The Research, Development, and Fielding Of A HUMS As An Enabler For Condition-Based Maintenance On U.S. Army Wheeled Ground Vehicles

Craig A. Hershey [1]

[1] U.S. Army Materiel Systems Analysis Activity, 392 Hopkins Road, Aberdeen Proving Ground, Maryland 21005-5071, United States of America

Abstract

The U.S. Army Materiel Systems Analysis Activity is researching, developing and implementing the tools and interfaces for enabling the U.S. Army's Condition Based Maintenance (CBM) strategy across multiple wheeled ground vehicle platforms. Generating requirements, developing HUMS and their corresponding prognostics algorithms has been difficult. Despite the difficulties, AMSAA has been successfully fielding HUMS on many Army wheeled vehicles. AMSAA's portion of the Army's CBM vision over the last two years has been developing and fielding Health and Usage Monitoring Systems and analyzing the corresponding data. The last two years of fielded HUMS has provided invaluable usage data that otherwise did not exist anywhere in the U.S. Army. The data has been used to provide maintainers, commanders, crew, Program Managers, logisticians, decision makers and engineers with valuable information about the vehicles and a baseline for developing health prediction algorithms for a successful CBM program.

Keywords: Health and Usage Monitoring System (HUMS), Condition Based Maintenance (CBM), system development, fielded usage data, prediction algorithms, wheeled ground vehicles.

Introduction

The U.S. Army transformation strategy for logistics prescribes a Condition-Based Maintenance (CBM) Policy that will virtually eliminate scheduled maintenance, predict the remaining useful life of Line Replaceable Units, and allow maintainers to more accurately diagnose subsystem failures. Condition Based Maintenance is maintenance that is driven based upon the vehicle's "condition" or "health." This maintenance strategy is not based on scheduled, interval or reactive maintenance, as the Army's ground vehicles are today, but upon performing maintenance on an as-needed basis. CBM will provide the Army real-time situational awareness, increased automation of the supply chain and maintenance procedures, and improved configuration management which reduces the number of vehicles needed. Streamlining the maintenance will increase vehicle readiness to give commanders an increased confidence of a successful mission. This paper will describe how the U.S. Army Materiel Systems Analysis Activity (AMSAA) is supporting this policy by researching and developing CBM concepts using Health and Usage Monitoring Systems (HUMS). AMSAA has implemented a global field instrumentation program on tactical wheeled vehicles in multiple terrains, climates, and usage scenarios as well as a research and development testing program to investigate

CBM feasibility. AMSAA is involved in data reporting, prognostics algorithm development, usage summary reporting, hardware development and seeded fault testing.

Development of Engineering HUMS

As an enabler to the program, AMSAA engineers have designed an Engineering Development Health and Usage Monitoring System (EDHUMS) by adapting and ruggedizing Commercial Off the Shelf (COTS) technology for use in the most austere environments including combat conditions. The particular data acquisition hardware chosen had environmental limitations and was adapted and tested to verify it would meet the specifications shown below. The particular COTS acquisition system was chosen for several reasons, such as: the ability to be easily programmed for collecting data from multiple sensors, ability to perform complicated data processing, on-board analysis and the accompanying post-processing data software. AMSAA is using this EDHUMS as a tool for developing usage, diagnostic and prognostic algorithms that will be implemented on future embedded HUMS.

The specifications the system must meet are:

- Dust and water tight connections
- Small overall size
- Robust military grade connectors
- 12V and 24 V power input compatible
- Remote switching capable (automatic on/off)
- Vehicle bus, GPS, displacement, strain, acceleration, temperature and current sensor supportable
- Operable in maximum outside ambient temperature of 120°F (49°C) with a solar radiation load up to 1120 W/m^2
- Conducted emissions and susceptibility requirements of MIL-STD-461 compatible
- Shock resistant to withstand typical vibration levels of various wheeled ground vehicles [1]

While the data acquisition system chosen was designed for industrial applications, it had many limitations for a military environment, including operating temperature range, Electromagnetic Interference (EMI) levels, and non-military grade connectors. To correct these problems, AMSAA had to modify the system in order to ensure survivability in the field, enhance the functionality, and control the EMI produced by the HUMS. A military grade superstructure was designed in Pro/Engineer to house the data acquisition system, shown in Figure 1. Devices such as DC/DC converters, circuit breakers, solid state relay, EMI filters and a six degree of freedom motion pack were added to the structure [1].

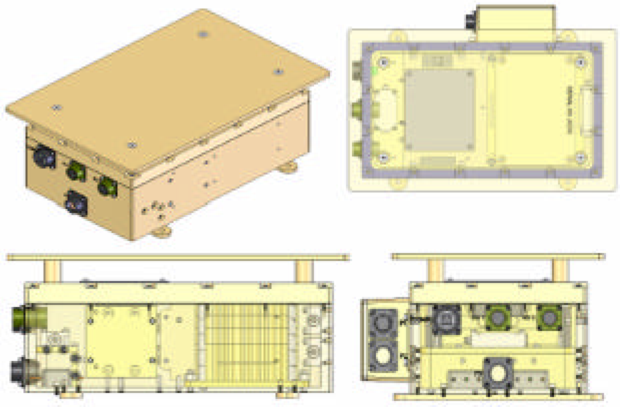

Figure 1 - Original 3D solid-model of system within superstructure

Thermal, vibration, solar loading, and EMI testing was performed on the prototype. Many design modifications were performed as testing proceeded to the version of the EDHUMS that was fielded. As the fielding process began, additional modifications were made to the design. The most recent version of the system is shown in Figure 2. The EDHUMS that is currently in the field is known as the System Health And Reliability Computer (SHARC) [1].

Figure 2 SHARC mounted on a vehicle

Embedded HUMS

AMSAA is also developing and has begun initial fielding of an embeddable HUMS. An embeddable HUMS is a system that would meet CBM and cost requirements to field across a fleet of vehicles. AMSAA has chosen a small cost efficient COTS data acquisition system as a way to produce concise usage and health reports on a larger sample of vehicles. The COTS embedded HUMS chosen is known as the Vehicle Monitoring Unit (VMU). The system's cost, size, and robustness make it a candidate for installation by vehicle manufacturers during assembly as well as integrating the VMU in the field and at vehicle refurbishment centers. The embedded HUMS retain most of the SHARC requirements, but with a few additions. The SHARC has immense computing power, memory and flexibility, but these advantages also come with increased cost. An embedded HUMS must be capable of providing usage summaries and vehicle health calculations on-board. The VMU has the ability to perform many calculations perceived to be necessary for on-board HUMS, as well as provide histograms and statistical data. Currently the VMU is performing calculations on-board and providing usage summaries or soldier reports with minimal post-processing. Figure 3 depicts a previous version of the SHARC side by side with the VMU.

Figure 3. SHARC (left) and VMU (right)

Requirements were initially developed for the embedded HUMS by analyzing the pros and cons of the EDHUMS and surveying the possible needs of all potential customers and users. Some requirements from different customers were conflicting. One example of a conflicting requirement is memory size on the HUMS. One customer requires large amounts of memory to record time-history data, while the other customer may only require a system health status. Increased HUMS memory not only increases cost of the HUMS but also increases cost and size of the database or data storage system. Increased memory would have a negative effect on data transfer time and cause bandwidth issues. AMSAA selected a system that had smaller memory but maintained vital information, including statistical measures on a given parameter and providing usage histograms of parameters. By recording the mean, maximum and minimum value of a channel over a few minutes an engineer could have the ability to determine system health at a given time. Another advantage of using histograms and statistics over time-histories is data processing time decreases when there is significantly less data to analyze.

Physical size was a requirement that was recognized as important during development and fielding of the SHARC. Many military vehicles have small amounts of storage space to install an additional system. Vehicles in today's Army have a large amount of added electronic systems for communication and protection from improvised explosive devices in addition to each soldier's equipment. It was readily evident when initially fielding the SHARC systems that each vehicle's proposed SHARC mounting location would not be able to be the same. By using a smaller HUMS, the system can be located on many different vehicles at whatever mounting location is available.

An additional requirement of an embedded HUMS is providing the crew with real-time alerts of vehicle health status. Healthy vehicles lead to a high probability of mission success. Conversely, if the vehicle has indications of an impending failure, maintenance can be performed which will eliminate recovery costs, unscheduled maintenance and possibly save lives. The VMU has the ability to be paired with a ruggedized crew information display. Currently VMU data is only obtained by downloading via a wired military-to-USB connection shown below in Figure 4. Development has begun to integrate results of the embedded system into the display, as well as eliminating post-processing of data. Additional tradeoffs need to be performed on which parameters and alerts should be displayed in real-time and which are available upon user request.

Figure 4 VMU with download harness

AMSAA took the most versatile version of the VMU and co-developed with the manufacturer the ability to meet specific requirements for an embedded HUMS. Once the first version of the VMU was available, AMSAA initiated tests at Aberdeen and Yuma Proving Grounds to prove the ability of the VMU. Two tests were performed with military vehicles having SHARC and VMU recording data simultaneously. The goal of the tests was to determine if the VMU could replicate the algorithms and reports generated by the SHARC. Results of previous tests and field data were analyzed and used to create the setup for the VMU. Tests confirmed that the VMU could produce reports that crews, maintainers, commanders, engineers, supply chain personnel, and project managers could refer to in their decision making processes. The next step was to customize the VMU for AMSAA requirements by formatting the processed data, improving the VMU harness system, adding additional internal calculation ability, improving the software interface and expanding the external sensor capability. The VMU purchased for initial fielding was a smaller system than tested and was customized for AMSAA's requirements. These requirements include accepting new sensors and the J1708 interface among other firmware upgrades. As fielding and development continues, firmware upgrades continue to be implemented. The current version of the VMU is shown below in Figure 5.

Figure 5 VMU with power and instrumentation cables

Prognostics and Data Reporting

The current focus uses the data to provide direct feedback to the crew, maintainers, program managers, and decision makers by reporting usage summaries and usage characterizations. Usage summaries typically include information on op-tempo, fuel, engine, terrain, and transmission statistics as well as histograms or other pertinent graphs and exceedance values. Usage comparisons by vehicle are also provided along with usage totals of vehicles over various time periods. An example portion of a usage summary is shown below in Figure 6.

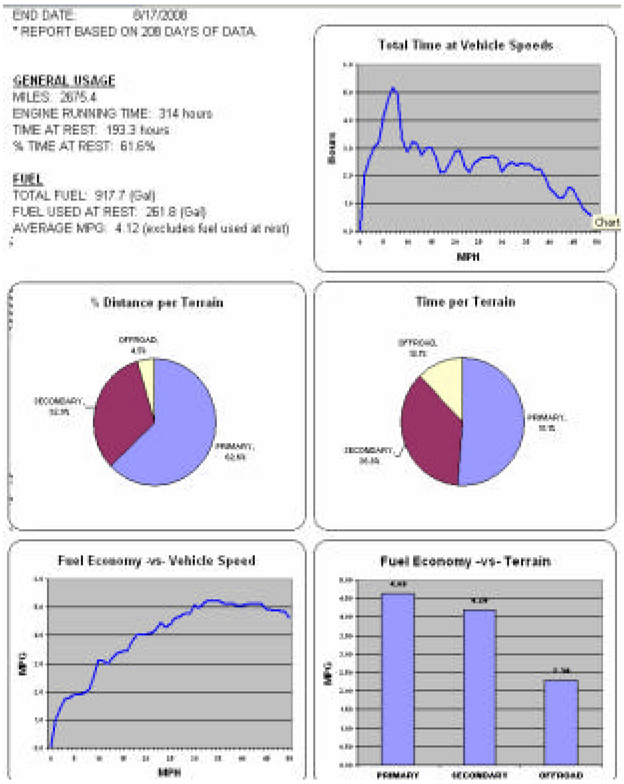

Figure 6 Example of Usage Summary (notional data)

As analysis continues, AMSAA will develop and refine algorithms that enable diagnostic and prognostic capabilities on board the Army's Tactical Wheeled Vehicle Fleet. The knowledge gained from data collection and the analyses of these data will prove essential to the implementation of a Condition-Based Maintenance Policy.

One of the most promising analytical processes AMSAA is developing is the real-time onboard identification, classification, and mapping of terrain types shown in Figure 7. This work has led to usable terrain identification and classification algorithm that has been implemented onboard vehicles around the world. While the current implementation is somewhat rudimentary, only three broad-spectrum short-wavelength surface roughness classifications are available, work is underway to incorporate long-wavelength classifications (hills, mountains, etc) as well as further refinement of the shorter-wavelength terrains.

Presently, the algorithm distinguishes three severities of surface roughness, primary road, secondary road, and off-road, using a root-mean-square calculation of data from unsprung mass accelerometers. This data is low-pass filtered at 30 Hz and compared with mean vehicle speed over twenty-second periods. Given that the suspension of the vehicle responds to short-wavelength terrain components (bumps, washboarding, etc) in the form of high accelerations, the accelerometer is an appropriate sensor for these shorter-wavelengths. On the other hand, the suspension does not respond to long wavelength components such as hills in any measurable amount, although, the overall vehicle orientation (i.e. pitch and roll angles) does. The appropriate sensor for this measurement is a gyroscope, which is currently integrated into the SHARC and is not a necessary sensor for the VMU at this time.

Figure 7 Latitude and longitude plot of speed (green) and terrain-induced vibration levels (pink)

Other algorithms currently under research and development include electrical system, coolant system, engine and transmission health. Determining failure alerts and health status is often difficult without manufacturer involvement or extensive failure testing and analysis. AMSAA is cooperating with many universities, private industry and Army organizations to determine what levels of parameters are harmful to the vehicle's health. AMSAA has been using extensive seeded fault testing on the engine and transmission to develop prognostics algorithms. Early indications have shown seeded fault testing to be very beneficial in developing health algorithms.

Conclusion

AMSAA has developed and is implementing a condition-based maintenance HUMS for military wheeled ground vehicles in order to plan maintenance based upon the actual condition of the system. This technology is enabled by the application of usage, diagnostic and prognostic processes. Proactive maintenance will streamline the Army's supply system and increase vehicle readiness rates, reducing the number of vehicles needed to ensure mission success. Increased readiness will give commanders more confidence in their mission planning and positively impact the Army's ability to transport assets and personnel for combat and peacekeeping missions. Real-time situational awareness, improved configuration management and further automation of the supply system and maintenance procedures are examples of added value once CBM is fully realized. Two HUMS were chosen and modified to meet military standards and usage requirements including the high operation tempo and extreme environments the vehicles regularly endure. Testing and analysis was performed to develop algorithms which predict vehicle system health. A system such as the VMU has potential to be used on all military vehicles in the future to provide operators, maintainers, suppliers and commanders with necessary data to make good fleet management decisions and ultimately saving time and money while increasing maintenance efficiency and operator safety.

Acknowledgements

The author would like to thank Mark Bounds for his contributions to this paper.

References

1. Bounds, M., Calomeris, M., Pohland, M. and Shepler, M. "On the Road To Condition-Based Maintenance for Army Vehicles", *Army Logistician*, Vol. 40, Issue 4, Jul-Aug 2008, pp. 43-44.