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INTRODUCTION

Bio-inspired robots outperform traditional robotics technology in terms of effectiveness, efficiency, and adaptability[1]. Therefore, in recent years, the scientific community has been increasingly involved with research in autonomous systems inspired from entities found in nature. Robots that attempt to mimic the characteristics and behavior of snakes, insects, birds, etc. have been created and documented by researchers all over the world.

Among various types of bio-inspired robots, bird-inspired robots have been of maximum fascination to engineers and hobbyists. Robotic birds present a wide spectrum of applications ranging from search and rescue missions in case of natural calamities such as earthquake to aerial surveillance of a crime spot. Ease of maneuverability of birds also creates a possibility of robotic birds being applied to more efficient planets and space exploration missions.

University of Maryland has been an active participant in bird-inspired robotics research. A team of mechanical engineering students at the Manufacturing Automation Laboratory (MAL) led by Dominik Mueller has built two robotic birds under the supervision of Dr. S.K. Gupta. The birds, named the Small bird and the Big bird are currently navigated with a radio control system. Each bird has its own R/C receiver onboard, and an operator navigates the birds by moving the control sticks' positions on the R/C transmitter. Both the robotic birds have been successfully tested for flight stability under radio-controlled navigation environment. The main features of the birds are presented below[2]:

	Small Bird	Big Bird
Overall Weight	12.9 grams	35.0 grams
Payload Capacity	2.5 grams	12.0 grams
Flapping Frequency	12.1 Hz	4.5 Hz
Wing Area	260 sq. cm	691.7 sq. cm
Wing Span	34.3 cm	57.2 cm
Flight Duration	5 minutes	7 minutes
Flight Velocity	4.4 m/s	3.75 m/s

Dominik's team, driven by incentive for advancement in bird-inspired robotics research, aims at developing another flapping wing robot, which will be bigger than the big bird. Currently named the Jumbo bird, the objectives are autonomous navigation, communication of in-flight visual information of surroundings to ground, higher payload and flight duration compared to big bird.

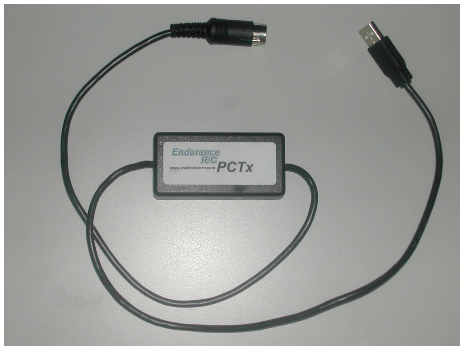
During my summer internship at the ISR, I was involved with research related to jumbo bird. As such, I had three major project goals that match closely with the objectives for jumbo bird. My first goal was to develop software for controlling jumbo bird's navigation from computer instead of an FM R/C transmitter. This goal had two levels. In the first level, I wanted to write a program for bird's navigation through keyboard inputs. In the second level, I wanted to develop an open loop program under control of which the bird would self-navigate with time, in some geometric path, which might be circular, triangular, or rectangular. My second goal was to develop a plan for a visual feedback system through which jumbo bird will be able to communicate the visual information of its in-flight surrounding, to the ground. My third project goal was to assemble electronics that would provide longer flight duration for the jumbo bird, compared to the big bird, which is 7 minutes.

APPROACH

Navigation from computer

A quick study of the R/C transmitter's inner circuit revealed that, control sticks on the transmitter are connected to analog potentiometers with three terminals (+,wiper,-). Changing position of the sticks causes a varying voltage between wiper and the - terminals. Consequently, Pulse Position Modulation (PPM) signal is encoded in transmitter's inner circuit board, and sent out to a compatible R/C receiver[3] that decodes the transmitted signal[4]. Analog potentiometers in an R/C transmitter can be replaced with digital potentiometers. The digital pots can also be integrated with the inner circuit board of the transmitter. Using a microcontroller, program can then be written to vary the wiper voltage in the digital potentiometer with respect to ground. Consequently, we can try to mimic the signal processing inside the transmitter from moving the control sticks, but this time the controls being from the computer.

An easier way for generating PPM signals was identified before I pursued the digital potentiometer approach. Endurance-RC has marketed a PC-to-transmitter interface hardware called PCTx[5]. PCTx connects to the computer via its USB port, and to a compatible R/C transmitter's trainer port via the trainer cable. The device sets up a one-directional communication link through which instructions can be sent from PC to the R/C transmitter, therefore making the transmitter programmable.



The Hardware

PC-Transmitter Connection

The path of PCTx was pursued for my project because of the inherent simplicity of the device. PCTx also seemed more achievable an approach for navigation control of Jumbo bird from computer, given the limited research period of 10 weeks, and two other major project goals that needed to be fulfilled.

Visual feedback system

Three wireless video cameras with their own transmitter and receiver were some possible options for Jumbo bird. The features of each of the cameras are presented below.

Option	Video Transmitter	Combined Mass	Camera Type
Camera 1	Built-in to the camera	9 grams	Color
Camera 2	Wire connection to camera	5 grams	B/W
Camera 3	Built-in to the camera	7 grams	Color

Given the mass, camera type, and price trade-offs associated with each of the identified options, it was decided that the second option camera would be the best choice for the Jumbo bird. The b/w camera is connected to its video transmitter with a short wire[6]. The camera system comes with its video receiver that decodes the signals transmitted from the video transmitter. The receiver is interfaced to the computer through a USB video capture device that allows for recording videos on the computer[7].

While the other two camera options have built-in transmitters, and are of color type, they are heavier compared to the b/w camera. Since mass is the biggest concern for us, b/w camera is acceptable as the first camera unit to go onboard the jumbo bird.

Longer flight duration

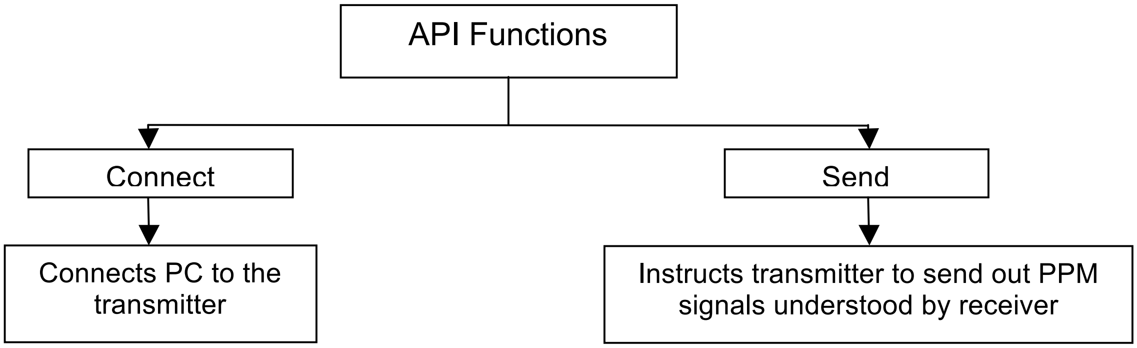
Big bird flies for about 7 minutes when powered by a 3.7V lithium-polymer battery. Therefore, for Jumbo bird to fly longer than 7 minutes, it would have to be powered by at least a 7.4V battery, depending on how much bigger compared to big bird the jumbo bird will be. Upgrading to 7.4V would mean that all or some of the other flight electronics might need to be upgraded too.

A 7.4V battery with current capacity of 300mAh is the best power choice for Jumbo bird[8]. The 13/6/11Y[9] brushless motor is compatible with input voltage in range of 3.7-11.1V, and provides six times larger thrust compared to the motor on big bird, when powered by 7.4V. The MPS VARBL3 Electronic Speed Controller (ESC) [10] accepts 7.4V input, and has a 5V Battery Eliminator Circuit (BEC) that regulates the input voltage down to 5V. Connecting the R/C receiver to the BEC terminals powers the receiver, therefore eliminating the need for a separate battery.

RESULTS AND DISCUSSION

Navigation from computer

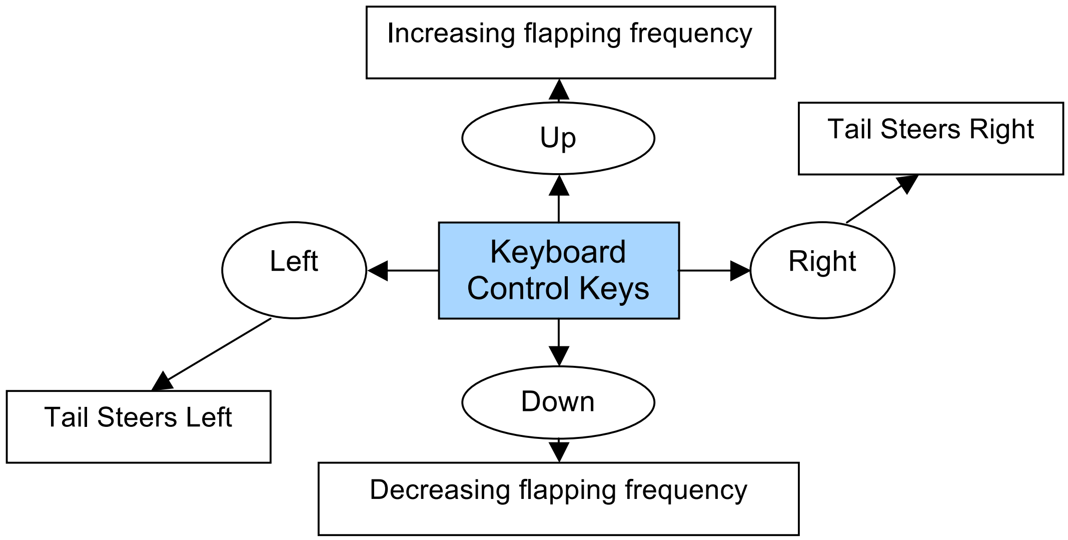
Endurance R/C, the seller of PCTx, provides Application Programming Interface (API) in C++ and Visual Basic, to be used for data communication through the PCTx interface. The C++ API was used for this project. The API consists of two major functions, Connect and Send.



Two separate programs incorporating the provided API were written. The first program is meant for navigation of jumbo bird through keyboard inputs. The second program is an open loop program, meant for self-navigation of jumbo bird with time.

Navigation through Keyboard Inputs

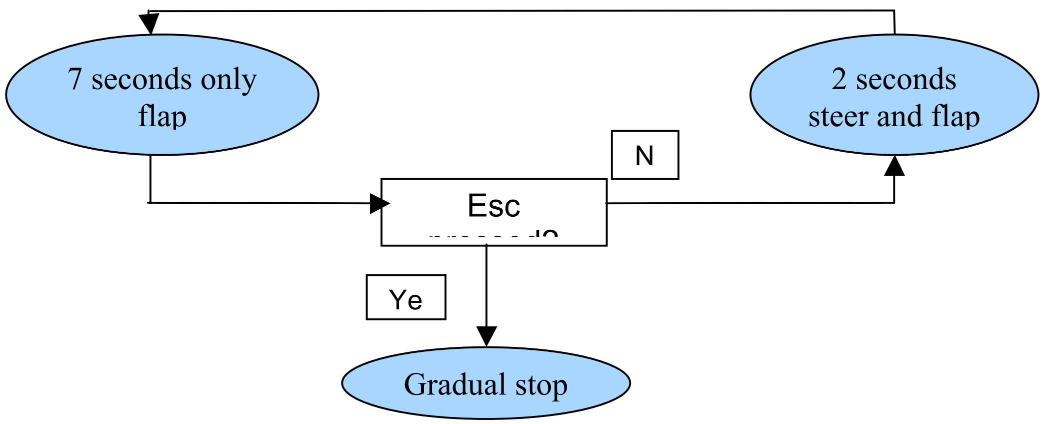
The program was tested on the big bird while it was clamped to the desk, to observe the flapping and steering responses of the bird. The keyboard controls for controlling flapping frequency are up and down arrow keys. Up arrow increases the flapping frequency and the down arrow decreases the flapping frequency. The controls for steering are left and right arrow keys. Left arrow is for steering to the left, and the right arrow for steering to the right. Escape (Esc) key ends the program, resulting in a gradual drop in flapping frequency to zero. While the keyboard is idle, the tail maintains its neutral position, and the flapping frequency from prior pressing of up or down arrow key is maintained. The keyboard controls can be easily modified in the program.



Quick research on flight dynamics, and observations of big bird's navigation under radio control revealed that flapping frequency is directly related to lift. With increasing flapping frequency, the bird climbs higher, and with decreasing frequency, the flight altitude decreases. Jumbo bird's flight can be navigated from keyboard only if its flapping frequency can be controlled from keyboard. Since keyboard control program was a success on the big bird, jumbo bird is also likely to demonstrate the same flapping and steering responses under keyboard control.

<u>Self-Navigation in Open Loop</u>

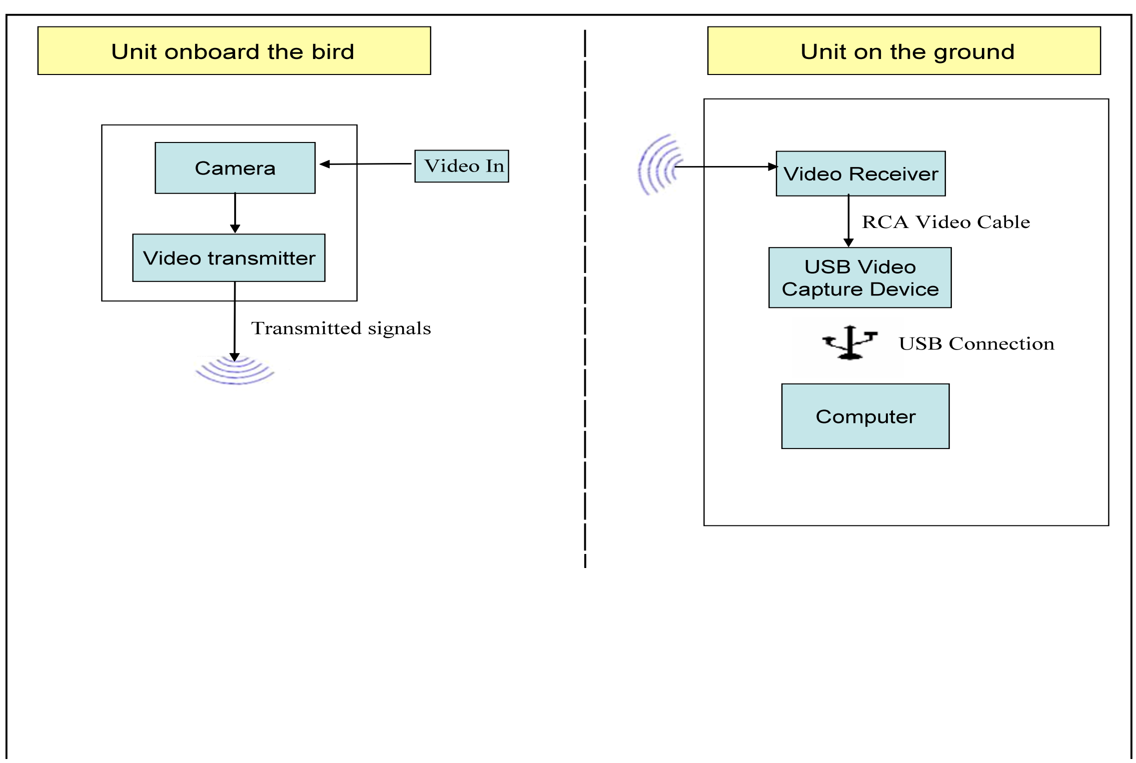
The open loop program was also tested on big bird, while it was clamped to the desk. While the program executes, wings flap at a constant frequency for 7 seconds. For the next 2 seconds, the tail steers to the right, while the constant flapping frequency is maintained. Pressing Escape (Esc) key ends the program, and the flapping frequency drops gradually to zero. The length of flapping and steering time and the constant flapping frequency can be adjusted in the program.



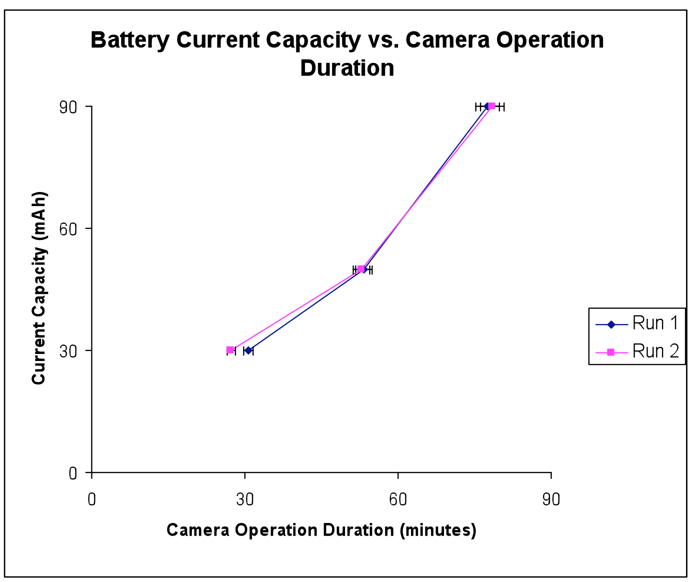
If the jumbo bird shows the same flapping and steering responses as the big bird, and is flown in an outdoor setting, it likely that the bird will fly in a rectangular path.

Visual feedback system

The visual feedback system was tested with the big bird's radio-navigated flight. The video transmitter transmits meaningful images of its surrounding, e.g. trees, cars on the street, buildings etc. The transmitted videos have been successfully saved to computer with the software Debut Express[11], and the video capture device's USB interface. The following shows a schematic layout of the overall operational visual feedback system.



The camera-transmitter unit to go onboard the jumbo bird requires an input voltage in the range of 6-12V DC. 7.4V lithium-polymer battery was our choice. Three 7.4V battery options were available, which had ratings of 30mAh, 50mAh, and 90mAh respectively. Mass of the onboard unit being our biggest concern, camera's demand for battery current capacity had to be determined, as battery mass is an increasing function of its current capacity. An experiment was therefore conducted with each of the three batteries, to determine the most suitable battery for the onboard feedback unit. Each of the batteries was fully charged, and the video camera was run on each battery until it was fully discharged. The shot video was recorded, and the operation duration of camera obtained from recording duration. Two such camera runs were done. The experiment results show that 30mAh battery is the best power source for the feedback unit given the current prediction that jumbo bird's flight time will not exceed 15 minutes.



Battery	Operation (minutes)	
	Run 1	Run 2
30mAh	30.7	27.3
50mAh	53.3	52.9
90mAh	77.6	78.4

From two runs, as presented above, the 30mAh battery provides on average, 29 minutes of camera operation. Similarly, 50mAh battery provides, on average, close to 53 minutes, and 90mAh battery provides about 78 minutes of camera operation

Poor image quality has been a major problem associated with the visual feedback system. One of the reasons for this problem could be possible loss of video signals as heat in the USB capture device. A temporary fix to this problem has been replacement of the capture device with a digital video recorder (DVR). Video signals from the receiver are recorded directly into the DVR, from which they are transferred into the computer. Two test flights were done with the big bird, using the DVR. The video quality has improved substantially compared to the video capture device approach; however, the image quality can still be improved furthermore.

Electronics for longer flight duration

The Electronic Speed Controller (ESC) that took input voltage of 7.4V got overheated hence damaged. We did not have enough time to re-order the part and assemble the electronics. However, all the other necessary electronics for Jumbo bird, e.g. stronger brushless motor, R/C receiver, tail servo motor, and 7.4V battery for longer flight duration are operational, and have been stored in the Manufacturing Automation Lab (MAL). A new ESC that accepts 7.4V input is all that is needed to put together all the electronics for jumbo bird.

CONCLUSIONS

Two of the three major goals of the project were fully accomplished. Software for navigation of jumbo bird from the computer was developed and successfully tested on the big bird. Jumbo bird, which is supposed to be similar to big bird, is also likely to provide positive results when tested with the software built this summer. Off-the-shelf visual feedback system components through which jumbo bird can send visual information of its surrounding during its flight was assembled and successfully tested on the big bird. Off-the-shelf electronics for longer flight duration of jumbo bird compared to big bird were purchased, but the full circuit with flight electronics was not completely assembled.

A possible work for future would be to build the circuit for jumbo bird's longer flight duration that I could not accomplish during my project. Furthermore, the jumbo bird is also to be built, and the software I developed needs to be tested on the robotic bird. If the software tests on the bird give positive results, further research directions would be to develop a vision-based feedback loop navigation program for self-navigation based solely on image processing.

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