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AUTOMATIC TERRAIN DETECTION

David Subert, Andrew Diepen, Kevin Hubert

GS Engineering, Houghton, MI

ABSTRACT

GS Engineering has developed technology to advance the sensory perception of autonomous systems. The Automatic Terrain Detection System (ATDS) is a technology that provides real time terrain detection. Vehicles deployed with ATDS have been able to yield improved mobility, automation of systems, and reduced fuel consumption. ATDS has been integrated into the MK23 MTVR, M1151 HMMWV for the ONR Predictive Adaptive Mobility (PAM) program, and into the Autonomous Ground Re-supply (AGR) by-wire kit for the Oshkosh Defense Palletized Load System (PLS). The ATDS is built upon proven sensors running integrated processing to replace or enhance existing vehicle systems.

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1. INTRODUCTION

Think about the following questions next time you get in your car to go for a drive.

1. Are you driving on a road? Is it paved?
2. How fast can you drive comfortably? Is this a washboard road?
3. Are your wheels spinning but you are not moving?
4. Is there snow or ice on the road?
5. Are you driving through sand where you may need to pay special attention?

Likely, none of us ask these questions when we get behind the wheel, why not? The answer is obvious; anyone that has driven in Michigan in the winter has adjusted their driving based on road conditions. When we look at more and more autonomy in vehicle systems, how do the computers know what the road conditions are?

Autonomous ground systems are built upon systems of sensors responsible for creating a digital world. This digital world is created to mimic our own senses to allow the algorithms and computing resources to operate as good as or ideally better than their manned counterparts. As better and better algorithms are developed, the systems and sensors supporting them need to advance to provide better and better perception to ultimately out-perform human counterparts with fewer mistakes and greater efficiency. This is how technical overmatch is achieved on the battleground.

GS Engineering is a technology focused small business specializing in ground systems and technology integration. Functioning as a prime contractor to the US Department of Defense and its major military commands, as a subcontractor to OEM's, or supporting small business and entrepreneurs, GS Engineering has evolved from a small services organization to an established company providing turn-key solutions across a broad spectrum of markets, clients, and products. This experience supports rapid adaptation to our client's challenges while maintaining quality. With a divers and skilled workforce, GS Engineering is often approached by the US Government and numerous commercial companies to accomplish what other organizations have not, or cannot accomplish due to aggressive schedules and objectives.

In 2012 GS Engineering started the development of the Automated Central Tire Inflation System (ACTIS) which would later become the Automatic Terrain Detection System (ATDS).

2. ATDS Heritage

ATDS was developed under a Phase I SBIR performed by GS Engineering to develop a system/solution enabling a HMMWV to achieve a Threshold Vehicle Cone Index (VCI) of 25 at a GVW of 15,500 lbs, as required by the HMMWV ORD clarification (dated 22 July 2010). The secondary objective was that the solution developed to optimize VCI, have the capability to dynamically adjust VCI to accommodate rapid transitions in operating conditions and terrains without the requirement of direct user input for mode assignment.

During execution of Phase I, the priority of objectives was re-focused to consider dynamic VCI adjustment as related to need for increased mobility of the MTVR platform, recognizing the presence of CTIS with the Original Equipment Manufacturer (OEM) vehicle providing a base for solution development. GS Engineering's primary task was to develop a Central Tire Inflation System (CTIS) control module and decision-making logic for the MTVR MK23, utilizing existing mechanical components and on-vehicle sensors, and supplementary sensors to evaluate and characterize terrain, then assign CTIS operating modes without user input.

This continued into development of a completely automated CTIS (ACTIS) using Commercial-Off-The-Shelf (COTS) components and a secondary sub-kit that provided terrain detection information to the J1939 bus for use by other vehicle systems.

An MTVR MK23 was made available to GS Engineering by MARCOR for baseline CTIS operational evaluation, which supported verification of vehicle tire pressures relative to published CTIS terrain and load settings, as well as preliminary vehicle data captured while driving over various terrain profiles (Figure 1).

Figure 1: MTVR Baseline Evaluation over Sand, Pavement, and 1" RMS

Development of the CTIS Control Module involved an in-cab user interface, presenting numerous benefits beyond the legacy control.

Replicating the legacy CTIS control space claim and mounting position, GS Engineering's user interface (Figure 2) is a cost effective design utilizing intuitive switch/indicator technologies to display actual and user commanded modes.

Figure 2: GS Engineering ACTIS Control Module User Interfaces

Building upon a basic sensor layout done during Phase I, sensor locations were completed for the MTVR and HMMWV. Figure 3 shows the layout of the sensor for the MTVR.

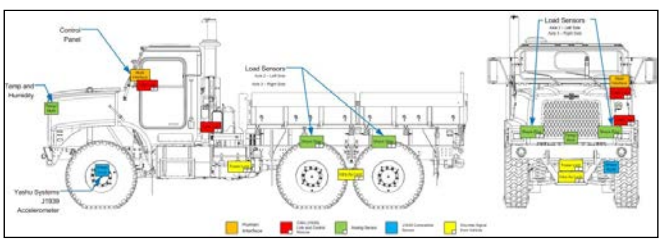


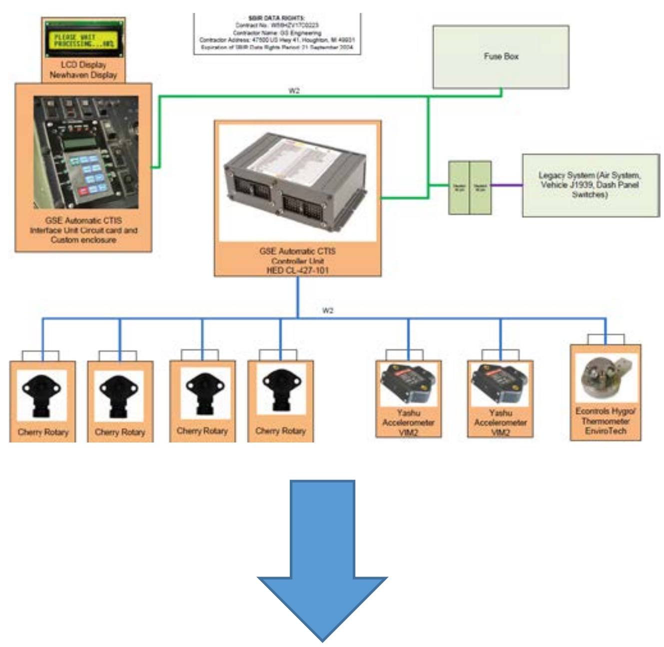
Figure 3: GS Engineering CTIS Control Module – Sensor Integration on MTVR

The results from Phase I and other efforts include a complete ACTIS vehicle kit and logic solution that achieves dynamic characterization of terrain conditions and selecting ideal tire inflation operating modes based on target VCI. This also presents benefits of improved fuel economy and reduction in tire and driveline wear. Supplementary sensor technologies provide a scalable solution with cost, durability, ease of integration, and system fidelity as trade-offs. GS Engineering has identified a solution specifically for the MTVR that is adaptable to other vehicle platforms with additional operating interfaces.

Under a Phase II SBIR, the MTVR system was later adapted to the HWWMV platform. This provided an opportunity to further evaluate and harden the software and electronic components of ATDS. The rich heritage of ATDS development for the MTVR and HWWMV provided the foundation for ATDS as it exists today on the AGR (Autonomous Ground Resupply) Palletized Loading System (PLS) vehicles.

3. ATDS Vehicle Architecture

The current generation of ATDS was also developed under a Phase II SBIR to adapt the system to the Palletized Loading System (PLS) under the Army's AGR (Autonomous Ground Resupply) program. ATDS for the PLS represents a new level of integration with existing vehicle systems. Under the new strategy, ATDS transmits the terrain state to the vehicle communication bus. This concept allows any system on the vehicle to adjust control strategies based on the current state of the terrain and is no longer encumbered by directly controlling the Central Tire Inflation System. This evolution in architecture leads to a dramatic simplification of the overall ATDS system as illustrated in (Figure 4).



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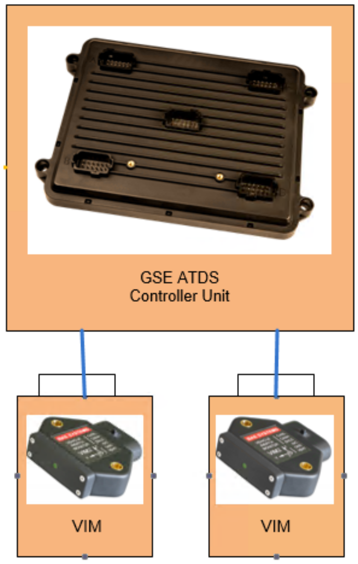

Figure 4: ATDS Architecture Simplification

As illustrated in Figure 4, ATDS is composed of 3 major components: two Vehicle Inertial Monitors (VIM) and one central controller. The function of each of these components will be described in detail.

3.1. Vehicle Inertial Monitor (VIM)

The Vehicle Inertial Monitor (VIM) serves as the primary means to detect changes in terrain. The system contains two VIMs mounted to each of the front wheel ends (un-sprung suspension mass). An illustrated location of the sensors on the PLS is provided in (Figure 5). The front suspension was chosen since it usually articulates the most as the vehicle is rolling over terrain.

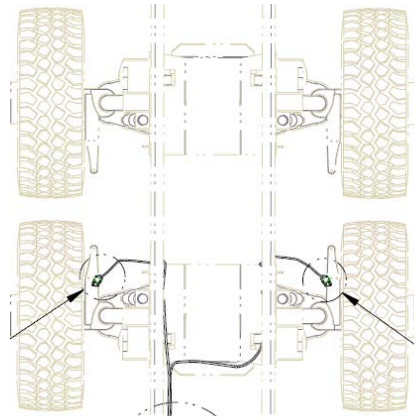

Figure 5: PLS VIM locations

Two VIMs are required due to the large amount of processing required to analyze the different types of vibration used within the terrain detection algorithm. One VIM is dedicated to sensing suspension displacement while the other VIM detects vibration in the wheel end. Each VIM heavily processes and filters the vibration data and then condenses it to transmit on the CAN bus. The data is then received by the ATDS controller to be factored into the terrain detection algorithm.

3.2. ATDS Controller

The ATDS controller serves as the primary integration point for vehicle systems. The conceptual PLS electronic architecture is provided in (Figure 6).

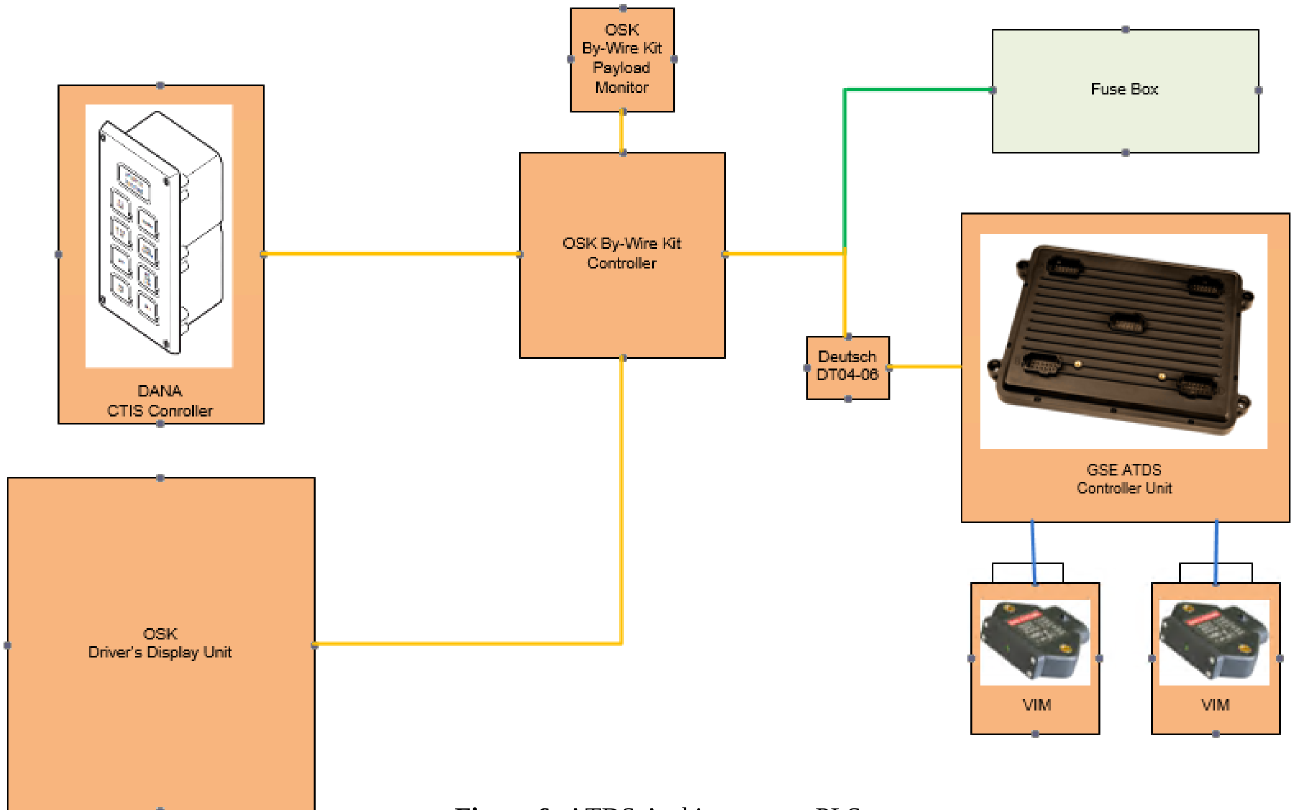

Figure 6: ATDS Architecture on PLS

The ATDS controller connects to the PLS via the CAN bus. The controller uses the CAN bus to collect a number of vehicle parameters such as wheel speed and wheel slip for use in the terrain detection algorithms. The vehicle CAN bus is also the integration point for the ATDS controller to transmit the detected terrain state. This terrain state is then used by the control systems on the PLS to configure the proper tire pressure via the CTIS controller. As mentioned before, this simplification greatly reduces the logic required within the ATDS controller. Instead of the ATDS controller having to directly control the CTIS, it simply transmits a terrain state allowing the vehicle systems to apply the information as required. This will also ease integration into future vehicles whose control systems can issue commands to their existing CTIS.

4. Theory of Operation

The terrain detection software algorithms are based on two classifications of data: vehicle vibration data and vehicle telemetry. The incorporation of the data into the software algorithms will be discussed below.

4.1. Vibration Data

Vibration data is collected by two separate VIMs that are each configured to capture a different type of vibration data.

The first VIM captures vibration data from a broad range of frequencies from the wheel ends. This data is used to determine if the terrain is hard or soft based on the concept that hard terrain would cause more wheel end vibration than soft terrain. The determination of hard/soft is then combined later on within the software algorithm to determine terrain type.

The second VIM captures vibration data corresponding to suspension movement. The suspension movement is used to estimate the wave number of the terrain, which determines if the terrain is smooth/medium/rough. The smooth/medium/rough determination is then factored into the software algorithm to determine overall terrain type.

4.2. Vehicle Telemetry

ATDS also relies on vehicle telemetry data monitored from the J1939 bus. The most critical data is vehicle ground speed and wheel slip. The telemetry data is used as more of an anecdotal factor in determining the final terrain type. For instance, if the vehicle is operating at a very high speed with almost no wheel slip, the probability is very high that the vehicle is driving over pavement. The vehicle telemetry portion of the algorithm provides a great deal of flexibility for vehicle types and application. The anecdotal results of the telemetry data is then combined with the determinations from the vibration data to resolve a final terrain type.

5. Vehicle Integration

The performance of ATDS relies on the two main vehicle integration tasks as described in the following sub-sections.

5.1. Vehicle Communication Bus

The ATDS relies on vehicle telemetry data that is typically available on a vehicle CAN bus. Some of this data includes: wheel speed, wheel slip, and transmission gear. All of this data is used in the algorithms that detect terrain. The vehicle communication bus will also be used by the ATDS controller to communicate the detected terrain.

5.2. Vehicle Characterization

The foundation for the ATDS software algorithms is a set of look-up tables that are used to detect the terrain a vehicle is rolling over. These look-up tables are generated by driving a vehicle over known terrains at a series of different speeds while capturing both VIM and vehicle telemetry data. The data captures are then statistically analyzed to generate look-up tables for use in the ATDS software algorithms. These look-up tables are then used by the software while the vehicle is in motion to determine the type of terrain the vehicle is rolling over.

6. Currently Fielded Hardware

ATDS is currently operational on six AGR Inc. II PLS vehicles. The ATDS is able to successfully distinguish the three primary CTIS operating modes (Mud Sand Snow, Cross Country, and Highway). As these six vehicles continue to gather hours during testing, vehicle data is continuously being captured to improve the effectiveness of ATDS and observe the robustness of the design. The ATDS installation on the PLS is illustrated in (Figure 7).

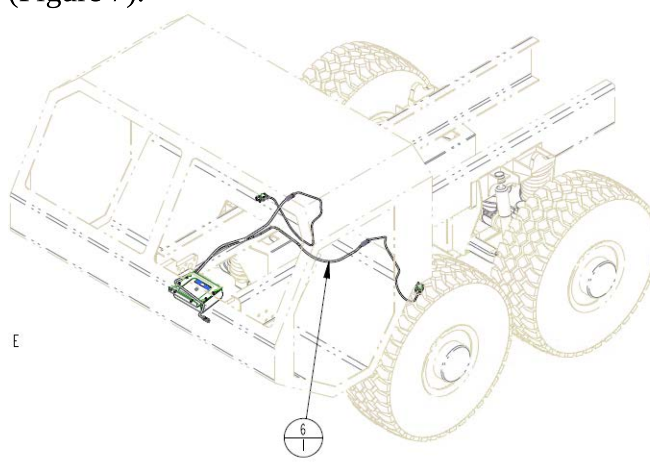

Figure 7: ATDS Installation on PLS

7. Future Plans

Developing the ATDS for the PLS opened a new opportunity for future technological advancement. Since the current generation of ATDS is dedicated to identifying terrain and not directly controlling CTIS hardware, more of the ATDS design can be focused on the most effective methods to detect the type of terrain a vehicle is driving over.

7.1. Space Claim

GS Engineering is currently investigating the reduction of the overall footprint of the ATDS. The current system includes two VIM sensors and an electronic controller that analyzes the sensor data to determine the type of terrain. The controller no-longer requires a large number of inputs & outputs to directly control a CTIS system. As a result, the controller can be down-sized or even eliminated by placing the intelligence of the controller into each VIM sensor.

7.2. Terrain Fidelity Improvement

While developing ATDS for the PLS, there was opportunity to improve the performance of the VIM sensors. These improvement increased the resolution of the sensor which demonstrated potential to increase the types of terrain ATDS can detect beyond the standard Highway, Cross Country, and Mud Sand Snow. Initial testing with the PLS demonstrated the ability to detect graded gravel apart from the previously detected Highway terrain. Vehicle characterization process changes are being investigated in an attempt to provide additional terrain types.

7.3. Fault Detection

As the ATDS continues to evolve closer to a production system, improvements in robustness will also be required. To this end, ATDS algorithms are being updated to provide detection of faults including a failed sensor or loss of vehicle communication. The next stage of this development will include algorithm refinement to continue operation in the event of loss of a sensor.

7.4. Reduced Vehicle Characterization

The current ATDS requires several weeks of vehicle testing in order to generate the look-up tables for the ATDS software algorithms. This characterization process is fairly expensive due to the time and expense associated with shipping a vehicle to the GS Engineering test course. Work is currently under-way to reduce the amount of time required to develop these look-up tables.