INTELLIGENT SENSOR NETWORKS FOR EXTREME ENVIRONMENTS

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ABSTRACT

A network of autonomous motes that are capable of detecting life in extreme environments may hold the key to finding habitable environments beyond Earth. Laying the foundation is Dr. Chris McKay's ongoing research to detect life in Mars and Europa analog environments. The primary goal of this investigation has been to find signs indicative of life and to design a device that will collect such data. Each mote will be designed to resist extreme environmental conditions (ex. hot and cold temperatures), provide a long term means of data collection by keeping power consumption to a minimum, and provide relevant and accurate data. Characteristics that differentiate this project from life-detecting rovers (such as the Mars Pathfinder or Viking) are the motes' size, ease of deployment and operation, low cost of production, and low environmental impact.

INTRODUCTION

By creating a network of autonomous motes to be deployed in extreme environments (i.e. those similar to conditions on Mars), this project aims to assist Chris McKay, PhD, in his research, and also meet Goal 5 of the NASA Goals and Objectives from the NASA Strategic Plan, Appendix III, which is to "Explore the solar system and the universe beyond, understand the origin and evolution of life, and search for evidence of life elsewhere."

By researching life in extreme environments on Earth, we can come closer to determining whether life, as defined by Earth standards, exists, had existed, or can exist on Mars. This issue will be fundamental to understanding our own origins and evolution, and answering the universal question, "Are we alone in this universe?"

An initial network of three motes equipped with sensors capable of detecting some of the important conditions for life will serve as the means of collecting data. A mote is defined in Wikipedia as a "device containing sensors, computing circuits, bi-directional wireless communications technology and a power supply".

The three motes will consist of one "super-mote" and two "environmental motes." The super-mote will collect specific indicators of life (i.e. lipid membranes and macromolecules including proteins, DNA, and carbohydrates). Environmental motes will measure specific characteristics such as temperature and humidity that complement the data collected by the super-mote.

METHODS

This project spans 3 semesters: Fall 2005 (Research), Spring 2006 (Design), and Fall 2006 (Build and Test). The mote network and its current design is based on prior research and feedback from experts in various fields.

The technical specification of each mote is designed to meet the anticipated environmental conditions that are expected to exist on Mars. To determine such conditions, we examined those Mars analog environments found on Earth (i.e. Chile's Atacama Desert, and the Arctic Dry Valleys), the previous conditions that the earlier Mars rovers encountered, and consulted with Dr. Victoria Hamilton, University of Hawaii's resident "Mars Expert."

Critical in this study is the choice of measurable indicators to determine what is life and how to detect it. Through meetings and emails with Dr. Andrew Boal and Dr. Chris McKay, it was decided that the mote network should detect lipid membranes (key indicators of life), and corresponding temperature and humidity to provide complementary information on the environmental conditions that allow that organism to survive. Dr.'s Dale Anderson, Daniel Jenkins, Wei Wen Su, and Alan Waggoner provided the needed insight into detecting such biological life signs. This bioenvironmental analysis led to the choosing of chemical gels as the most viable means of bio-detection.

The Zoë Mars rover, developed by the researchers at Carnegie Mellon University, has previously used chemical gels to detect organic molecules in the Atacama Desert. Spraying the dyes on the ground cause organic molecules to fluoresce. The fluorescence is captured using a specialized CCD cooling camera, and the images are analyzed for variations in wavelengths/color that indicate which molecules are present.

The mote network will be similar to that previously developed by the PODS project researchers at the University of Hawaii. Dr. Edo Biagioni, PODS researcher and Computer Science Professor, provided the necessary guidance on possible network technologies, alternative power consumption issues, and legal permission regarding the use of Kilauea as the test site.

DESIGN

Many aspects of engineering and biology go hand-in-hand. This paper will have an overview of bio-detection and mote networking, but its primary focus will be on the design of the protective casing and power supply, which have been the author's main tasks in this project this semester.

Bio-detectors

Lipid membranes have been determined to be the best indicator of life. DNA, while also an indicator of life, may not be the same on Mars as it is on Earth. However, the lipid membranes that surround and protect the inner cell seem to be common among all living organisms. To detect these lipid membranes, chemical gels will be used. The chemical gels will be released beneath the topsoil where they will bond with any lipid membranes and cause a chemical reaction that produces a fluorescent glow. Photodiode arrays will detect the specific wavelength(s) emitted. From the data collected by the photodiode arrays, it can be determined whether lipid membranes exist in the soil or not.

Networking/Communications

Jennic's IEEE802.15.4 evaluation kit will be used to implement the wireless sensor network. Data will be sent and received via 2.4GHz IEEE802.15.4 compliant radio waves. The star networking topology will be used such that each mote is wirelessly connected to a central mote that will send the desired data to the main computer for data collection and analysis. Each mote is capable of being programmed so that data can be sent at certain intervals throughout the day, rather than continuously. By collecting data at discrete times, each mote saves power by reducing power consumption during times of inactivity, thus extending the life of the system.

Casing

A cone shaped casing will enclose and protect the circuitry of each mote from the extreme environmental conditions it may face (refer to Figure 1). This conical shape has been chosen for several reasons:

- The circular base provides a strong foundation by eliminating stress points (i.e. any vertices at the base) that may cause the casing to crack upon deployment and consequently expose the circuitry to dust.

- The heavier bottom increases the probability that the mote will land and remain upright for its duration of use.

- The angled sides reduce dust build up, allowing maximal sun absorption by the solar panels, and providing the ideal location for the antenna (at the top of the cone) where dust collection is least, keeping the communications open for the longest period of time.

Additionally, a hollow spike, central in the casing, will provide a means of penetrating the soil to release the chemical dyes it holds. Organisms on the direct surface of Mars are more difficult to detect as the high UV radiation on the surface destroys or greatly alters genetic material, decreasing the chances that anything will be found. Therefore, by releasing the bio-chemicals below the immediate surface, the data collected would be a more accurate and in-depth look into whether life exists on Mars.

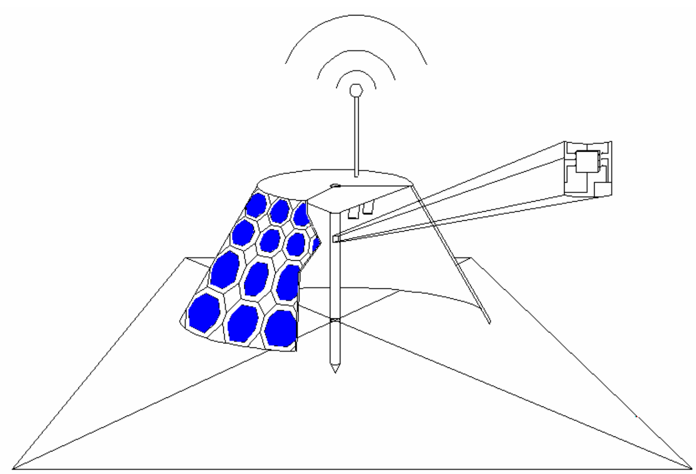

Figure 1: Cross-sectional diagram of casing showing central spike and outer solar panels.

Ideally, the casing would be constructed using similar materials used for the Mars Exploration Rover; an aluminum honeycomb structure sandwiched between graphite-epoxy face sheets covered by an additional layer of phenolic honeycomb filled with ablator, a material that dissipates heat by atmospheric friction. However, due to budget limitations, off-the-shelf materials will be used instead. Unable to find an aluminum cone for a reasonable price, a traffic cone will suffice as the conical structure that will house the mote components. A pipe will be affixed as the spike that will contain the chemical dyes. The spike will be attached to the cone using epoxy glue. Solar panels will also be mounted to the cone using epoxy.

Power Supply

To power the mote efficiently and for the longest period of time, it was necessary that a renewable energy source be incorporated to recharge the batteries. Solar panels mounted on the conical casing were the best option. A circuit consisting of solar cells, rechargeable NiMH batteries, and a Schottky diode will be used (refer to Figure 2).

Flexible thin film solar modules have been chosen because of its lightweight, paper thin, and durable qualities. The flexibility of the solar panels is important since it will be wrapped around a conical casing. These solar modules have been specifically developed to recharge AA, AAA, plus 6 and 12 volt batteries.

The solar modules purchased operate at a voltage of 6.0 V and 100 mA. The size in inches (L x W x T) of each solar module is 4.5 x 5.9 x 0.01. Based on these specifications, the solar cell's energy conversion efficiency (i.e. the power converted from absorbed light to electrical energy) can be calculated:

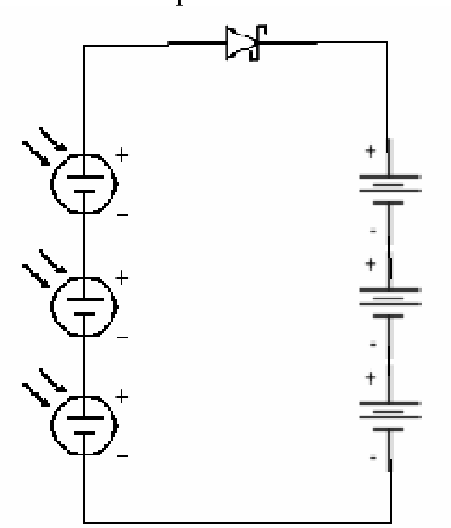

Figure 2: Circuit diagram of power supply.

Let η = the energy conversion efficiency
Let P_M = the maximum power point
Let E = the input light irradiance
Let A_C = the surface area of the solar cells
Let $\eta = P_M / (E \times A_C)$

Substituting values into the equations for P_M, A_C, and η,

$P_M = (6\text{ V})(0.1\text{ A}) = 0.6\text{ W}$
$E = 589.2\text{ W/m}^2$ (taken from Mars data sheet)
$A_C = (4.5\text{ inches})(5.9\text{ inches}) = (0.1143\text{ m})(0.16968\text{ m}) = 0.017129\text{ m}^2$
$\eta = 0.6 / [(589.2\text{ W/m}^2)(0.017129\text{ m}^2) = 0.059451 \approx 5.95\%$
The solar modules convert approximately 5.95% of the absorbed sunlight into usable energy.

Referring to the datasheet for the devices purchased, the maximum value used for the voltage and current are 3.6 V and 50 mA, respectively. The maximum power consumed would be P = (3.6 V)(50 mA) = 0.18 W, or 1.67% of a 6 V, 1800 mA battery. Therefore, each solar panel module would be sufficient in charging five batteries, or one battery pack.

The batteries used will be 6 V, 1800 mAh, nickel medal hydride (NiMH) rechargeable battery packs (each pack contains 5 AA batteries connected in series). Compared with the similar NiCd battery, NiMH batteries are more environmentally friendly as its anode is made from a hydrogen-absorbing alloy instead of cadmium. This reinforces one of this project's goals, which was to create motes that are least invasive to the environment. Additional benefits in using NiMH batteries instead of rechargeable NiCd batteries are: lower memory effect so batteries do not require full discharge before recharge and can hold more charge, a higher internal resistance best suited for devices that do not require a lot of power, and long term maintenance by low duty cycle pulses of high current rather than continuous low current (which is ideal since the solar panels will be unable to provide a continuous low current to the batteries at night).

A Schottky diode will prevent the batteries from discharging through the solar cells at night. Schottky diodes are especially useful for the discharge protection of solar cells because of its low forward-voltage drop and quick switching.

CONCLUSION

Based on the design developed, a prototype mote network will be built to demonstrate the effectiveness and feasibility of using such technologies as an alternative means of detecting life in extreme environments such as Mars (i.e. compared to life detecting rovers). If initial tests in Hawaii prove successful, further tests in Chile's Atacama Desert, a site that has been used by other NASA researches as a "Mars analog environment," will be conducted. The data collected will be used to determine whether life exists or could exist, thus, opening up the options for further space exploration.

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