FABRICATION OF A WIRELESS SENSOR NETWORK FOR EXTREME ENVIRONMENTS

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ABSTRACT

The ability to detect and measure water is crucial to identifying possible sites for human colonies/inhabitance in environments beyond Earth. A network of autonomous motes has the potential to augment current missions that have already found water on Mars by covering a greater area to determine how much water is present, over what area, and if it is enough to sustain life. Environmental factors – temperature, humidity, and light – will provide complementary data.

INTRODUCTION

An upcoming Mars Mission Simulation at the Flashline Mars Arctic Research Station (FMARS) at Devon Island will serve as the analog Mars environment in which the sensor network will be tested and for which the component specifications are based. The similar geology and permafrost in the rocky dry deserts of the Arctic make it ideal for testing how permafrost changes as temperature changes and how life responds to those changes. Dr. Kim Binsted, project mentor, will be participating with Dr. Chris McKay and his team in the 2007 Arctic mission.

Note that this project is a continuation of last semester's "Intelligent Sensor Network for Extreme Environments" which sought to find life by detecting bio-signs such as DNA, proteins, and macromolecules. This project, however, has been modified to meet the new goals of the upcoming Mars Mission Simulation. The revised block diagram of each mote is given in Figure 1 and each subsection subsequently discussed.

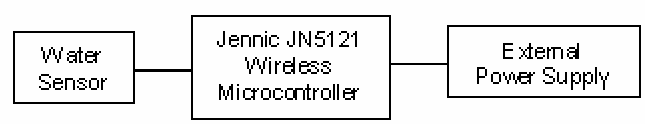

Figure 1: Revised block diagram of a mote.

NETWORK

Jennic's IEEE802.15.4 evaluation kit has been used to implement the wireless sensor network. Data is sent and received via 2.4GHz IEEE802.15.4 compliant radio waves. The star networking topology is currently being 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. An alternative to the star topology is having the motes communicate between each other, "hopping" information between outlaying motes until it reaches the central mote where it is sent to the computer.

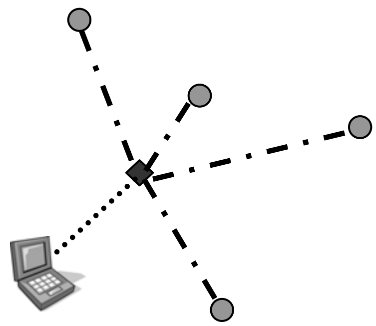

Figure 2: Star networking topology currently configured on the motes.

Figure 2 shows graphically how the motes are connected. The black diamond represents the central mote, while the gray circles represent the outlaying motes. Dashed lines represent the [wireless] communication between motes and the main mote, and between the main mote and the computer.

Data is sent at certain intervals throughout the day, rather than continuously. Data packets can be tracked using the Daintree Sensor Network Analyzer. By monitoring data packets, it can be determined which motes continue to send useable data, and which are no longer functionally working in the network. 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. To extend the life of the system further, an external power supply has been designed to recharge the rechargeable batteries that are supplying the power to the mote.

The current sensor network will be upgraded to use the Zigbee software so that it will be compatible with the kit purchased by Dr. Chris McKay.

POWER SUPPLY

Since the Arctic will now be the test location, the solar cell's energy conversion efficiency has been recalculated (i.e. from last semester):

Let η = Energy conversion efficiency
Let P_M = Maximum power point
Let E = Input light irradiance
Let A_C = Surface area of solar cell
Let $\eta = P_M/(E \times A_C)$
Substituting values into the equations for P_M, A_C, and η,
$P_M = (6\ V)(0.1\ A) = 0.6\ W$
$E = 5.8\ kWh\ m^{-2}\ day^{-1} = 5800\ Wh\ m^{-2}\ day^{-1}\ (1\ day / 24hours) = 241.667\ W/m^2$
$A_C = (4.5\ inches)(5.9\ inches) = (0.1143\ m)(0.16968\ m) = 0.017129\ m^2$
$\eta = 0.6 / ((241.667\ W/m^2)(0.017129\ m^2)) = 0.14535 \approx 14.535\%$

The input light irradiance was calculated by averaging the input light irradiance for the months May through August (since the 2007 Mars Simulation in the Arctic will span those four months). Monthly values were found on the International Solar Irradiation Database from the University of Massachusetts Lowell Photovoltaic Program. Therefore, on average, the solar modules will convert approximately 14.535% of the absorbed sunlight into usable energy.

For the solar modules to charge the battery, its voltage must be higher than that of the battery. Each solar module consists of 10 cells arranged in two series strings of five cells. One solar module will be used with one battery to ensure that the current from the solar module does not exceed 10% of the battery's operating current (a general rule so as not to damage the components). Justification for the chosen power supply parts are provided in last semester's fellowship report.

The battery will be the source of power for both the mote and the water sensor. Both, however, require different operating voltages, which created the need to incorporate such a constraint into the design.

WATER SENSOR

A Honeywell LLE series sensor was chosen and purchased commercially. The water sensor operates based on the principle of total internal reflection, or the amount of incident light that is reflected at the boundary between two mediums. A LED and phototransistor are housed in a plastic dome. Changes in the internal reflection of light from the LED to the phototransistor at the dome-liquid boundary provide the appropriate output. If water is present, the refractive index at the boundary changes such that light from the LED escapes; otherwise, the light is reflected back to the phototransistor giving a high output, indicating no water. The output from the water sensor, labeled ADC1 in Figure 3, is connected to the microcontroller on the mote via the mote's expansion connector.

FABRICATION AND ASSEMBLY

The circuit below was fabricated in the lab. This prototype circuit recharges the battery pack, and powers the water sensor and mote. From left to right are the solar module, Schottky diode, rechargeable battery, water sensor, and voltage regulator.

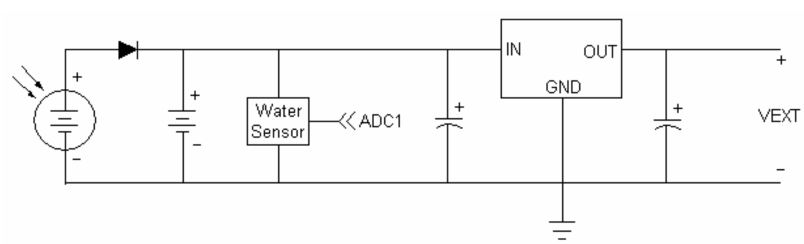

Figure 3: Circuit diagram for prototype

The plastic coating from each of the leads of the solar module was removed using needle nose pliers, being careful not to damage the metal contacts underneath. A digital multimeter was used to test each side for polarity and a sharpie pen was used to mark polarity (+ or –) on the backside of the solar module. As recommended by the solar module data sheet, 24 AWG wire was used. Wires were connected to the exposed metal solar module contacts using a solder "dot." Referencing data sheets for the remaining parts ensured the correct polarity such that all components share a common ground.

The outputs ADC1 and VEXT are inputs into the mote. ADC1 is the output from the water sensor whose voltage is low (i.e. 0 V) when water is present, and high otherwise. Since the water sensor requires 5 to 12 V of power, compared to the 2.7 – 3.6 V required by the mote, it is placed in parallel with the 6 V rechargeable battery. A voltage regulator was used to reduce and maintain the supplied 6 V from the battery to a constant output voltage of 3.3 V, VEXT, which is the supply voltage to the mote. VEXT is connected to a 2.5 mm jack socket that can be plugged directly into the main mote.

EXPERIMENTAL RESULTS

With the star topology, outlaying motes can communicate within a radius of approximately 50 feet from the main mote. The temperature, humidity, and light sensors were tested by comparing measurements from a mote placed in the freezer and a mote placed in the refrigerator. The main mote was kept outside, at room temperature, as a control. Room temperature conditions indoors were measured at 29° C, 75% humidity, with no light. The measurements from the freezer mote decreased steadily to 5° C with 20% humidity; thereafter, decreases were slower, but eventually went to 0° C. In the refrigerator, the temperature steadily decreased to 10° C with 51% humidity; similar to the mote in the freezer, decreases were slower thereafter, eventually reaching approximately 4° C. When the refrigerator and freezer lights turned on, both motes indicated light, however, there was a slight delay in sending that data to the main mote by 1 – 2 seconds.

Alarms on the mote can be specified at a desired value to alert the user when that value is reached. The temperature alarm can be set to go off between 0° C (low) and 100° C (high), the humidity alarm for 0% (low) to 100% (high), and the light alarm for complete illumination (high) to mostly dark (low). A display flashes on the main mote when the desired value is reached.

A partnership was established with Dr. Eric Miller from the Hawaii Natural Energy Institute and his graduate students – Noah Hafner, Blaine Hironaga, and Dennis How – to test the behavior of the solar modules in the lab under ideal conditions. AM1.5 solar simulated light was used to measure the overall cell efficiency, determine the voltage/current characteristics, and obtain the current/voltage response curves. Measuring the quantum efficiency at different cell biases determined the solar module's sensitivity and how it responds to differing sunlight (for example, if there is cloud coverage). The collected data has been plotted by Noah Hafner, Blaine Hironaga, and Dennis How and is given in Figure 4 and Figure 5.

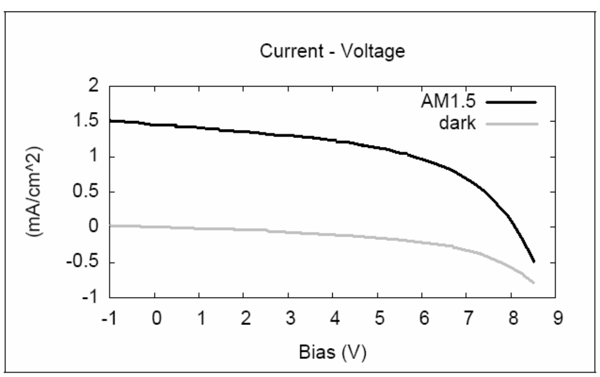

Figure 4: Current-Voltage plot of simulated AM1.5 light and dark JV

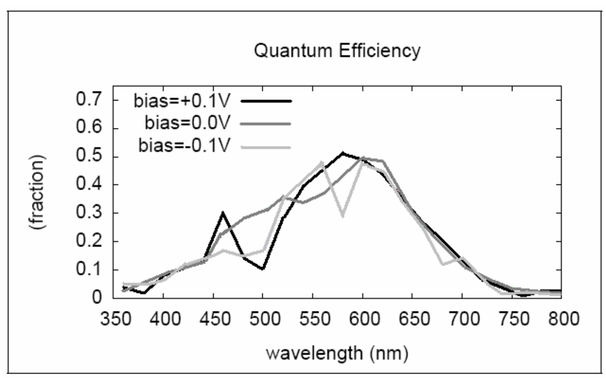

Figure 5: Plot of Quantum Efficiency for different valued biases.

The water sensor output is low when water is present, and high otherwise. In water, the sensor output yields 0 V. With no water, the sensor output voltage starts at the input voltage and decreases continually to about 2 V. Placed against an ice cube and submerged in large shards of ice did not give a positive detection of water. A drop of water on the sensor also did not yield a positive detection of water. The waterproofing on the water sensor was also tested and survived numerous tests of complete submersion in water.

ANALYSIS AND DISCUSSION

For a more accurate measurement of environmental factors, data should be collected between larger intervals to account for the gradual decreases that occur after reaching an initial steady state, which seem to be approximately 5° C greater than the actual final temperature. To extend the range of the network, the star topology can be reconfigured to use the mesh topology. The mesh topology will allow data hopping between outlaying motes if they are unable to reach the main mote directly.

A projected lifetime for the battery and life of the mote can be predicted based on the amount of light measured by the light sensor and absorbed by the solar module. For example, on days of greater sunlight, it would be expected that the batteries are recharging more often than discharging and will have more stored power to supply in times of no sunlight.

From Figure 4, the current-voltage curves for the solar module under the AM1.5 simulated solar light and that in the dark are similar; both decrease with an increasing bias voltage. The quantum efficiency for cell biases at –0.1 V, 0.0 V, and +0.1 V are also similar, resembling a bell-shaped curve as shown in Figure 5. The axis over which the quantum efficiency is plotted represents a range of wavelengths in sunlight from UVB and UVA (320 – 400 nm), the visible spectrum (400 – 760 nm), and infrared (greater than 760 nm). The wavelength at which the quantum efficiency is greatest is within the visible range.

The water sensor will perform ideally when submerged in water. Therefore, it would be best to incorporate several water sensors on each mote to increase the probability that the mote will detect water should only a small area under the mote will result in the positive detection of liquid water. Temperature is crucial in distinguishing between water and ice should water be detected.

CONCLUSION

In conclusion, a robust network of five motes has been designed and built to achieve the goals of this project: water is detected as an element necessary for life; a rechargeable power source extends the life of the system; most components, whenever possible, are RoHS compliant and thus environmentally friendly; data collected provides reasonably accurate and useful information; and low cost and use of commercially available materials make the sensor network easy to manufacture.

ACKNOWLDGEMENTS

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