MAVERIC: An Autonomous Balloon System for Mars Exploration

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Abstract: *This paper describes the architecture of a prototype autonomous balloon system for Mars exploration, developed by final year undergraduates at the University of Kent. The system uses a state-of-the-art embedded Linux core (CerfCube, XScale) powerful enough to navigate the balloon using GPS data, and to transmit real time video and other scientific data to a mobile ground station. We have found that this architecture is extremely versatile, and is likely to be suitable for a wide variety of autonomous platform applications.*

Keywords: Mars balloon, autonomous platforms, embedded systems, remote access laboratory.

1. Introduction

Robotic planetary surface exploration is now 40 years old. The early Surveyor missions to the Moon and Viking missions to Mars consisted of fixed landing vehicles with basic robotic manipulation capability. The Soviet Lunakhod rover missions of the 1970s added significant mobility, but with direct control from Earth.

The Mars Pathfinder mission in 1997, demonstrated the utility of a small roving vehicle with elementary autonomous capabilities.

After several notable mission failures, NASA plans to launch two Mars Excursion Rovers this year, and ESA will carry the British Beagle2 lander to Mars orbit, from where it will descend to the Martian surface and deploy a small 'mole' for surface and sub-surface sampling [1].

In the early 1980s, Prof. Jacques Blamont [2] pointed out that whereas conventional roving vehicles would only be able to explore in the local domain of the landing site with currently available or foreseen technologies, a balloon floating in the Martian atmosphere could conduct surveys on a global scale.

Some early designs for Mars balloon systems were based on the idea of an 'instrumented snake'. By day, as the gas in its envelope expanded, the balloon would rise and be borne by Martian winds. By night, it would descend; its rate of descent and horizontal motion near the surface being reduced by the instrumented snake being dragged along the surface.

In 2000, Pioneer Astronautics demonstrated a 'hot air balloon' which inflated using solar heated methanol [3]. The 25 ft^3 balloon was inflated at an altitude of over 100,000 ft from a pint-sized container.

Since the year 2000, in a unique collaboration with the Australian Space Research Institute [4], the University of Kent has been able to offer final year undergraduates the opportunity to design and construct small payloads for launch by Zuni sounding rockets from Woomera, South Australia. In the 2002-2003 academic year, this programme is being extended to include the testing of a roving vehicle and a balloon system in a Martian terrain analogue area on the Woomera Range. The MAVERIC (Mars Airborne Vessel for Exploration and Research with Intelligent Control) project, undertaken by three final year B.Eng students, has focused on candidate electrical and computer system solutions for autonomous control of a balloon operating in the Martian atmosphere. Elements such as power supply, propulsion, sensors and sensory interfaces, navigation, communication and intelligent control have been integrated swiftly, economically and efficiently using commercial off-the-shelf (COTS) components.

2. Candidate Designs

Implementation of such a system is subject to several constraints. First, the system needs a fair

TABLE 1. Embedded system candidates

Name	CPU	Memory	Storage Capacity	External Connections
Arcom Pegasus	AMD SC520, AM5x86, 133MHz	64MB	16MB	10/100, RS232, parallel port
Arcturus uCdimm ColdFire 5272	Motorola ColdFire RISC	8MB	2MB	10/100, USB, RS232
Intrinsyc CerfCube XScale	Intel PXA250, 400MHz	64MB	32MB	2x10/100, 3xRS232, USB host/controller, JTAG, PCMCIA

amount of intelligence (computing power) in order to be capable of handling a wide variety of input sensors and at the same time to control the navigation process. Yet, in spite of this requirement, the power consumption should be as low as possible. Moreover, in a real mission, the weight (and size) of the payload should be kept low, since this has a significant impact on the size of the balloon and more importantly on the cost of launch from Earth to Mars. On the other hand, it is a good idea to have a design capable of multiple incremental improvements.

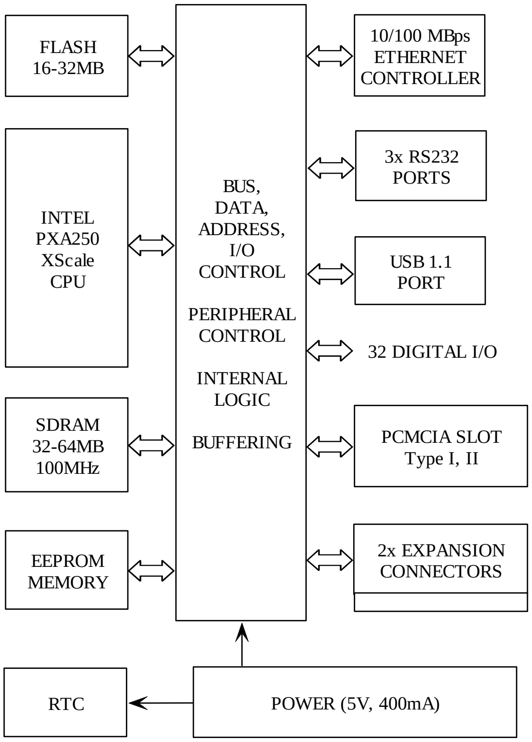

FIGURE 1. CerfCube Structure

All these requirements combined together, constitute a significant constraint imposed on the designer. Bearing in mind the above and the fact that in reality the balloon will be tested in the Australian desert, several alternatives were considered. After a careful analysis, three of the most promising solutions were selected.

The first and the most obvious solution was to employ a system based on microcontrollers in order to control the entire system. This can lead to a potentially complex design, using several 8 bit PIC microcontrollers, each of them handling a certain aspect of the design. This is indeed an appealing solution, but its limited computing power and future expansibility could constitute a drawback.

The second alternative was to use a laptop motherboard as the computer system. This solution was considered unsuitable due to the relatively high power consumption, limited future expansion, more difficult interfacing with the peripherals, and the size/weight of the entire ensemble. Furthermore, several hardware/software modifications were required in order to eliminate some of the redundant components like the keyboard, floppy drive and the hard-disk (which needs to be replaced with a solid state memory, much more reliable and capable of withstanding mechanical shocks).

The third solution was to use commercial low powered embedded computer systems. The final decision was to use this solution, combined with a microcontroller based unit used mainly for interfacing with the sensors. Again, several embedded systems were selected as possible candidates, as TABLE 1 identifies.

After comparing the three embedded systems, it was decided to use the Intrinsyc CerfCube. There are several reasons for this selection: faster processor allowing for processing of digital video, large amount of system memory, largest flash storage capacity, several RS232 ports, 10/100 Ethernet connection, presence of USB ports and easy upgradeability via the PCMCIA slot (e.g. 802.11b wireless cards, extra storage, such as 512MB flash, 1GB IBM Microdrive). The only disadvantage of the CerfCube was its price compared with the Arcom system, but this was well compensated for by its excellent features. A simplified structure of the CerfCube is shown in FIGURE 1.

Furthermore, the system runs an embedded Linux OS which is free, open-source and widely used and supported around the world. There are many programming tools and utilities available for software development, and due to its open-source philosophy, in case of any problems with the drivers or with the OS itself, these can be easily rectified compared with an closed-source operating system such as Microsoft Windows CE.

3. Practical Implementation

The block schematic of the entire system is presented in FIGURE 3.

The digital sensor interface is built around a PIC 16F877 microcontroller which acts as an interface between the sensor array and the main computer system via an RS232 interface. The main computer system handles all aspects related to navigational strategy and control, data logging, telemetry and communications.

Flight control and navigation relies on an on-board

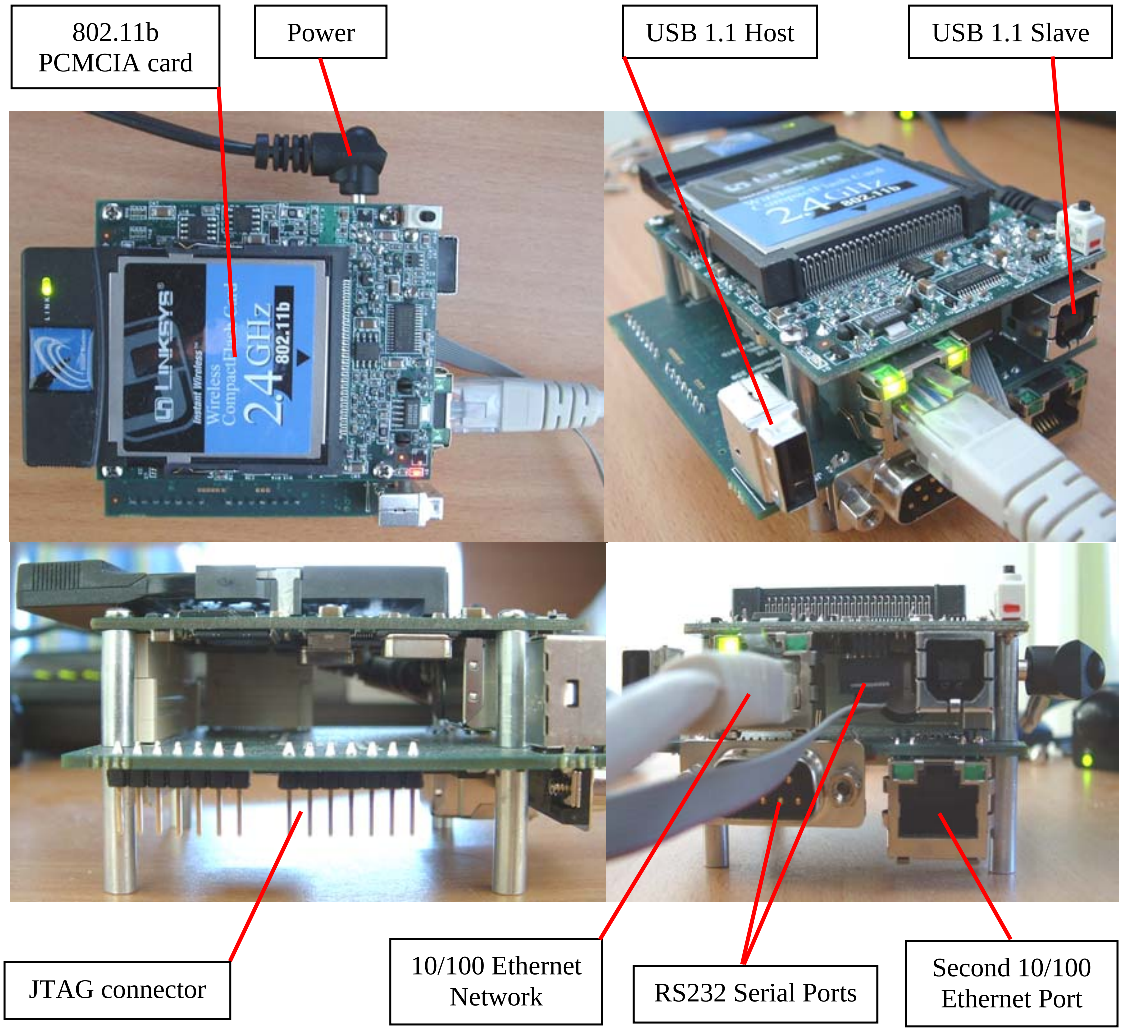

FIGURE 2. The CerfCube

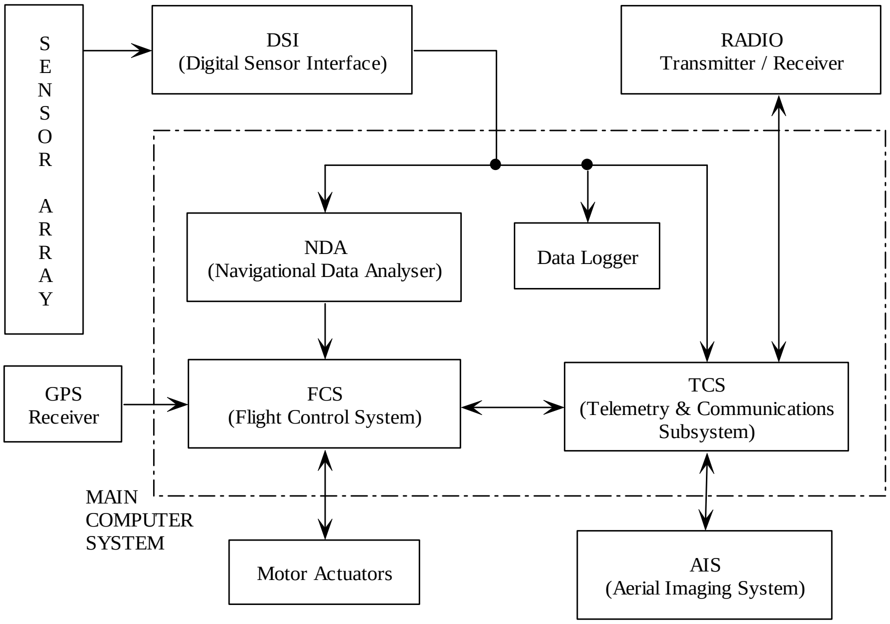

FIGURE 3. Block schematic of the MAVERIC system

GPS receiver and partially on data supplied by the sensor array (e.g. digital compass). Based on this data, the main computer issues the appropriate commands for the motor actuators. All relevant data is logged and stored in the flash memory. The GPS module communicates directly with the CerfCube via one of the RS232 ports. The software deals with the interpretation of the data supplied by the GPS module (e.g. NMEA protocol).

An important part of the system is the aerial imaging subsystem which uses a high resolution (640x480 pixels) USB webcam to capture and send video data using the onboard radio transmitter. Interfacing with the onboard computer is conveniently done by using one of the USB ports provided by the CerfCube.

The communication subsystem handles all bidirectional data flow, and uses a PCMCIA wireless card based on the 802.11b protocol, interfaced with an external antenna in order to maximise the communication range. The system uses the licence-free 2.4GHz microwave band which has several channels for public use, can offer a bandwidth of up to 11Mbps, and steps down to 5.5Mbps, 2.5Mbps and 1Mbps. This means that the connection can still continue even with degraded signal strength and that the link is less likely to be lost. Besides the video stream, the system is capable of sending telemetry data and receiving commands from the mission base.

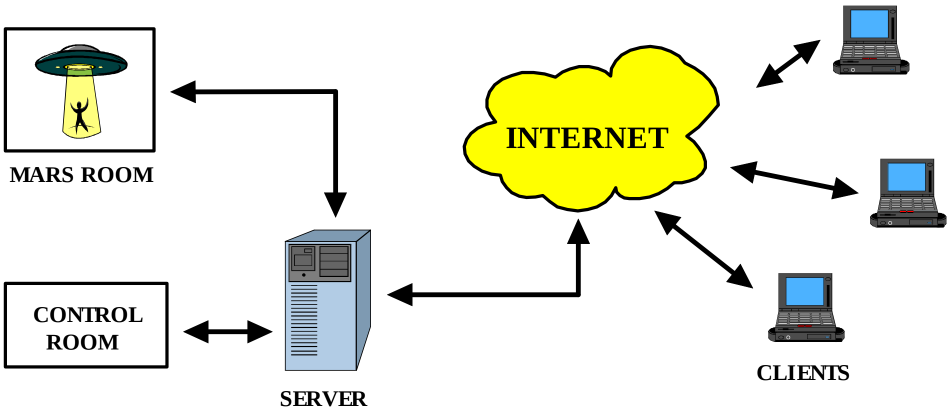

FIGURE 4. Architecture of the Remote Access Laboratory

4. Results and Further Work

As part of the formal evaluation of their project work, the student team has successfully demonstrated control of the propulsion system from a networked PC. The communication subsystem was operated over 400 metres and tested to 11 Mbps, and the location of the balloon payload, as recorded by the Flight Control System (FCS) was plotted over a period of time to validate the GPS receiver's interface with the FCS.

The successful development of key elements of the MAVERIC system design enables us to offer a *Remote Access Laboratory* experience for robotic education which uses the same system architecture, based on a CerfCube core.

As the UK's Beagle2 Mars lander heads for the Red Planet, and as a contribution to increasing public, and particularly school pupils', awareness of the science and technologies behind planetary surface exploration, the University of Kent will be offering *Desktop Explorers* the opportunity to plan and conduct simulated Mars surface exploration missions using a model roving vehicle on a 4 x 4 metre Martian surface. The first demonstrations of this facility will take place during the 'Walking With Robots' residential summer school, 2-4 August.

It is envisaged that school pupils, working in teams of four, will be given several challenges. The control teams will not have any direct access to the Martian surface, but will send commands to and receive telemetry from the roving vehicle via an Internet link between a PC in the *Control Centre* and a server in the *Mars Room* which in turn will communicate via a wireless link carrying IP traffic with the roving vehicle (FIGURE 4).

Telemetry available to the teams will include regularly updated images from a miniature camera on board the rover and from a panoramic camera looking vertically downwards from the ceiling of the *Mars Room*. The latter camera images are to simulate data available from a spacecraft in Mars orbit. Other telemetry data will include wheel rotation counts for use in simulating missions with strict power usage constraints.

In the first challenge, the teams will control the roving vehicle in real time, but with a delay built into the communications link of the order of tens of seconds to illustrate the difficulties that would be experienced in a real mission to Mars. A typical task would be to drive the vehicle from one corner of Mars to the opposite corner, turn the vehicle around to face its starting point and take a picture of the Earth (a suitable poster on the wall of the *Mars Room*) rising above the Martian terrain.

In the second challenge, the teams will be able to plan a path through the Martian terrain, and then implement that plan by downloading a sequence of commands to the onboard computer of the roving vehicle. Some limited supervisory command activity during the simulated mission will be allowed.

Extensions of this basic experience are envisaged. Depending on acquisition of a suitable level of operational funding, we plan to offer the *Mars Room* to secondary schools in Kent and then elsewhere in the UK supported by a suitable support package for teachers.

In the longer term, we plan to develop a *Remote Access Balloon* system capable of feeding real-time imaging and other data straight to a web server. This system will join MAVERIC's architecture with the idea of a Remote Access Laboratory and it will be built around the existing CerfCube core.

5. Acknowledgements

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