Recent Progress in the Development of On-Board Electronics for Micro Air Vehicles

Jason Plew
Jason@mil.ufl.edu

Jason Grzywna
number9@mil.ufl.edu

M. C. Nechyba
Nechyba@mil.ufl.edu

Machine Intelligence Lab
Department of Electrical and Computer Engineering
University of Florida, Gainesville, 32611
Gainesville, FL 32611

Abstract

There is a growing need in both the military and civilian sectors for aircraft with many unique capabilities. This includes Micro Air Vehicles, or MAVs, which have been defined by the military to be any airplane with a wingspan of less then two feet. However, the small characteristics of MAVs makes them quite difficult to control. Furthermore, many of the roles MAVs are being targeted for include some form of autonomous surveillance, and often the aircraft would benefit from advanced intelligence as well, such as the ability to find a specific target and fly towards it. Therefore, on-board electronics system are often required.

However, the small size and weight capacity of such aircraft make the design of these systems rather challenging, especially when the advanced roles above are considered. This paper will detail the progress we have made over the past year in the development of electronic systems for MAVs that are being implemented for several Air Force programs. These systems currently range from miniature controllers that supplement a human pilot using on-board accelerometers, to a system that sends GPS and Video Telemetry to a ground station, which can then control and navigate the aircraft. In the latter system, Vision is used to stabilize the aircraft, as well as for the more advanced capabilities. In all cases, a ground station component is required. However, initial progress will be discussed on the development of a new system with a full Inertial Navigation System (INS), which will allow the aircraft to be stabilized using on-board systems. This new controller, once complete, will allow us to continue to move towards a MAV with full onboard control.

Introduction

In last year's paper discussing our work on MAVs [1], we discussed the flight system that had been developed for an Air Force grant, the Active Vision For Control of Agile Autonomous Flight, or AVCAAF. The goal of this program is to demonstrate within five years a MAV that is capable of urban operations . A MAV flying with that hardware was briefly demonstrated at Eglin AFB on July 23th, 2003. However, many issues remained with the flight hardware. The weight of the system was to high for a MAV with a wingspan of 2 feet, which was our targeted aircraft. A 30 inch platform was used instead. Furthermore, the 3DM-G INS unit was found to be inadequate for use as a sensor for our MAV Controller. Therefore, over the next several months, we made major improvements to the hardware. Two iterations of the system were developed. As the flight hardware discussed in [1] used a MAV128 Flight Computer, Revision 3, the subsequent systems were referred to as Rev 4 and Rev 5.

System Development: Revision 4

The end goal was to develop a lighter replacement for the R3 system that would also include INS sensors capable of closing the control loop on-board. However, these tasks would require a major redesign of the overall system. Given the fact that another demonstration would occur at Eglin in October 2003, the schedule would have been challenging. However, the development of the vision system, discussed in [2], had progressed to the point where the system could utilize the horizon tracking system to obtain both a roll angle and a pitch percentage. As a result, it was decided to put off the development of a full blown INS to the Rev 5 system, and use the Vision System as a temporary replacement. Rev 4 would instead focus solely on reducing the weight of the flight hardware.

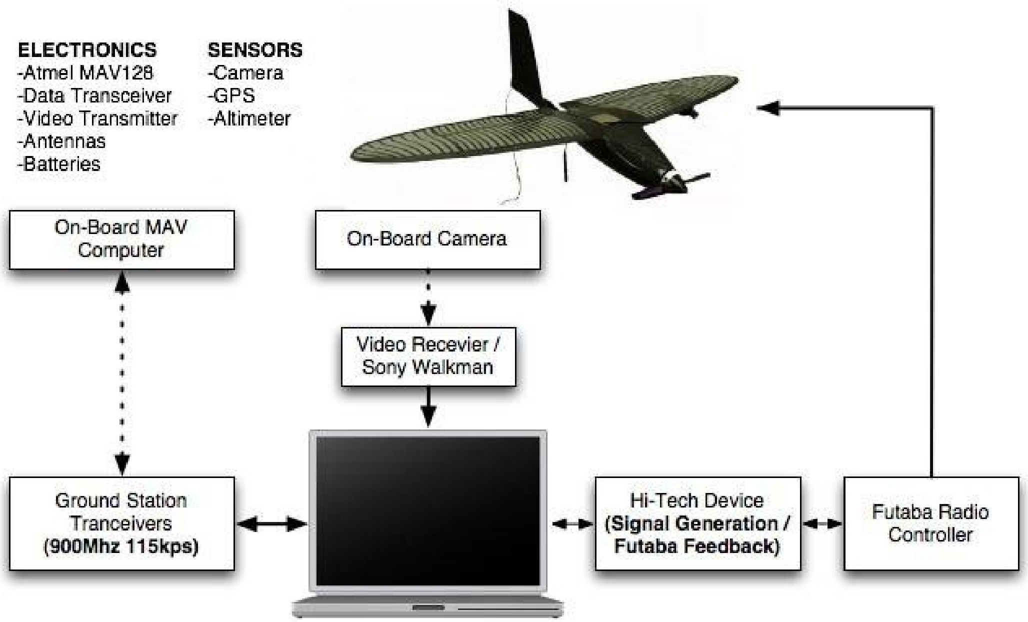

Figure 1: System Layout

The overall Rev 4 system is shown in Figure 1. The onboard system includes the MAV128, which records GPS telemetry and the data from the Altimeter, and sends it the ground station to be used by the control system. An onboard camera transmits the video signal to the ground station, which then runs the vision system to track the horizon [2]. The ground station can then generate the appropriate servo commands, which is sent to the airplane through the regular RC system.

The interface between the ground station computer and the RC system takes place through the Hi-Tech device. This is merely a MAV128 R3 that is running code that can read serial data from the computer, and generate a pulse train corresponding to servo commands that is understood by a Standard RC Controller. The system can also read the commands being generated by the RC Controller, allowing us to base the controller of of servo settings for a plane that has already been trimmed. Since this would result in an aircraft flying nominally level, the ability greatly simplified the process of developing a controller.

The MAV128 Computer went through a small redesign. Though the major focus of Revision 4 was to reduce the weight of the flight hardware, the form factor of the MAV128 did increase. This was because some of the functionality of the Rev 3 system had been developed after the board design was complete, and were accomplished through add-on boards. Added into the core system were servo control, an altimeter, and power for the datalink. Offsetting this was a change in the processor. Though the Mega128 was still used, a leadless package replaced the standard chip, resulting in a 66% reduction in size.

The Axion GPS unit was also replaced with a unit from Furuno, the GH-80. Though the communications protocol did change, there was also a reduction in weight of 10 grams. However, some of this weight reduction was lost, since the unit's integrated antenna did not always preform adequately unless it was well grounded. It was found that the use of a thin copper plate underneath the GPS unit would adequately provide this, resulting in the GH-80 usually acquiring a lock on several GPS satellites within a few minutes.

A major reduction in weight occurred with the replacement of the datalink. An Aerocomm AC-4490 Transceiver, which had comparable performance in a greatly reduced size, was now used to send telemetry to the ground station. Furthermore, the previous datalink had operated at 2.4 GHz, which caused interference with the onboard video transmitter. While not necessarily critical for a human observer, there was the potential that the noise would interfere with the vision system, which was critical for flight stabilization. The AC-4490, on the other hand,

Table 1: Weights (Grams)						
	Rev 3		Rev 4		Rev 5	
Flight Computer	MAV128 R3	16	MAV128 R4	10	MAV128 R5	16
INS	3DM-G	30	-			
GPS	Axiom Swift A2	28	Furuno GH-80	12	Furuno GH-80	12
Datalink	Microhard MHX-910	86	Aerocomm AC4490-500	12	Aerocomm AC4490-500	12
Battery	Two Cell Li-Poly	52	Two Cell Li-Poly	52	*	
Total		212		86		40

* Using Motor Battery

operates at 900 MHz, and therefore the datalink and video system were no longer in conflict.

The full system was shown at Eglin AFB on October 27th 2003. Though a full controller was not yet finalized, flight tests both before and after the trip eventually resulted in a Proportional Controller that was able to use the vision system to stabilize the aircraft and the GPS to navigate between waypoints.

System Development: Revision 5

With Rev 4 successfully demonstrated attention turned to the next iteration of the hardware. The MAV128 would be the major improvement to the Revision 5 system. Other systems remained the same as that shown in Figure 1. The new MAV128 would see the addition of an Inertial Navigation System, as well as numerous smaller

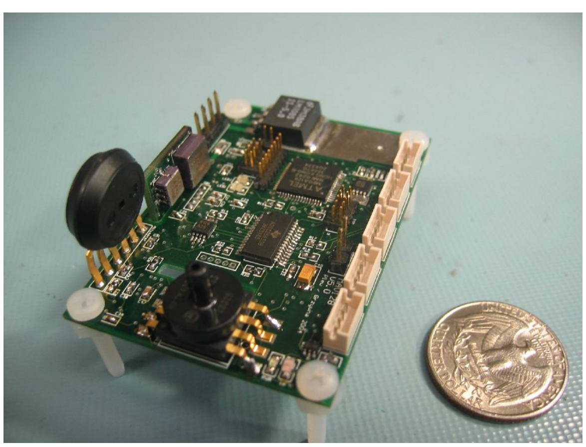

Figure 3: MAV128 Revision 5

Figure 2: Revision 5 Onboard Electronics

enhancements. There was also some issues that became apparent during the testing of the Rev 4 system that had to be resolved. The major issue was the power system. The Mega128 and the Sensors required a supply of 5V, while the AC4490 and the GPS used 3.3V. Rev 4 had a single 5V 1A voltage regulator to regulate the battery voltage. 3.3V regulators tapped off this source to power the GPS and the transceiver. However, the system had only been sending GPS telemetry, and so the transceiver was only used once a second. Now that INS data would be transmitted , the AC4490 would be used nearly continuously. As a result, current draw for the overall system exceeded 0.5A. Furthermore, weight was still an issue, and so the multiple batteries that supplied power to the different systems on the MAV needed to be consolidated. While previously a single two cell battery had powered the electronics at 7V, they would now be

Table 2: Revision 5 Sensors				
INS (All INS Sensors are on 24 bit Serial ADC)				
Sensor	Data	Max / Min	Device	Manufacturer
Acceleration	X, Y, Z	±2G	ADXL203J	Analog Devices
Angular Rates	Roll, Pitch, Yaw	±300 Deg/Sec	ADXRS300	Analog Devices
Altitude	kPA	15 – 115 kPa	MPX4115A	Motorola
Airspeed	kPA	0 – 6 kPa from Ambient	MPXV4006G	Motorola
Navigation (GPS)				
Sensor	Data		Device	Manufacturer
Position	Latitude, Longitude		GH-80D	Furuno GPS
	Altitude		GH-80D	Furuno GPS
Course	Speed		GH-80D	Furuno GPS
	Heading		GH-80D	Furuno GPS
Other Sensors				
Sensor	Data		Device	Manufacturer
Time	Month, Date, Year, Hour, Min., Sec		GH-80D	Furuno GPS
Temperature			ADXRS300/ Mega128 ADC	Analog Devices
Servo Positions	Voltage Reading from Servo Potentiometer		Mega128 ADC	Atmel
Battery Voltage	Input Battery / Four		Mega128 ADC	Atmel

run off the motor's three cell battery, which could exceed 12V. This increased the power dissipation capability of the input voltage regulator to be increased over ten times. An initial test of the power system under these conditions resulted in the voltage regulators going into thermal shutdown in less then a minute.

As a result, the power system was completely redesigned. A large input regulator would drop the battery voltage to 5.5V. The new regulator used a large package, and so was able to dissipate over 2W. Smaller regulators would then power the Mega 128, sensors, and the GPS. Another large voltage regulator would be used to power the transceiver from the 5.5V source. Both devices would be tied to exposed copper to allow them to dissipate heat into both the board and the ambient air. Though these copper pads took up significant board space, it was necessary to ensure the survival of the aircraft during flight. Though the regulators could handle the increased power requirements, the heat they radiated was hot enough to damage the other components including the transceiver, so both the transceiver connector and the sensors were moved to the opposite side of the board.

The other major issue to be resolved was the altimeter. A pressure sensor was being used to measure the altitude of the airplane. However, the pressure range of the sensor was so large that the Mega128's Analog to Digital Converter (ADC) was only theoretically capable of a resolution of around ten feet. Furthermore, the fact that the processor was operating at the same time has the samples were being taken resulted in even less accuracy. Therefore, for the MAV128 Rev 5 board, the analog system was separated from the digital, with different ground planes being used to further isolate the sensors from the Mega128. An eight channel 24 bit ADC was used to further increase the capabilities of the MAV128. As the ADC had advanced filtering capabilities, the INS telemetry will be far more accurate then using the previous ADC system. For example, initial testing has shown a improvement in the resolution of the altimeter to around 2 to 5 Feet. The sensors on the MAV128 Rev 5 are shown in Table 2.

Conclusion

We are currently doing preliminary flight testing of the Revision 5 System. The ability of the onboard electronics to be powered off of the three cell battery and yet not go into thermal shutdown has been verified, as has the datalink system. Our next step will be to verify the functionality of the INS system by developing a simple controller to keep the aircraft in the air. This controller will then be merged with the Vision Stabilization / GPS Navigation Controller developed for Revision Four.

With the completion of the controller, we will have successfully demonstrated onboard autonomous flight, a capability first hinted at with last year's Revision 3 system. Furthermore, we will have done so while at the same time decreasing the weight of the system by a factor of five. While the first MAV we flew autonomously had a wingspan of 30”, we are now flying with a wingspan of 24” (shown in Figure 4), and are targeting even smaller platforms.

Development of the Revision 5 Platform is therefore nearly complete. Accordingly, we are now beginning to shift focus to the Revision 6 System. The new system will include a completely new processing unit for onboard the MAV, and will be based around some combination of a DSP and FPGA. This will allow us to move all the features currently in the Mega128 into the FPGA, and yet also begin moving some of the vision system into the plane as well. Its development will move our project even closer to the goal of autonomous flight in an urban environment.

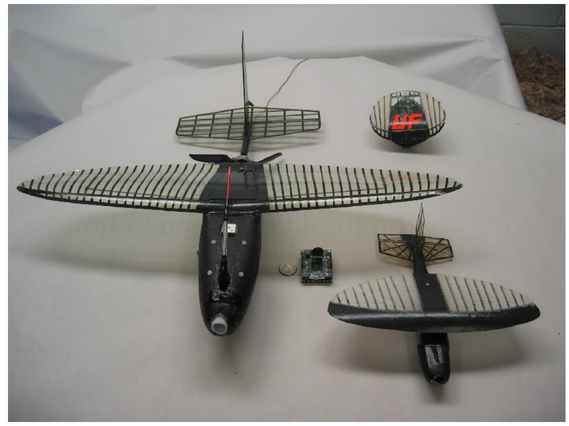

Figure 4: 4”, 10” , and 24” MAVs with the Onboard System

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