequencies and a very slight phase lag, again only at the higher frequencies. Just about all of the inputs resulted in some coupling between roll and pitch. Any coupling with yaw was very erratic and could not be pinpointed to a specific cause. The yaw frequency sweeps are difficult to analyze. Because of the unbalanced control power, the helicopter would get into a high left yaw rate, which the right input could not overcome, but only at high amplitudes and high frequencies.

Conclusion

This project demonstrates a tool, which can be used to develop and test simple control architectures. It has demonstrated that data can be recorded from a radio-controlled helicopter, which can be used to analyze the system response. Also, with relative ease, students can implement a control law in the firmware and test fly their design. This system gives students the ability to test control systems and collect data from a dynamic platform, such as a radio controlled helicopter, in a safe, easy to use, environment.

Acknowledgement

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