TELEMETRY SYSTEM FOR THE SOLAR MINER VII

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ABSTRACT

This paper describes a telemetry system used in the Missouri S&T solar car, which competed in the American Solar Challenge. The system monitors parameters of a number of the on-board electronic and mechanical systems, and also the activities of the vehicle driver. This data is transmitted to a lead vehicle, where the support team analyzes the performance in real-time to optimize the vehicle's performance. In previous vehicles the data was displayed using a LabVIEW based user interface. In this work we will describe a custom software solution, which provides the team with additional flexibility to display and analyze the data.

Keywords: Telemetry System, Alternative Energy, Graphical User Interface

INTRODUCTION

This paper describes some of the issues faced when developing a telemetry system for an automobile used in the semi-annual American Solar Challenge race. The paper begins with a summary of the competition, along with the vehicles and personnel used during the race. It then describes the electrical subsystems of the race vehicle, along with the parameters which need to be monitored and transmitted to the support personnel during the race. Finally, the paper describes the motivation for altering the graphical user interface for the telemetry system.

AMERICAN SOLAR CHALLENGE

One of the earliest long-distance solar vehicle races was the World Solar Challenge (WSC) held in Australia in 1987. The winning team in that race had a substantial fleet of support vehicles, and ran a car that attained an average speed of just under 67 km/h. The WSC has been held every two or three years since its inception. Eventually the vehicles were traveling at the posted speed limit of 110 km/h.

The remote location of the WSC has always made it a logistical, and financial, challenge for universities based in North America to send teams. To help address this problem, in 1990 the

Sunrayce USA was introduced. As with the WSC, the Sunrayce covers thousands of km over state and national highways. The race has been held every two or three years, with the most recent event held in June 2010. The name of the race has changed as its sponsorship has changed, morphing from the Sunrayce in the 1990's, to the American Solar Challenge [1]. The race route has varied from just under 2,000 km, to over 4,000 km. The 2010 race route was from Tulsa, OK to Naperville IL (see Fig. 1).

Figure 1. 2010 American Solar Challenge Race Route
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A total of 14 schools from four countries qualified for the 2010 race. A student team from Missouri S&T (formerly known as the University of Missouri – Rolla) has competed in the ASC since 1993, with the most recent entry christened Solar Miner VII. The telemetry system described in this paper was used to support the Solar Miner VII vehicle.

All vehicles in the race are powered exclusively from energy generated by an on-board solar array, although the vehicle is allowed to start the race with fully charged batteries. The solar array can be no larger than 6.00 m^2 (or 9.00 m^2 if using one of the ASC approved photovoltaic cell types), while the overall vehicle dimensions are limited to 5.0 m length, 1.8 m width and 1.6 m height. As with the WSC, most years the vehicle speeds are limited only by the posted speed limits, and the quality of the road surface.

SOLAR CAR TELEMETRY

Because the solar car is an unconventional design, and has a low profile, for safety it is driven between a lead and chase vehicle [2]. Additional support vehicles for scouting the race route and supporting the car may also be driven in the race, although they are not in close proximity to the solar car. The chase vehicle, see Fig. 2, in addition to alerting drivers to the presence of the solar car, also carries an ASC observer, and must maintain 2-way voice communication with the solar car driver.

Figure 2. Solar Miner VII and Chase Vehicle

Given the limited amount of power generated by the solar array, and the variable weather and traffic conditions, the race strategy is critically important. It is also important that the support team be able to monitor the performance of the driver, to insure he or she is operating the vehicle in a manner which best conforms to this strategy. To accomplish this, a telemetry system is built into the solar vehicle, with the data transmitted to the chase vehicle.

A block diagram of the electrical system for the Solar Miner VII is shown in Fig. 3. A large number of parameters are monitored on the vehicle. The solar panel current and voltage, motor voltage and current draw, a number of voltages in the battery pack, along with the charge/discharge current, motor gap, pedal activation by the driver, and a variety of other parameters. All parameters are transmitted to the chase vehicle every 500 msec on average. A summary of the various subsystems follows.

BATTERY SYSTEM

The solar car stores excess energy generated by the solar array and regenerative braking system in a bank of lithium polymer (Li-poly) batteries. This 25 kg battery bank consists of 26 modules wired in series. Each module contains 6 Li-poly cells in parallel. This combination provides a voltage between 96.2 and 109.2 volts at the battery pack output. It is critically important that the support team monitor the voltage across each module, along with the total bank voltage. Inside each module, there is an INA 148 difference amplifier to measure the module voltage. The amplifier output is fed to a 12 bit analog-to-digital converter, which is working on a 5 volt reference, since the maximum battery cell voltage is approximately 4.23 V. This provides the support team with a precision of 1.22 mV per quantization step.

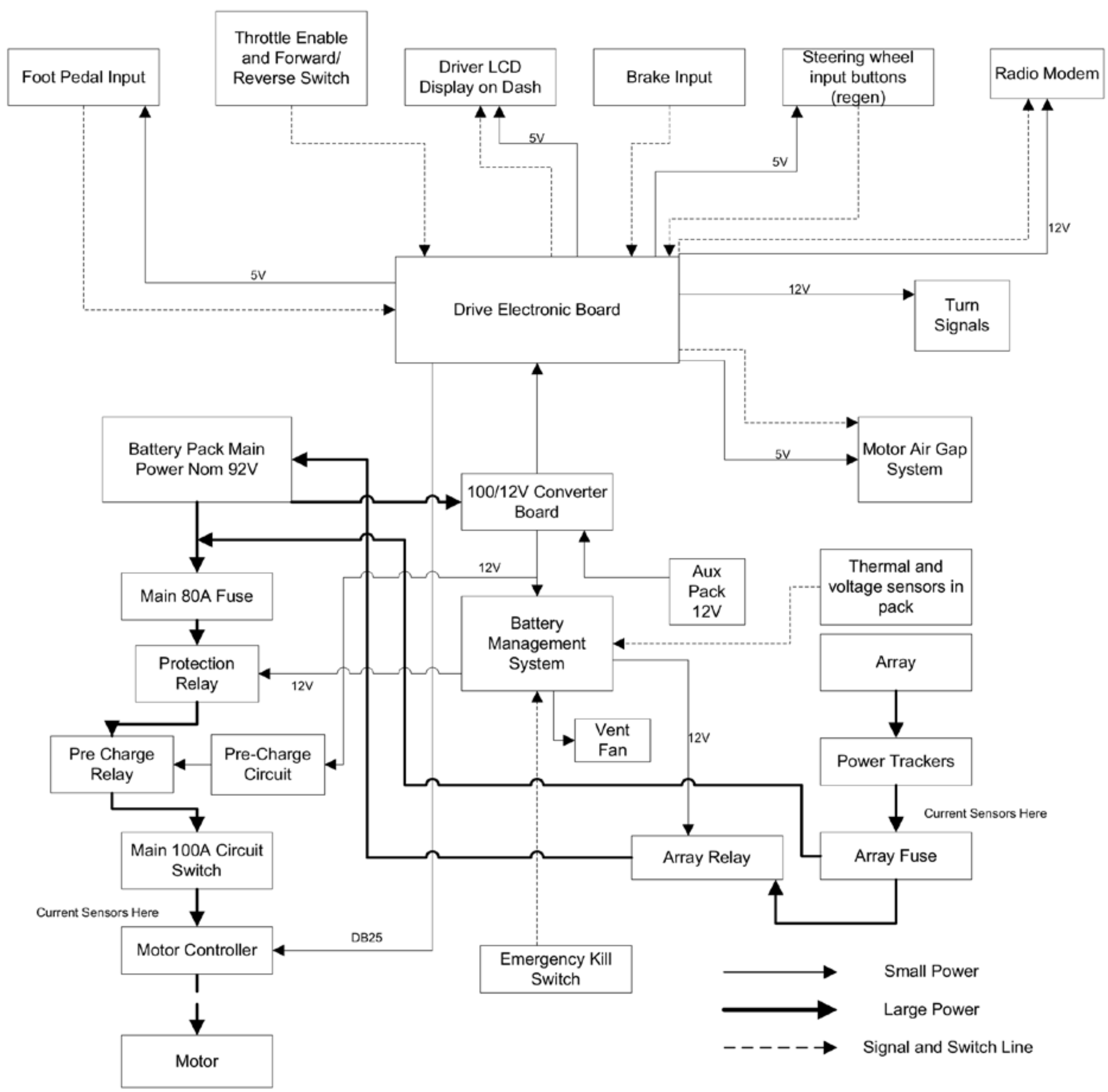

Figure 3. Solar Miner VII Electrical Subsystems

While Li-poly cells are high performance, they are a bit tricky to charge [3]. Under ideal conditions, all cells would be charged with a constant current source, until all modules reach a voltage of 4.2 V. When this target voltage first occurs, the battery pack has reached approximately 70% of its rated capacity. At this point it is best to use a voltage source to charge the cells, up to their rated capacity. Once the battery pack is fully charged, all charging current must be terminated. Overcharged Li-poly batteries are a safety hazard. The measured battery voltages are monitored by the on-board battery protection system. In addition, the voltages are transmitted to the chase vehicle, as part of the telemetry frame. In addition, the battery pack current is monitored on-board, and sent to the chase vehicle.

EMI ISSUES AND SENSOR CALIBRATION

Electromagnetic interference has been a significant challenge [6] when making voltage and current measurements. In the initial design, the Hall Effect current sensors were placed at some distance from the digitizer, and no analog filtering was used on the sensor. This provided very inaccurate readings. The design was then changed so that all sensors now have a low pass analog filter in close proximity to the sensor, and the 12 bit ADC were moved as close as practical to the sensors. To further reduce the impact of noise, digital filters were added in the telemetry processor. This moving average digital signal processing (DSP) filter computes the average current and voltage over one second intervals. This window provides a significant amount of noise reduction, and is appropriate for solar panel output since changes in panel illumination is usually slow compared to the one second interval. The one second averaging can be a bit long when monitoring motor current consumption, especially during regenerative braking operations.

To calibrate the current sensors, a Bitrode™ current source was used. This calibrated source [4] was set to generate currents from 5 to 50 amps. The sensor voltage was monitored for 3 seconds at each of the current points, with the results shown in Fig. 4. The test confirmed that the linearity of the sensor was well within the system performance specifications. The sensors have a differential output which could increase the accuracy of the measurement. However since the single ended input was easier to use, and meets our design goals, we elected not use the differential signaling.

DRIVE MOTOR MONITORING

One of the important parameters to monitor is the “gear” the car is in. There are quotes around the word “gear”, because the vehicle does not have a conventional transmission. The Solar Miner VII uses a brushless DC motor with an adjustable air gap between the rotor and the stator in the axial direction [5]. This adjustable gap provides the variable torque/speed ratio of a conventional transmission, without the weight and mechanical losses of physical gears. The gap space ranges from 1.75 mm to 6 mm, and the speed ranges from 600 to 1200 RPM, when the motor is operating in its most efficient range. The gap distance is measured using a precision potentiometer that is connected to the gap adjust sprocket. The analog signal produced by this pot is fed to an ADC, which gives the support staff a measure of gap position with approximately 6 bit accuracy.

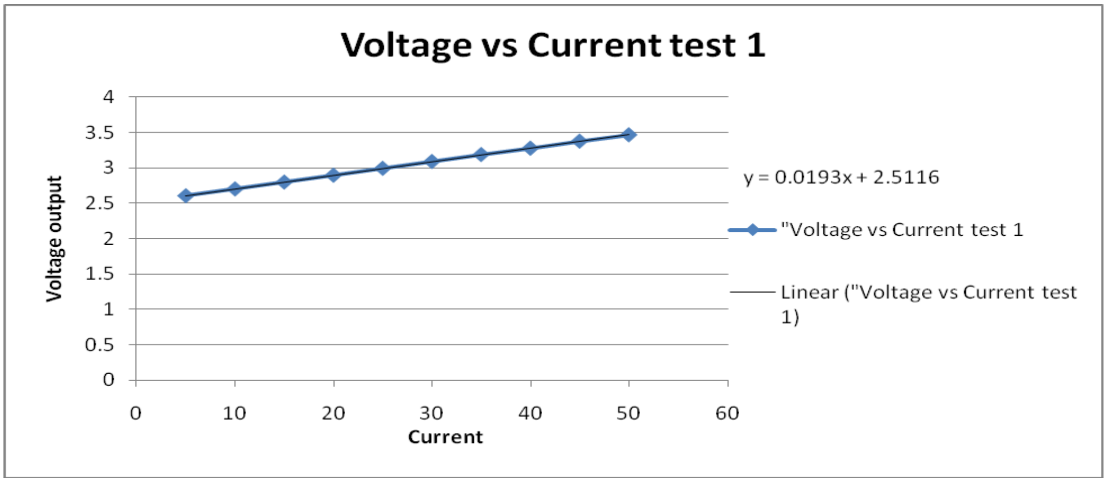

Figure 4. Calibration Data for Current Sensor – Test 1

A spread sheet has been constructed, which allows the user to enter the desired gear ratio, vehicle wheel diameter, and gap range on the pot. The spread sheet will then indicate the optimal gap position for a particular range of speeds. During the race, the strategist will call out a target speed and the appropriate gap position for the target speed. This information will be relayed to the driver.

MONITORING DRIVER PERFORMANCE

Prior to the race, extensive data is collected on the drag coefficient and rolling resistor of the vehicle. The battery pack is also exercised. The pack is discharged at different rates, to determine the amount of energy that can be extracted as the car travels at different speeds, and with different lighting conditions. The race route is entered into a geographic information system, which calculates the elevation and slope of the roadway at closely spaced intervals.

During the race, a GPS receiver will track the current position of the vehicle. This is used with the GIS data to calculate the elevation changes, bearing angle, and sun angle throughout the day. Forecast and measured wind velocity, cloud cover, and weather conditions are also used during the race, along with the posted legal speed limits and current and anticipated traffic conditions.

Finally, information from the telemetry system on estimated battery charge, current solar array power generation, potential return from regenerative breaking, and vehicle speed are provided to the strategist in the chase vehicle. The strategist then relays to the driver the target motor gap for the “transmission”, target speed, and use of regenerative braking to optimize the vehicle’s performance.

During the race, a calculation of watt-hours per mile is calculated for each driver. This data is exported in a csv format, so it can be readily read by spread sheets and plotted. These logged files help the support team to determine which drivers have the best performance. The data is used to both select drivers for future days, and also to help train all the drivers. The data can also be used to determine which driver is purchasing the refreshments at the end of the day.

GRAPHICAL USER INTERFACE

In previous Solar Minor vehicles, much of the data manipulation was performed by the on-board processor. Results of these calculations were transmitted to the chase vehicle, where a LabVIEW™ based system was used to display the results, similar to that shown in Fig. 5. The Solar Miner VII will take a different approach. The on-board processor is being reduced in size, power and complexity, to an 8051 based microcontroller. This processor will not support the numerical processing load of the previously used telemetry processor, and in particular will not support multiple thread processing. If all the data manipulation is kept on the vehicle, the rate that the key parameters can be measured and updated will be greatly restricted.

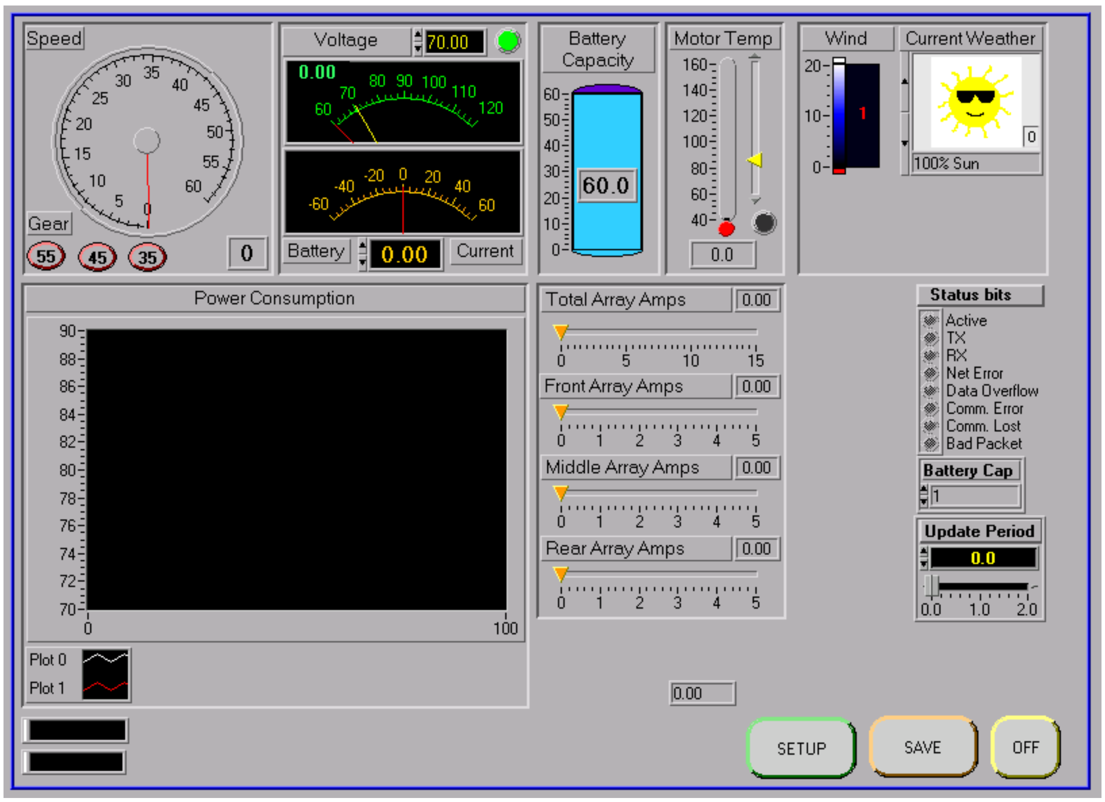

Figure 5. LabVIEW™ Graphical User Interface

The new telemetry system will offload more of the processing to the chase vehicle processors, where Matlab™ will be used for both numerical manipulation and graphical display. Part of the motivation for this, is that the chase vehicle has essentially unlimited processing power – at least when compared to the low-power, low-weight and small size restrictions placed on the solar car telemetry processor. We anticipate the Matlab™ code will be easier to monitor and modify during the race, and also it will be easier to export the data in a format that it can be manipulated by spread sheets and other numerical analysis programs. Finally – and this is not intended to insult the solar car driver – there is simply more brain power in the chase vehicle to view, manipulate and interpret the data. The solar car driver has a full work load, keeping up with road conditions and monitoring the basic vehicle performance.

CONCLUSION

The American Solar Challenge provides an opportunity for university teams to develop vehicle technology, and alternative energy systems. To make the most efficient use of these vehicles, a wide variety of measurements are collected, and sent to a nearby chase vehicle. This paper described portions of the telemetry system used on the Solar Miner VII vehicle development by Missouri S&T, which was used in the ASC 2010 race.

REFERENCES

[1] http://americansolarchallenge.org/events/asc2010/
[2] 2010 American Solar Challenge Regulations, Rev. D, Innovators Educational Foundation, June 2010
[3] Harding Battery Handbook, Harding Energy Inc., Norton Shores, MI, Jan. 2004
[4] http://www.bitrode.com/
[5] J. Loarie and C. Wang, "Novel Brushless DC Motors", Appliance Design, BNP Media, Jan. 2001
[6] J. Dean et. al., "EMI and Software Improvements to the Solar Miner IV Telemetry Processor", International Telemetry Conference / USA, Oct. 2004