AN INVESTIGATION INTO AEROBOT TECHNOLOGIES FOR PLANETARY EXPLORATION

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ABSTRACT

For those planets and moons that support an atmosphere, flying robots are likely to provide a practical solution to the problem of extended planetary surface coverage for terrain mapping, and surface/sub-surface composition surveying. Not only could such devices be used for suborbital mapping of terrain regions, but they could be used to transport and deploy science packages or even microrovers at different geographically separate land sites.

Whilst much attention has been given to the use of rovers for planetary exploration, most notably the NASA Jet Propulsion Laboratory (JPL) Mars Pathfinder mission and the Sojourner rover [1], the use of flying robots, or aerobots, for planetary exploration represents a highly innovative concept. Whilst rover technology is clearly competent at facilitating useful science, their application is terrain limited. They are capable of travelling relatively small distances and much of a planet's terrain is impassable to small wheeled vehicles, aerobots in comparison have no such limitations.

The technological challenges posed by planetary aerobots are significant, and the authors are investigating the design and control of helium filled balloon robots that can fly autonomously to designated landing sites. To study these problems we have constructed ALTAIR-1 which is the first aerobot to be designed as part of our ALTAIR (Aberystwyth Lighter Than Air Intelligent Robot) research programme. ALTAIR-1 is a modular laboratory based aerobot designed for rapid prototyping and experimentation within a controlled environment. Typical modules include: flight control and navigation microcontroller(s), beacon detection, altimeter and landing sensors, electrical power, vectored propulsion units, and aerobot to ground station RF communications. All modules are housed in the ALTAIR-1 gondola, which is supported from a helium filled spherical balloon. This paper provides an overview of our ALTAIR-1 aerobot.

1. INTRODUCTION

The challenge of flying a planetary aerobot encompasses mobility control and autonomous navigation in a constantly changing 3D environment. Inter-planetary distances prohibit the real-time communication of external meteorological and internal robot state data which would allow human remote control from Earth. An aerobot's long term endurance and ultimate survival can be achieved only if sophisticated autonomous flight control and navigation methods are employed. It is to address these challenges that our research is dedicated.

For an aerobot to function autonomously within a dynamic 3D environment, it must possess the necessary sensors and actuators for control and navigation purposes. Low power, low mass, low volume and ideally, low cost, are important criteria when it comes to the design and construction of these sensors and actuators. However, designers wish to maximise functionality and reliability, and invariably, a trade-off is required.

If a "faster-better-cheaper" [2] space mission policy is to be adopted, as is the trend, then the issue of testing becomes paramount. Aerobot designers need access to a test vehicle that allows them to prototype ideas rapidly, and conduct extensive research experiments. Thus such a vehicle must facilitate both hardware and software ease of installation and modification, and provide a support infrastructure that allows test results to be gathered, visualised, analysed and reported upon.

This paper provides an overview of our work on ALTAIR-1 which has been designed as part of our ALTAIR (Aberystwyth Lighter Than Air Intelligent Robot) research programme. This is a laboratory based vehicle and is the first in a proposed series of aerobot test platforms.

2. LIGHTER THAN AIR (LTA) AEROBOT RESEARCH

The simplest LTA aerobots are unmanned balloons and the first to visit other planets were the two French/Russian VEGA balloons that explored the atmosphere of Venus for two days in 1985 [3, 4]. Using only simple data acquisition sequences, these aerobots measured temperatures, pressures, wind speeds, and cloud particle properties of Venus. However they could not control their movements autonomously. For extended missions, planetary aerobots must be able to function autonomously without relying on constant guidance from Earth. An autonomous planetary aerobot must be able to determine its position, altitude, and velocity, acquire scientific data, actively control its altitude and direction, and land at designated surface sites.

Aerobot research is being conducted by the NASA JPL [5, 6, 7], who are interested in surveying planets from high altitudes due to the improved resolution of the data gathered, as compared to that obtained by orbital surveying [8]. Interest in aerobots for planetary exploration is increasing due to the ability to traverse large areas of a planet's surface rapidly, as compared to a rover vehicle.

JPL have investigated a number of sensors that are required by an aerobot such as celestial, inertial, ranging and radiometric [9]. Examples of these have been implemented on their *Planetary Aerobot Testbed* (PAT) [10] which was designed to be a flying testbed for aerobot technology.

The NASA JPL planetary aerobot activities have continued in the area of solar Montgolfiere balloons for Mars exploration [11], and ultra long duration balloons [12].

Common to the LTA aerobot research areas, is the problem of sensor and actuator hardware and software performance testing. Although software simulation methods have an important rôle within a research programme, there is no substitute for tests on a real aerobot. Controlled experiments are required if we are to advance our understanding of autonomous aerobot navigation and control. We argue that extensive laboratory trials are required first, which can be followed up by outdoor terrestrial experiments. Not until we have proven satisfactorily our ideas using such test facilities, we will have the confidence to send aerobot technology to other planets.

The NASA JPL PAT facility provided an excellent foundation for terrestrial aerobot system tests, and it is to augment this work that our ALTAIR-1 aerobot is focused.

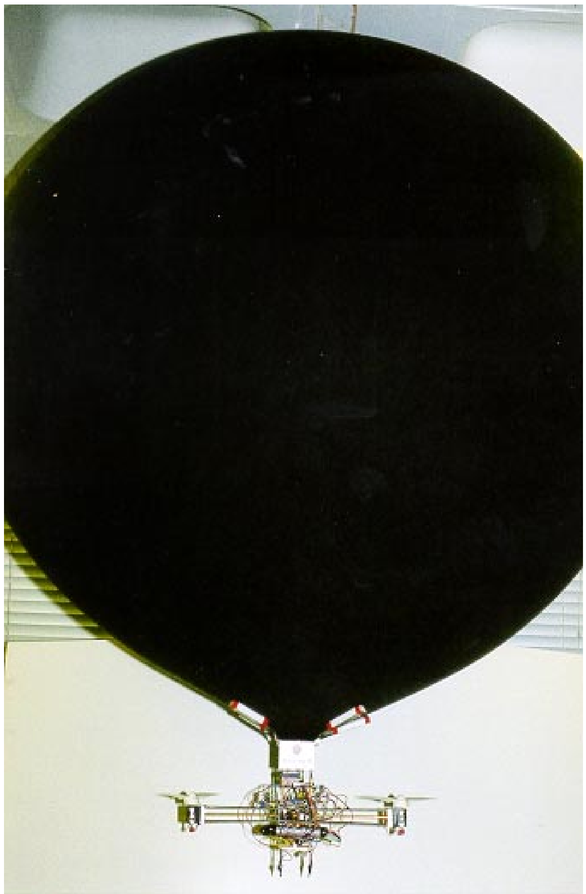

Figure 1. *ALTAIR-1.*

3. ALTAIR-1 OVERVIEW

ALTAIR-1 is composed of a helium filled balloon from which hangs a robotic gondola, see figure 1. The gondola contains electronics, sensors and actuators and has a mass of approximately $1.6 - 1.8kg$ depending upon which experiment is being conducted. The balloon diameter required to support this mass at neutral buoyancy is approximately $1.75\ m$ and contains approximately $2.8\ m^3$ of 99.9 % helium at $1\ atm$. The total mass of ALTAIR-1 can reach $2.2\ kg$ depending upon experiment hardware and atmospheric conditions. The bulk of the gondola mass is a central support structure that contains servos, gears, motors, propellers and struts, see figure 2. The propulsion units (motors and propellers) can be vectored independently, for maximum flight control. Figures 1 and 2 show both propulsion units in a vertical flight position.

A modular approach was taken when designing ALTAIR-1, both for hardware and software. The aim was to provide greater flexibility to the overall system, and allow different sensors to be connected and disconnected with ease, depending upon the experiment being conducted. Our studies resulted in the design of hardware and software architectures for ALTAIR-1.

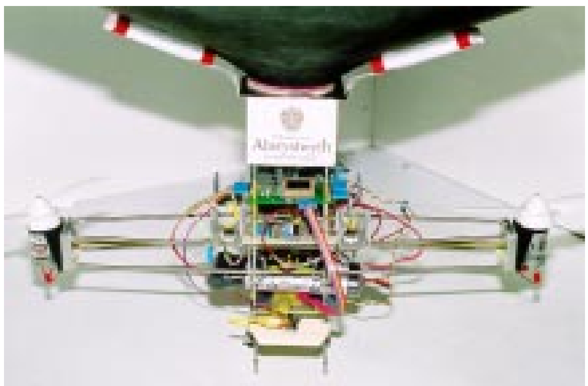

Figure 2. *The ALTAIR-1 gondola.*

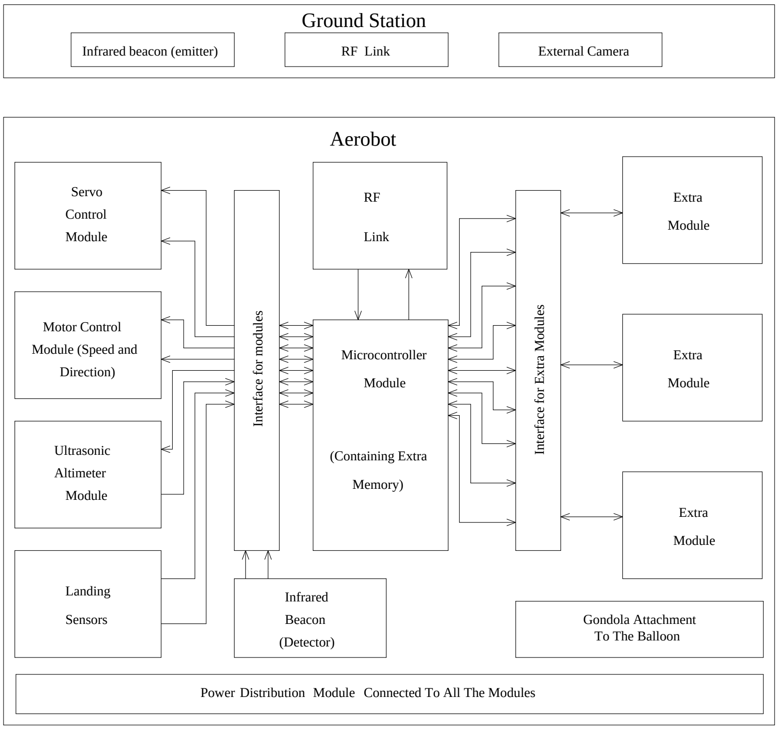

Figure 3. *The hardware architecture of ALTAIR-1.*

4. ALTAIR-1 HARDWARE ARCHITECTURE

A block diagram representation of the ALTAIR-1 hardware architecture can be seen in figure 3. This shows a number of example hardware modules, and the architecture is composed of individual ground station and aerobot modules. All ground station hardware modules are interfaced to a PC machine (Windows NT) which is networked to other PCs and Sun (Unix) workstations. All aerobot hardware modules have common features such as size and power and input/output connections. A common interface allows them to be interchanged easily, and new modules added for experimentation purposes. Central to the hardware architecture is the microcontroller unit module (MCU). There is also a mechanical module that allows the gondola to be attached to the balloon, and a power distribution module to which all electronic modules are connected. The average electronic module mass is 50 gm.

5. ALTAIR-1 SOFTWARE ARCHITECTURE

A block diagram representation of the ALTAIR-1 software architecture can be seen in figure 4. This is composed of individual ground station and aerobot modules. Every hardware module has its own associated software, allowing it to be included and utilised within an experiment when required. The ground station incorporates THRSim11 [13] software used to simulate the MCU. This allows an experimenter to develop new algorithms and control routines in a safe environment, without having to go through the process of sending new untried software to the aerobot. All software routines are validated using the simulator before they are sent to the aerobot MCU module.

6. DISCUSSION AND CONCLUSION

Our aim has been to design an aerobot test vehicle that facilitates both hardware and software ease of installation and modification, and provides a support infrastructure that allows test results to be gathered, visualised, analysed and reported upon. A number of experiments using different ground station and aerobot hardware and software modules have been conducted, and have included investigations into future control algorithms required for autonomous flight [14].

Supporting our ALTAIR-1 aerobot, we have developed an infrastructure for experimentation with the aid of motion tracking facilities and aerobot telemetry monitoring software. The inclusion of internet server software into our Monitor module, with the ability to conduct experiments via the world wide web in the future, will create new opportunities for remote experimenters. We argue that if we are to send aerobot technology to other planets within our solar system, then extensive laboratory trials are required first. These should then be followed by outdoor terrestrial experiments so as to increase both our know-how and confidence. We believe that with ALTAIR-1, we have made a small inroad into the creation of a versatile experimental laboratory aerobot. The 'descendants' of which some day in the near future, may be used for planetary exploration.

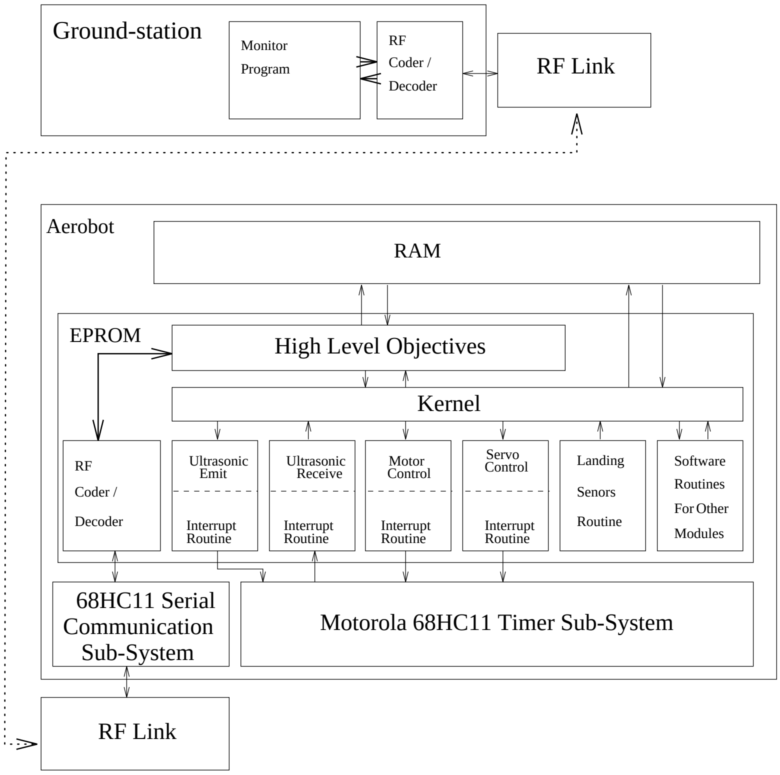

Figure 4. *The software architecture of ALTAIR-1.*

7. ACKNOWLEDGMENTS

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