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Automated Data Acquisition for a Prognostics and Diagnostics Health Monitoring System

by Gregory Mitchell, Marvin Conn, Russell Harris, and Andrew Bayba

ARL-TR-4523 July 2008

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

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1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED (From - To)
July 2008	Final	January 1, 2008 to June 12, 2008

4. TITLE AND SUBTITLE Automated Data Acquisition for a Prognostics and Diagnostics Health Monitoring System	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Gregory Mitchell, Marvin Conn, Russell Harris, and Andrew Bayba	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory ATTN: AMSRD-ARL-SE-RE 2800 Powder Mill Road Adelphi, MD 20783-1197	8. PERFORMING ORGANIZATION REPORT NUMBER ARL-TR-4523
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) P&D Mission Funds	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The military has mandated the need for continuous health monitoring to be implemented for Prognostics and Diagnostics (PD) applications at the mechanical and electronic level of fielded systems. The variety of military systems dictates the need for a highly flexible design that can be easily modified for different applications. Data acquisition is a core component of the PD process to get valuable information from the monitored system to a processing module for the execution of PD algorithms. This report addresses the design architecture of a PD Sensor Module (PDSM) for a Prognostics and Diagnostics Health Monitoring System (PDHMS) that can be introduced for electronics PD in a wide range of military systems. The use of this PDSM prototype in provoked electronic fault testing (PEFT) on a specific military platform will also be discussed.

15. SUBJECT TERMS
Prognostics and diagnostics, wireless health monitoring system, data acquisition, provoked fault testing

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Gregory Mitchell
U	U	U	SAR	18	19b. TELEPHONE NUMBER *(Include area code)* 301-394-2322

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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Acknowledgments

We would like to thank Kwok Tom and Derwin Washington of ARL for their efforts in collecting the sensor data discussed in this report. We would like to thank George Garcia and Michael Lospinuso from Picatiny Arsenal for allowing us access to the CROWS test bed. We also thank Scott Schmidt, engineering student at Drexel University for his contributions on the design of the PDHMS.

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1. Introduction

The growing complexity of military platforms creates a need for the integration of Prognostics and Diagnostics Health Monitoring Systems (PDHMS). PDHMS acquire, store, and communicate data gathered from sensors that monitor essential platform components to determine its current diagnostic status, and use this diagnostic data to make reliable prognostications of remaining operational life expectancy based on a platform usage profile. The need to monitor legacy platforms that do not have integrated prognostics and diagnostics (PD) capability means the PDHMS architecture must be flexible enough to meet varying data acquisition, communication, processing, and storage requirements.

Benefits of integrating an automated PDHMS include continuous user awareness of platform operational status and a reduction of maintenance costs by facilitating condition based maintenance as opposed to a fixed time based maintenance schedule. Automating the PDHMS mean that diagnostics sensors can run continuously and discretely with functionality remaining transparent to the user. This data transfers to a remote PC, laptop, or handheld device acting as the Prognostics and Diagnostics Control Station (PDCS).

This report discusses implementation details of a highly flexible automated PD sensor module (PDSM) prototype presently under development at the U.S. Army Research Laboratory (ARL) to be incorporated for data acquisition in a PDHMS. The ARL PDSMP has the capabilities to monitor fielded electronic systems and perform data acquisition functions on key test points of both legacy platforms and new platforms for PD analysis. These test points include system ambient temperatures, component surface temperatures, component voltage and current levels, and system vibration and shock behavior. The PDSM also keeps historical records of when measured parameters cross known thresholds that can lead to system failures. Threshold and usage data can be used strictly as a precursor or also to develop more sophisticated prognostics algorithms for the platform in question.

2. The CROWS Platform

Though the flexible design of the ARL PDSM can be implemented in a variety of electronic systems, we are using the Common Remotely Operated Weapons Station (CROWS) as the initial test platform. CROWS is a gunner-operated system capable of remotely aiming and firing a suite of crew-served weapons from inside the relative safety of a vehicle (*1*).

2.1 System Functionality

CROWS integrates four separate drives individually controlled by four identical circuit cards. These drives control the sensor unit, actuator, 360 degree azimuth rotational pivot, and 80 degree vertical elevation control unit, which are indicated in figure 1.

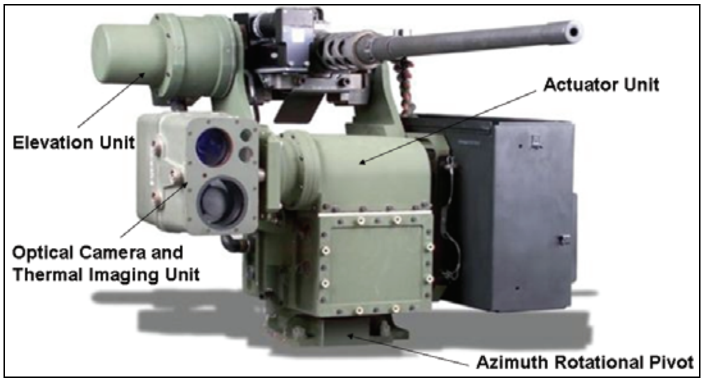

Figure 1. CROWS platform highlighting the four elements controlled by the drives.

The actuator engages the weapon's cocking mechanism and activates the trigger. The sensor unit incorporates a live video camera for daytime use and a thermal imaging camera for use in darkness. Both cameras use a laser range finder, which allows the gunner to zoom on targets, lock onto them, and maintain that lock accurately while the vehicle is in motion. The camera and the weapon can be used together or separately, allowing the gunner to look one way with the weapon pointed another.

The gun itself is controlled by a joystick which gives the gunner 100-percent functionality, allowing the operator to control the weapon with just one hand. The weapon can be aimed up to 60 degrees above and 20 degrees below horizontal and can turn a full 360 degrees in azimuth (*1*).

2.2 Provoked Electronic Fault Testing

Provoked electronic fault testing (PEFT) is defined as intentionally overloading the electronics in the system to provoke a fault. For the CROWS system, PEFT is used to characterize indicators preceding a fuse trip, and fuse degradation caused by multiple trips. The fuse trips as a result of a temperature increase caused by an increased power draw in the control circuit. An example of a drive control circuit and fuse is shown in figure 2.

Currently, the prototype PDSM is being developed to monitor fuse temperatures, component surface temperatures, component voltage and current levels, and system vibration and shock behavior. The temperature, current, and voltage sensors will continuously monitor the fuses and surrounding circuitry to collect data on system behavior leading up to the provoked electronic fault. This data will be used to develop monitoring techniques and algorithms to detect and prevent possible fuse failure in other military systems.

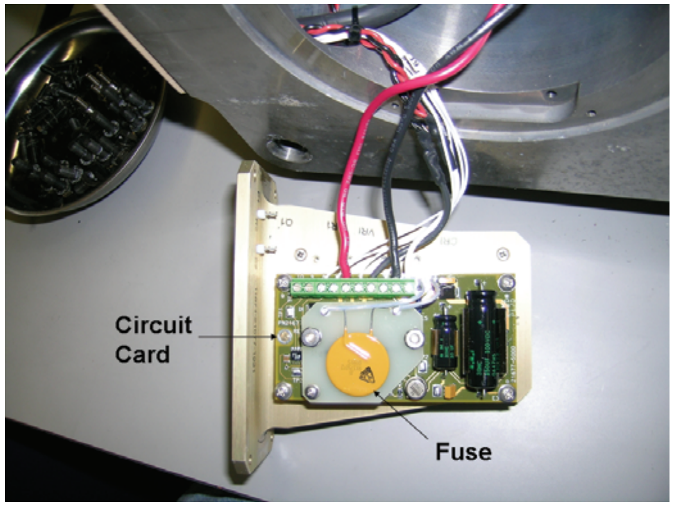

Figure 2. CROWS drive control circuit card. Each drive has an identical card with a fuse.

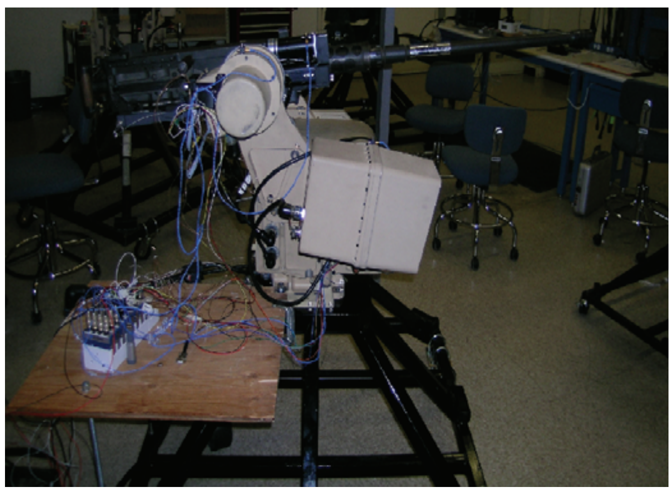

Figure 3. Operational laboratory data collection system implemented on the CROWS test bed.

Presently, to obtain data from the CROWS system the drives must be dismantled and sensors are manually attached to the circuit cards in a laboratory. An example of an active data collection setup is illustrated in figure 3. While this setup successfully collects the data needed to develop PD analysis on the CROWS test bed in the laboratory, to perform PD on a fielded system the data acquisition must be unobtrusive and transparent to the system operator. The ARL PDSM will be exclusively internal, and use the wireless IEEE 802.15.4 protocol to transfer data to the PDCS within the vehicle cabin. This eliminates the need for any external circuitry, and the need for the operator to manually extract data from the system.

3. The Prognostics and Diagnostics Sensor Module (PDSM)

Figure 4 shows the overall system design concept of the full PDHMS. The PDHMS is composed of one or more PDSMs designed to independently take measurements on test points of interest and the PDCS. The PDSM is programmed through the use of the standard JTAG interface, and can be programmed to have its wireless IEEE 802.15.4 hardware enabled or disabled depending on the application.

The PDSM is designed to store the data acquired from the test points until the data can be transferred to the PDCS. A PDCS running the wireless protocol can remotely request and retrieve all acquired data from the PDSM, and perform a more extensive data analysis.

A flexible design means any number of PDSMs can be incorporated into a PDHMS to monitor a system of interest. They can communicate with the PDCS either via wireless communications, or through the I2C hardwired serial interface.

The PDSM is fabricated on a custom printed circuit board (PCB) using commercial off the shelf components. The heart of the design is the use of the Texas Instruments low power MSP430 microcontroller (MCU) and the CC2420 ZIGBEE low power transceiver. The PCB dimensions are 2 inches by 4 inches. The MSP430 can operate from either a 6 megahertz (MHz) clock or a slower 32 kilohertz (KHz) clock. Because measurements will be made from multiple sensors, and the aggregate data rates are anticipated to be higher than can be supported by the 32 KHz clock, the 6 MHz clock will be required.

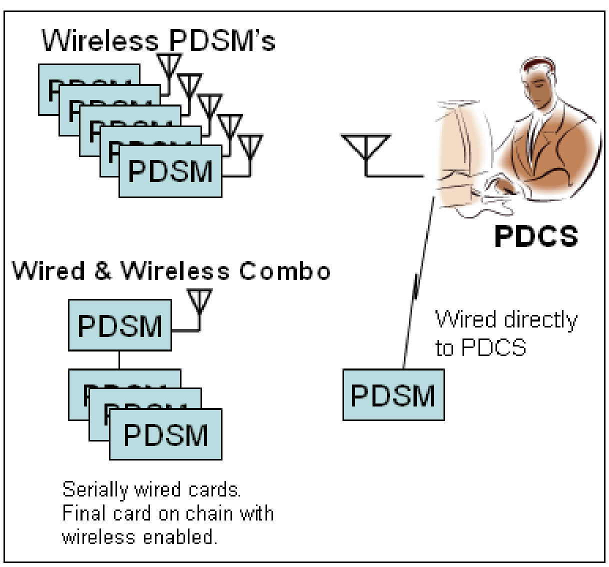

Figure 4. Overall design concept for a full PDHMS.

3.1 PDSM Design

Figure 5 shows a block diagram showing the general layout of the PDSM design. The general functionality of the PDSM is to measure system current draws, surface temperatures voltages of interest, and shock and vibration behavior of various test points. Due to the low voltage MCU, all sensors have circuit protection hardware inline with the sensor test pins to minimize the possibility of damage to the micro-controller.

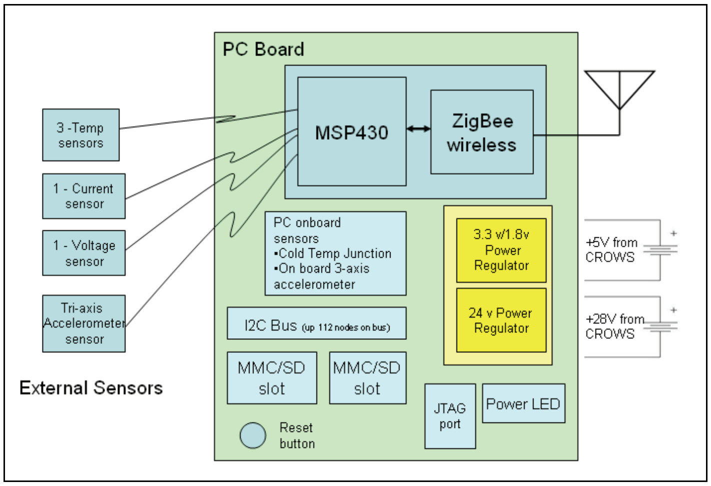

Figure 5. PDSM block diagram.

The PDSM is designed to be easily integrated into a variety of applications. The card is powered by +5 volts and +28 volts provided by the test platform itself. When the PDSM is placed within system casing the wireless capability can be disabled to prevent interference system functionality. When the wireless communications capability is disabled, an I2C interface allows data transmission via serial communications across two serial wires.

To measure current draw, a CSA-1V-SO surface mount Hall Effect current sensor is used. This is done by placing the CSA-1V-SO chip assembled on a PCB near the test point of interest and relaying measurements to the PDSM through one of the MCU sensor connections.

Surface temperatures are measured using K-type thermocouples because of their general flexibility. There are three MCU connections for connecting thermocouple sensors for temperature measurements. Standard signal conditioning and establishing an isothermal block is required in the design for these thermocouple inputs so that analog-to-digital converters (ADCs) can make the proper measurements.

Shock data is measured using a Vibra Metrics Model 3000 Miniature Tri-Axial Accelerometer capable of measuring ±500G’s. Proper signal conditioning is provided from the sensor board to interface to the accelerometer. In addition to supporting accelerometer measurements, an inexpensive ST LIS302DL SPI/I2C interface 3-axis accelerometer capable of making measurements at a maximum of ±8g’s and 400 Hz is integrated onto the PCB.

To support PDSM data storage, the design incorporates multimedia memory storage cards capable of storing gigabytes of data. The PDSM has two Multimedia Card/ Secure Digital (MMC/SD) slots. One is used for data storage, and the other is a spare that allows for an additional insertion point of one of the many commercially available products such as IEEE 802.11, Bluetooth, Modem's, or GPS devices to name a few.

Key to the performance of the PDHMS is the design of a flexible software architecture that will provide PDSM, and will interface to the PDCS. Software development will be implemented through the use of the IAR Embedded Workbench software development package for programming the MSP430 architecture, and C++ for control on the workstation.

3.2 Wireless Communications

The PDSM includes the ability to enable wireless communications for transferring acquired data. This feature enables the PDSM to operate within systems that may have wiring or weight restrictions related to the addition of cables for communication purposes. Since the PDSM will have to operate in a variety of environments, the 2.4 gigahertz (GHz) international Industrial, Scientific, and Medical (ISM) band is used.

IEEE 802.15.4 is the standard used to implement wireless communications in the PDSM. This addresses the needs of low-rate wireless personal area networks (LR-WPANs) with a focus on enabling wireless sensor networks. WPANs are used to convey information over relatively short distances. Unlike wireless local area networks (WLANs), connections effected via WPANs involve little or no infrastructure. This feature allows small, power-efficient, inexpensive solutions to be implemented for a wide range of devices (*2*).

The standard is characterized by maintaining a high level of simplicity, allowing for quick application software development that can operate with a wide variety of different sensors.

4. Provoked Electronic Fault Data

Figure 6 shows current data for a PEFT test performed on the elevation drive control circuit fuse. The initial spike in the data signifies the initiation of the PEFT as the elevation of the gun is driven to its hard stop at 60 degrees above horizontal. A second increase in current levels at 26 seconds signifies a precursor to the tripping of the fuse. The fuse trips at 32 seconds, and is illustrated in the data by the sharp drop in current to 0 amps. When the fuse trips, no current can pass through, and this renders the CROWS system inoperable. This fuse-current data gives a clear indicator that may be used to predict what causes the fuse to trip in electronic system components. However, different indicators may be required to properly evaluate a potential fault and initiate preventive measures prior to component failure.

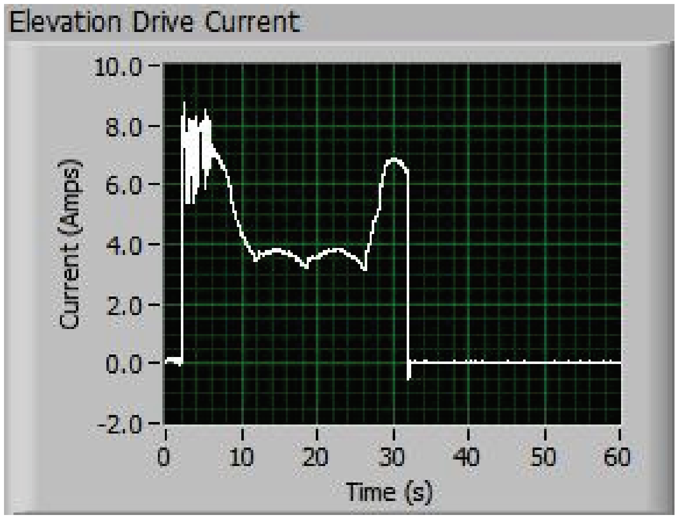

Figure 6. Current data acquired for a faulty fuse on the elevation control circuit card.

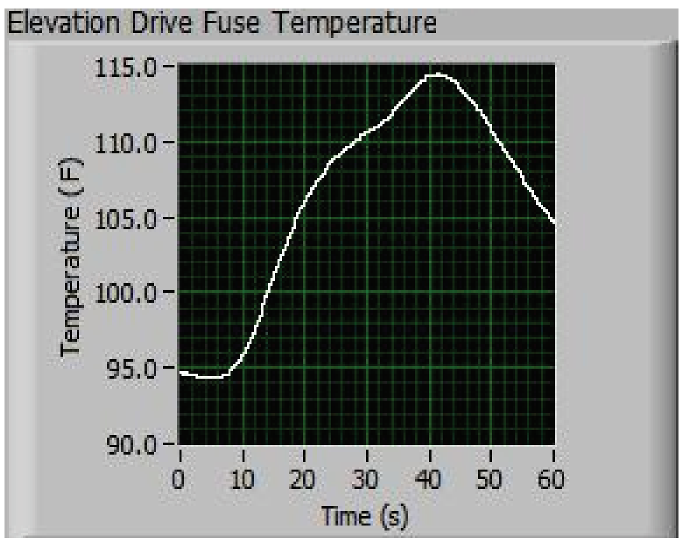

Figure 7. Ambient temperature data for a faulty fuse and surrounding circuitry on the elevation control circuit card.

Figure 7 shows fuse temperature of the elevation drive control circuit during the same PEFT. There is about a 7 second delay in the correspondence of the measured fuse temperature to the current data. The temperature sensor is located on the external casing of the fuse, and the delay is caused by the thermal propagation in the casing. While the current data shows a shorter spike in current levels prior to tripping the fuse, the fuse temperature data has a steadier rise characteristic. The decline in fuse temperature indicates that the fuse has tripped and current is no longer flowing through it. The drop off time is also affected by the thermal propagation delay of the location of the temperature sensor on the fuse casing.

Figures 6 and 7 are two examples of the types of failure precursor data that the ARL PDSM needs to collect and transmit in real time to provide the PDCS with the ability to perform PD functions on the system being monitored.

5. Conclusion

There is a growing need for automated data acquisition in military systems driven by the implementation of PD analysis. The ARL PDSM is highly flexible and can be configured to monitor key data test points in a variety of electronic systems. By remaining transparent to the user, the PDSM can accurately acquire and transfer necessary data to a processing station without the need for manual data extraction.

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