DEVELOPMENT OF A VEHICLE HEALTH MONITORING SYSTEM

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ABSTRACT

The Semi-Autonomous Underwater Vehicle for Intervention Missions (SAUVIM) under development in the Autonomous Syste[illegible] within the Department of Mechanical Engineering at the University of [illegible] requires the development and integration of a system capable of monitoring key [illegible] to ensure the health status of some of its core systems. The core systems are [illegible] main pressure vessels mounted inside the vehicle. The monitoring system that [illegible] and built consists of two types of sensor suites per pressure vessel to provid[illegible] information and a level of redundancy. The primary sensor suite is integ[illegible] vehicle's main computers to monitor pressure, moisture, and temperature at [illegible] inside each pressure vessel as well as battery bank voltage and current draw. [illegible] sensor suite is a standalone unit that operates independently of the vehicle'[illegible] computers. The standalone sensor suite monitors pressure, moisture, [illegible] and internal power while incorporating a triggered audio alarm and ou[illegible] signal. Both types of sensor suites are modular, easily removable and interch[illegible] the pressure vessels.

INTRODU[illegible]

A vehicle health monitoring system is ne[illegible]ove safety and reliability as well as reducing operating and maintenance c[illegible]ologically advanced vehicles. Vehicles such as spacecraft, aircraft, and su[illegible]enefit greatly from a health monitoring system. Through the use of these [illegible]icle can eliminate or at least minimize failure through early warning and on-[illegible]. The SAUVIM vehicle, like a spacecraft, encounters a widely varying rang[illegible]al factors in the course of a mission and it needs to closely monitor these [illegible]e appropriate action in the event of abnormal readings. Many of the facto[illegible] guarded against are the same in spacecraft as they are in deep diving su[illegible]h as temperature, pressure, condensation, and power considerations. In [illegible]VIM vehicle will face some additional environmental hazards not found in [illegible] as the threat of liquid water buildup from pressure vessel leaks.

METH[illegible]

Just as a spacecraft experiences major [illegible]changes when moving from sunlight to shade, the SAUVIM vehicle will ex[illegible] temperature changes. While in direct sunlight, on the deck of a ship or on [illegible] water, the pressure vessel temperatures on the SAUVIM vehicle can rise [illegible]diving to maximum depth of 20,000ft. below the ocean surface the temp[illegible]op to near freezing and the external pressure can climb to 10,000psi. This drastic change in environment can result in temperature swings inside the pressure vessels of about 110°F. Condensation can occur due to large changes in temperature affecting gas in a fixed volume. To prevent condensation from occurring the pressure vessels are evacuated and filled with nitrogen gas to a pressure of 15psi. During the evacuation process pressure sensors inside the vessels are used to prevent over evacuation and damage to sensitive components. For this, the standalone sensor suites are used because they are able to function without the vehicle's computers or power. Once underway, the vehicle must be able to continuously monitor the pressures and temperatures inside the pressure vessels as well as identify the presence of liquid water and monitor the battery voltage and the current draw.

All health monitoring data from the primary sensor suites are reported to the vehicle's two main VME computers to be analyzed and stored. For any conceived recoverable failure condition (as opposed to a catastrophic failure such as pressure vessel implosion or a main structural frame failure) the vehicle must be programmed to detect such a condition based on abnormal readings from the sensors on the health monitoring network and notify the supervisory program and/or personnel. Just like a spacecraft, the pressure vessels and electronic components can fail due to any of the following identified conditions: 1) excessive moisture from condensation 2) excessive heat buildup 3) pressure vessel leaks 4) under pressure (over evacuation of bottles) 5) over pressure 6) low voltage 7) battery overdraw 8) miscellaneous factors.

Additional constraints are place on the design of the sensor arrays in the form of size, interchangeability, sensor functionality, operating time, and ruggedness. The standalone sensor boxes are limited in size to 1" x 2" x 3" and must contain their own power source for 12 hours of operation. The primary sensor boxes are also limited to the same size but contain different circuitry, additional sensors, and a computer interface used for power supply and signal routing.

RESULTS

Preparation began by brainstorming SAUVIM failure scenarios and thoroughly characterizing the operating environment. A suite of sensors was chosen for each bottle to detect temperature, pressure, power bus, power shunt, and leaks. Additional work and research was done in generating system block diagrams for both sets of sensors as well as contacting sensor manufacturers for sourcing and technical specifications. Preliminary sensor tests were carried out to measure accuracy and precision of various brands of components.

To provide a level of independent checking capacity and redundancy, two separate monitoring systems were built. The primary sensor suite that runs on vehicle power is linked to the main VME computers through an RS-485 network while the secondary standalone system operates independently from the main computers and vehicle power. The following general tasks were accomplished for the primary sensor suite; preliminary testing of sample components, selection and ordering of components, building interface circuitry, bench calibrating each class of sensor and integrating sensors onto the data acquisition nodes. An integral part of the Vehicle Health Monitoring System is the C-code used to monitor and interpret the voltages being fed into the computer from the various sensors via A/D converters. Programming tasks included data channel addressing of each sensor and conversion of voltage readings into measured values. Additional work was left to be done in coding the detection routines for sifting for abnormal values. Software development took place on a DOS based PC using Borland Turbo C. Attention to using standard C libraries was done to ensure portability of final code onto the VME VxWorks environment of the SAUVIM vehicle. The code has been written to handle 6 separate channels for each RS-485 circuit; however, each A/D converter is capable of handling 8 channels leaving room for expansion. The six channels currently being used are for battery bank voltage, battery shunt, two separate thermistors for temperature readings, a leak sensor and a pressure sensor. The temperature sensors and leak sensor are variable resistance sensors attached to the sensor boxes by a short length of wire allowing for strategic placement inside the pressure vessels. In addition, all the temperature sensors and leak sensors are standardized and interchangeable between any of the sensor boxes and are attached using standard 3.5mm mini audio plugs and jacks. Routing of signals and communications resulting from the health monitoring network sensors needs to be fairly noise resistant and straightforward. For this great attention was given to ensuring electrical isolation of the sensor circuitry from the vehicle's electrically noisy environment.

The standalone units are all completely analog circuitry based. Any fault condition triggers reporting by means of two techniques: a loud piezo buzzer and via an analog line feeding into the vehicle's main VME computers. All of the support circuitry as well as the power supply for the standalone units are enclosed within a portable housing placed within each of the six main pressure vessels. Design criteria requires continuous operation of the standalone sensor suites for a minimum of 12 hours, therefore, they are attached to the interior of the pressure vessels with Velcro strips to simplify removal for battery replacement and service. Every effort was made to use easily available commodity items with a minimum number of exotic components and a minimum power draw in order to maximize reliability and operating time. By having portions of the health monitoring system independent of the main SAUVIM power systems continued monitoring is provided even during a power loss or during deck handling when the power is not yet on.

Once sensor selection was complete preliminary circuit design began for the standalone sensor suites. Designs for the circuit were initially constructed on socket-board for ease of testing. Once a design was decided upon the components were soldered onto a circuit board for additional testing and calibration. After making numerous modifications to decrease power consumption the circuit was assembled and integrated into a plastic housing. The housing was then fitted with 3.5mm mini audio input jacks for each of the two temperature sensors, two leak sensors, and the output signal cable (fig. 1). After further refinement of the prototype a final circuit design was decided upon (fig. 2). The final stand-alone sensor boxes each contain a 9-Volt Lithium ion battery, a piezo buzzer, two temperature sensors, two leak sensors, a pressure sensor, and an LED to signal low internal battery voltage. In the design of the primary sensor circuit extra care was taken to ensure the sensors were electrically isolated from noise on the ground lines of the vehicle. This was done through the use of two optical isolators between the signal source and the remainder of the circuit in addition to using an isolated power supply for each circuit (fig. 3). Like the stand-alone circuit, designs were initially constructed on socket-board for testing and analysis.

During the course of this project much time was spent troubleshooting anomalies in the performance of the circuits. Though the final sensor suites now work as designed, the initial circuits developed encountered numerous problems. With the initial circuit designs for the primary sensor suite many seemingly unpredictable fluctuations in voltage were being measured at different nodes along the circuit. Because the circuits were designed with specific voltages and currents across each branch, deviations from these values were easily noticed by taking measurements. At times, these deviations in voltages were as high as 20% from the calculated values. After further analysis of the circuit it was found that the signal ground line was not truly grounded by the interfacing cable inside the PC being used for testing. Therefore, the signal ground was actually floating and causing unreliable results and intermittent fault triggering. By experimenting with different circuit designs an alternative configuration was found that eliminated the problem. Another problem arose as a result of the isolation amplifier. Because it was necessary to use an HCPL 7800A optical isolator, the input signal is only able to be in a range of 0.0-0.3 volts before saturation occurs. The signal source that must be read into the circuit for measurement falls in the range of 24-144 volts. To make this measurement possible all the voltages are scaled down to 24 volts before entering the circuit. The 24-volt signal is then further scaled down in the circuit until the full range of possible battery bank voltages falls between 0.0-0.3 volts. This then allows the proper voltages to be passed through the optical isolators. Finally, the circuit scales up the signal to a range of 0-5 volts before passing it on to the computer for measurement where the software then converts the voltage readings into true battery bank voltages.

Problems in the standalone circuits were encountered as a result of errors in construction of the final sensor suites and faulty pressure sensors. Much time was spent troubleshooting these errors before they could be fixed because they varied from sensor box to sensor box.

DISCUSSION

The SAUVIM vehicle is an advanced technology demonstrator that requires spans of several years for research, design, and fabrication. Upon the completion of this project the final vehicle had not been finished and therefore the actual performance of the sensor suites on the SAUVIM vehicle cannot be evaluated; however, a small prototype vehicle dubbed the ODIN for Omni Directional Intelligent Navigator had been constructed and served as a preliminary test bed for the SAUVIM vehicle. Using the ODIN vehicle the standalone sensor suites were tested and found to work as designed with a high level of reliability. The primary sensor suites have not been integrated onto ODIN so all testing has been carried out in the lab with the use of a PC to simulate the onboard computers.

CONCLUSION

The objectives of this project were not entirely completed because the final integrated sensor suites were not integrated onto the SAUVIM vehicle and therefore final testing never occurred. However, the primary objective of designing and building the sensors and circuitry was completed and initial testing did occur with favorable results. In addition, the knowledge gained from work on this project can be directly applied to a sensor suite used for spacecraft or aircraft. By combining a modular design with the flexibility of sensor selection a broad range of low cost and rugged sensor systems can be produced to fit a variety of applications.

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Figure 1: Sensor suite in enclosure.

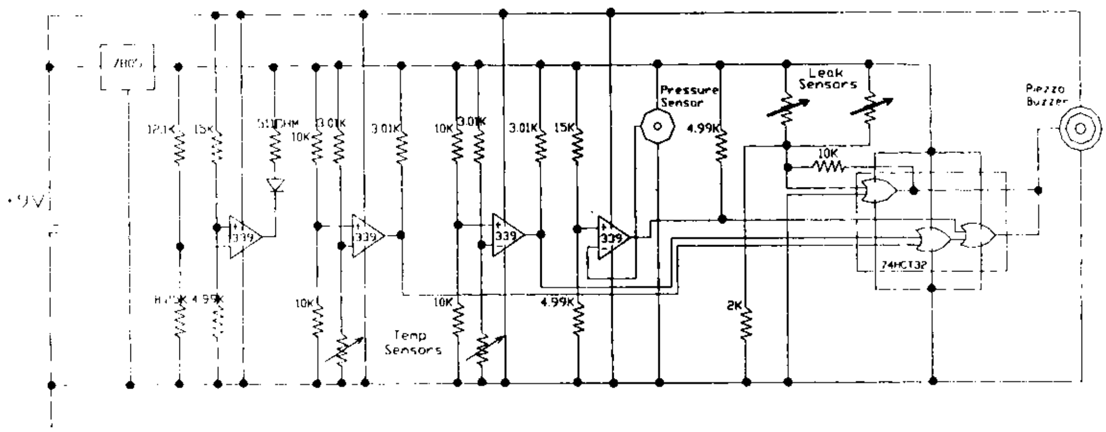

Figure 2: Circuit diagram of standalone sensor suite.

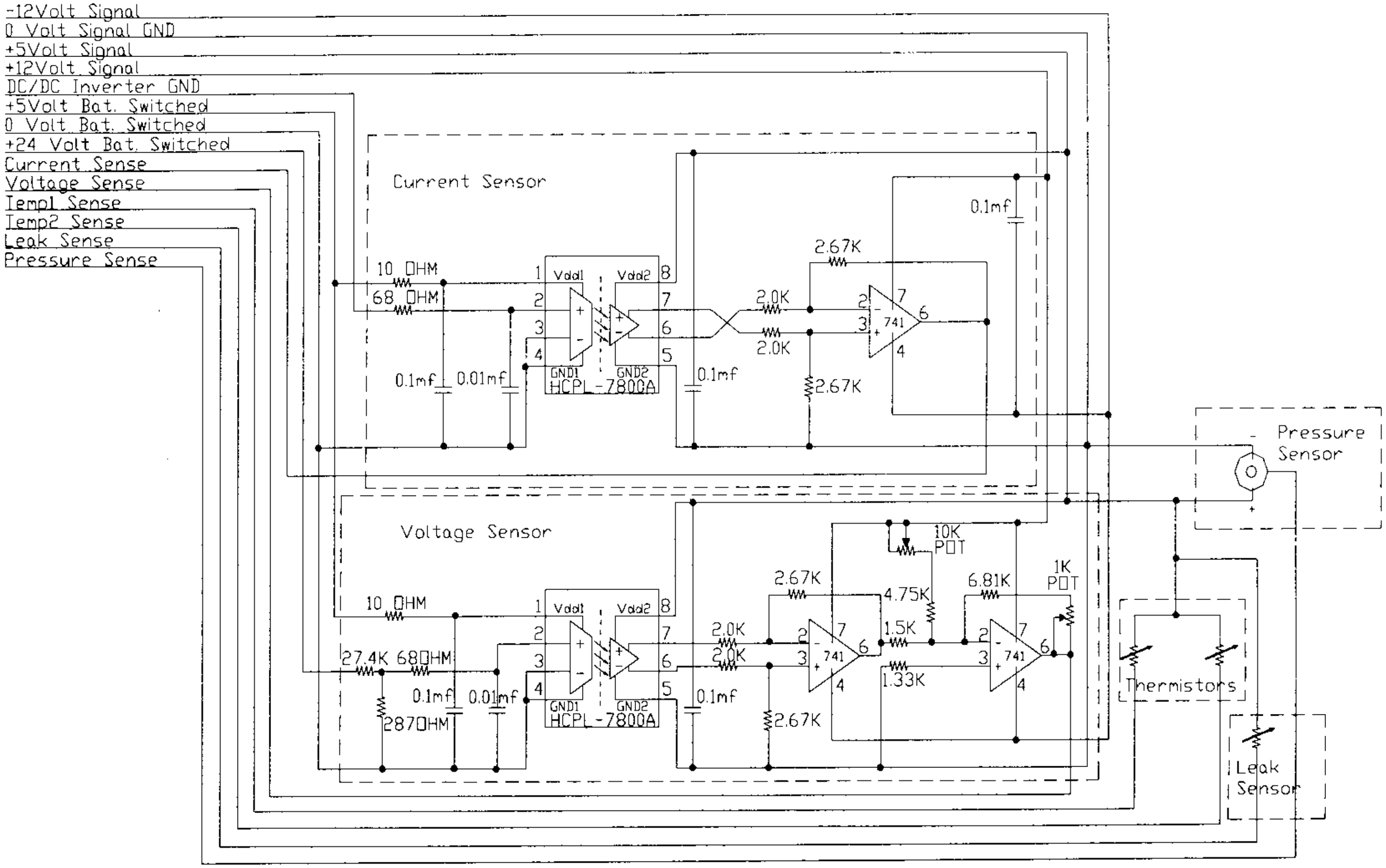

Figure 3: Circuit diagram of primary sensor suite.