Enabling Autonomous MAV Flight

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***Abstract*— Micro Air Vehicles (MAVs) are miniature airplanes constructed from state-of-the-art materials, designed to be small, light, and highly resilient. Current applications include surveillance, reconnaissance, and munitions. Many of the planes, because of their size, have unconventional designs with respect to the wings and control surfaces. Instability introduced by the small non-traditional aircraft designs must be addressed, to eliminate the need for an expert pilot for aircraft control and navigation. Previous research includes the design of a vision-based horizon tracking system and simple waypoint navigation with a GPS. Our goal is to further develop a navigation system with built-in autonomous flight capability. In this paper we present a microcontroller-based flight control system that was built at the Machine Intelligence Laboratory. This custom computer gathers data from a multitude of sensors and is capable of closed-loop control to enable autonomous flight and navigation.**

I. Introduction

Micro-scale aircraft have a plethora of applications in both the commercial and military sectors. Payloads, ranging from cameras to acoustics to munitions, allow for very diverse applications within the three-dimensional freedom of the sky. MAVs have a natural resemblance to flying creatures such as birds and bats, and thus a natural camouflage. Quiet electric motors, along with this natural camouflage, allow MAVs to operate, even at low altitudes, non-intrusively.

Most MAVs are fully human piloted and make use of off-the-shelf radio control systems. A steep learning curve is associated with flying MAVs. These planes are difficult to fly due to their unconventional designs and sometimes unpredictable flight characteristics. Another limitation of human piloted MAVs, besides the range of the radio control transmitter, is the range of the pilot's sight. Cameras have been used on MAVs to extend their usable range; however mapping three-dimensional control inputs from a two-dimensional video stream is foreign for most pilots.

A goal of this project is to simplify the task of operating a MAV. To alleviate the necessity of an expert pilot, some form of augmented control must exist. This problem is addressed by placing a computer on-board the aircraft. This computer inputs the humans control directives and data from the sensor suite. It then generates the necessary actuation signals based on those inputs and a built-in flight model. This closed-loop system can perform input conditioning and dampening to make the plane more stable with respect to its model. Simple augmented control is the initial step to enabling autonomous flight.

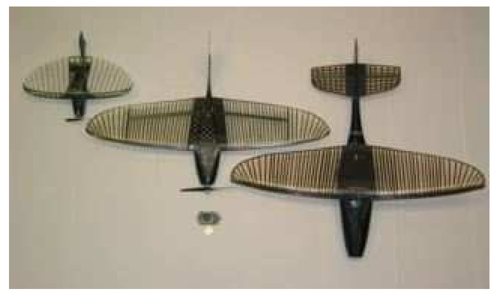

Fig. 1. MAV Platforms: 10", 24", and High Capacity 24"

II. System Overview

In developing MAVs, biological inspiration from observations of birds and bats led to the implementation of a flexible wing design. Traditional aircraft use a rigid wing structure to avoid catastrophic failures due to structural dynamics. The flexible wing design used by birds, bats, and MAVs produces a passive mechanism, called adaptive washout, which suppresses the effects of wind gusts on their flight stability. Intricate designs using primarily carbon fiber form the basis for both the wings and the fuselage. This durable lightweight material is used to produce the aircraft used in this research. The planes developed have wingspans ranging from 24 inches down to 10 inches and use two actuators, shown in Figure 1.

All initial testing has been performed in the high-capacity 24 inch aircraft. This plane has a payload capacity of about 300 grams in addition to its motor, servos, receiver, and motor battery. It is capable of sustained flight up to 30 minutes with this payload. Maximizing the duration of flight time is critical for autonomous operation.

III. On-board Flight System

The integration of an on-board computer into a MAV capable of closed-loop augmented flight control and full autonomous control is a novel concept. An off-the-shelf solution did not exist within the stringent size, weight, and

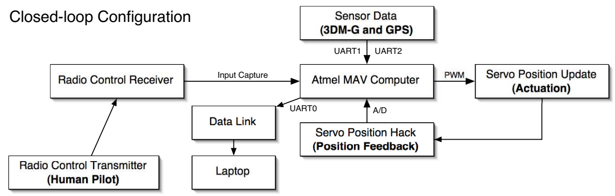

Fig. 2. Block Diagram of On-board Hardware

power specifications required for these experiments. As a result, a microcontroller-based flight system was developed. It was critical that the on-board computer support multiple sensor interfaces, have the capability to record time-stamped/ synchronized flight data from all of the active sensors and actuators, and relay that information to a ground station if desired.

To perform augmented control, information must be known about the current state of the aircraft, as well as the human inputs. The state data is obtained from two on-board sensors, a 3D position sensor and a global positioning system (GPS). These sensors are directly interfaced to the on-board flight system, the MAV128. A wireless data transceiver is present for communicating with a ground station. Human control signals from a radio control system are decoded by the on-board computer, calculations are performed based on sensor feedback, and actuation is performed. This process is illustrated in Figure 2. Telemetry from the aircraft can be viewed and recorded at the ground station.

Aircraft stability is described as the inner-loop control problem, while navigation is described as the outer-loop control problem. General stability of the aircraft is the most important aspect of autonomous flight, and also the most computationally intensive. Since the aircraft moves quickly through the air, state updates about its accelerations, roll rates, and position must happen multiple times per second. The MAV128 on-board computer receives data from the 3D position sensor at 30Hz. Waypoint navigation is considered part of the outer-loop control problem. This data can be reported much slower because it is assumed that large distances exists between waypoints with respect to the size of the MAV. GPS data is retrieved at 1Hz, which is more than sufficient for navigation.

IV. Hardware Description

The on-board flight system, known as the MAV128 and shown in Figure 3, is designed around the AVR Mega 128 microcontroller from Atmel. This is an 8-bit processor which has 2 RS-232 ports, an 8 channel 10-bit A/D, 4Kb SRAM, and 128Kb flash memory. This microcontroller has internal systems to capture signals and to generate pulse-width modulated (PWM) waveforms. A third UART has been implemented virtually in software to create another serial port. A memory expansion board was designed to be mounted on the main computer board and support up to 256MB of non-volatile flash memory. Interfaced to this board via two separate serial channels are the MicroStrain 3DM-G, a 3D position sensor, and the Axiom Navigation Swift A2 GPS module.

Fig. 3. MAV Atmel-based Computer - MAV128

The 3DM-G is comprised of three angular rate gyros with three orthogonal DC accelerometers, three orthogonal magnetometers, and an embedded microcontroller, which provide three orientation angles in a dynamic environment. The multitude of configurations capable with this sensor extend beyond the scope of this paper. The maximum output data rate is 100Hz when only one data set is sampled.

The GPS is integrated with a ceramic patch antenna, therefore no external antenna is required. This module is comprised of a differential GPS processor, multipath mitigation hardware, and a satellite-tracking engine. NMEA v2.2 messages are used by the on-board computer. Longitude, latitude, altitude, and time are decoded from the output strings of the GPS. The data is output once per second.

On-board data logging is enabled with the memory expansion board. All sensor and actuator values can be logged during a flight for retrieval at some later time. A 900MHz compactRF wireless link from Microhard Systems is used for telemetry. It operates at 19.2kbps with a range of 10 miles.

V. Software Description

AVR GCC was used to build all of the on-board software for the MAV128. This system continuously gathers data from sensors and possible human inputs, processes this information, and then generates actuator commands. Human inputs are decoded through the timing of the servo pulse-train generated

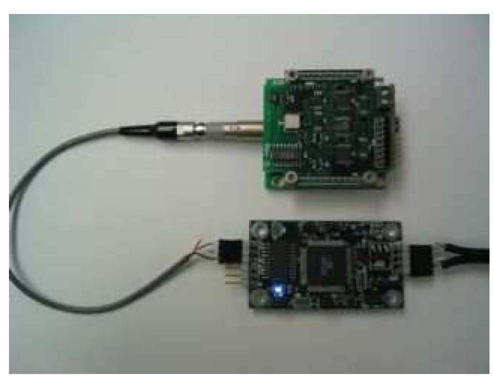

Fig. 4. MAV128 Computer with 3DM-G

by the radio receiver. These inputs are conditioned, based on sensor and actuator data, in the control loop. The augmented control signals are then output to the actuators, allowing for assisted flight control. The system was designed to allow the current state of the system (sensor, actuator, human control data) to be sent to a ground station through the wireless link. Data could be processed on the ground in tandem and relayed back up to the aircraft.

Inner-loop position control data are processed on-board the airplane, but outer-loop navigation data are processed on the ground for these experiments. The ground station tracks a set of waypoints, know as the mission, and the current location of the aircraft. It then generates bearings and distances to the next waypoint. The mission data can be changed during the flight to allow for waypoints to be added and removed.

The ground station software was developed in C under the Linux operating system. It utilizes a text-based GUI; therefore, it can run on any system capable of running Linux, including palm-based and notebook computers.

VI. Conclusion

Augmented control is the initial step to enabling autonomous flight. It is a goal of this work to enable autonomous flight through the inclusion of an on-board flight computer capable of using a 3D position sensor and a GPS to assist in the control of the aircraft. It is also the goal of this work to design a robust flight control system for further experimentation and research in the field of MAVs. Previous work used a vision-based setup for stabilization. In future work, vision will be tightly integrated on-board with this current computer for additional augmented control and also, more importantly, for obstacle avoidance and tracking.

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