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NEW TECHNOLOGY ADDRESSES REAL-WORLD VEHICLE ELECTRONICS PROBLEMS: MOTOR CHATTER CASE STUDY

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ABSTRACT

The Bradley Combat Vehicle Motor Chatter case study focuses on one aspect of a combat vehicle program, specifically, responding to a vehicle production situation where combat vehicles produced with in-spec components and subsystems exhibit out-of-spec and failing system behavior. This typically results in an extended production line-down or line-degraded situation lasting for several quarters until the problem can be diagnosed, fixed, validated and verified. Subsequently, adequate quantities of the modified or replaced sub-systems must be put back into the production flow. The direct and indirect costs of an occurrence like this in peace-time are measured in the 10's to 100's of Millions of dollars. The schedule, program and perception impact to the vehicle platform can be potentially devastating. In war-time all of these impacts are magnified greatly by the added risk to soldiers' lives.

This paper describes the Bradley Combat Vehicle Motor Chatter case study and the revolutionary tools and systems engineering approach utilized by CPU Tech and BAE Systems that determined the root cause, verified and validated the fix, and implemented the fix without impact to the Bradley Combat Vehicle production. CPU Tech utilized a unique real-time nonintrusive (RTNI) diagnostics and configuration port built into the TDCUII LRU and a full vehicle, real-time Bradley Model developed for the SystemLab PS® Virtual Systems Integration Lab (VSIL) to diagnose, replicate and fix the problem on the production Bradley Combat Vehicles in York, PA and work with BAE Systems and the Army to validate and verify the solution in Yuma, AZ.

CPU Tech and BAE Systems were able to upgrade 150 production Bradley Combat Vehicles in 4 days using the RTNI port, an Ethernet cable and a laptop without removing a single LRU.

INTRODUCTION

This case study focuses on one aspect of a vehicle program, specifically, responding to a vehicle production situation where vehicles produced with in-spec components and subsystems exhibit out-of-spec and failing system behavior. With SystemLab PS® in support of CPU Tech's Turret Drive Control Unit II (TDCUII) LRU, BAE Systems was able to deliver a validated solution to a significant production problem in one month with no disruption to production.

CONTEXT

This case is representative of a common vehicle production problem where in-spec or unspecified behavior of components or subsystems can interact at the vehicle level to create out-of spec system behavior. This typically results in an extended production line-down or line-degraded situation lasting for several quarters until the problem can be diagnosed, fixed, validated and verified. Subsequently, adequate quantities of the modified or replaced sub-systems must be put back into the production flow. The direct and indirect costs of an occurrence like this in peace-time are measured in the 10's of Millions of dollars. The schedule, program and perception impact to the vehicle platform can be potentially devastating. In war-time all of these impacts are magnified greatly by the added risk to soldiers' lives and to missions.

BACKGROUND

The TDCU in the Bradley Combat Vehicle provides closed-loop control of all of the drive motors of the Bradley Turret in response to operator inputs and *adaptive to system and environmental conditions.*

CPU Tech, in coordination with BAE Systems Bradley Engineering Team, developed the modernized version of the TDCU to address accumulating electronic component obsolescence and reliability issues. The approach we adopted for modernizing the TDCU provides the following:

1. 100% Software Compatible with the Legacy Code -Form, Fit & Function Equivalent

2. Improved Sustainability
    - Visibility into the operation of the hardware and software
    - Diagnostics, repair and upgrade in-place capabilities
3. Lifecycle Management

100% Software Compatible with the Legacy Code – Form, Fit & Function Equivalent

The modernization effort eliminated electronic component obsolescence in the TDCU in the following areas: processors, digital logic, power circuitry, analog circuitry, external interfaces and backplane and bussing. At the same time, CPU Tech preserved the investment in software development, debug, qualification and combat field years by maintaining 100% software code compatibility with the legacy TDCU. The TDCUII is form-fit-function equivalent with the original TDCU and directly replaces the legacy TDCU LRU while increasing the Bradley Combat Vehicle's reliability and sustainability.

Improved Sustainability

The modernized TDCUII solution is architected to include a *mission-independent service processor* and an Open-Architecture (Ethernet) based real-time non-intrusive (RTNI) diagnostics and configuration port. *The digital logic is re-engineered from COTS-bound devices to soft intellectual property (IP) that is mapped into an FPGA.*

The resultant LRU provides the following new benefits beyond the legacy version.

- *Remote visibility into the operation of the hardware and software*
- *Remote diagnostics, repair and upgrade in-place capabilities*
- *Protection from supply-chain induced component obsolescence*
- *Detection of / protection from supply-chain tamper*

CPU Tech and BAE Systems implemented two companion capabilities to the modernized TDCUII LRU. Based on CPU Tech's SystemLab PS Platform Simulator, the engineering team developed a real-time hardware and software accurate vehicle model of the Bradley vehicle electronics, providing the capability to reproduce vehicle behavior in an instrumented virtual System Integration Lab (SIL).

Secondly, CPU Tech created a real-time system hardware and executable software simulation model of the TDCUII electronics that allows rapid development, sustainability and lifecycle management of the TDCUII hardware and software.

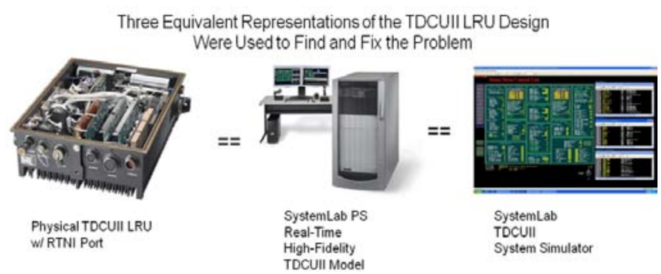

Figure 1: CPU Tech LRU Solution.

All three of these realizations of the TDCUII design (physical LRU, real-time vehicle model and system hw/sw simulator) are based on the actual hardware and executable software deployed in the TDCUII. All three of the TDCUII realizations share the same visibility and control capabilities and the same hardware and software sustainability capabilities.

Lifecycle Management

The real-time high fidelity TDCUII model is an electronic specification of the LRU captured in a SystemLab PS Virtual SIL environment with automated regression testing. This enables lifecycle management of this LRU to add new software or hardware capability or mitigate future obsolescence cost effectively.

Figure 2: BAE Systems Bradley Combat Vehicles.

CASE: MOTOR CHATTER IN PRODUCTION VEHICLES

BAE York (Pennsylvania) Production reported several instances of what is described as “chatter” in the traverse motor when the TDCUII is installed in certain vehicles. This coincided with the use of a new source of turret motors in the Bradley Combat System. With the new motor, the vehicle turret would noticeably “chatter” left and right around the commanded turret position while the turret was traversing during a Turret Traverse Low Rate Test.

This is an unacceptable system behavior and would result in a production halt if not addressed. The problem cause needed to be understood and most importantly, a verified and validated solution needed to be implemented to eliminate the problem.

TDCU and Traverse Motor

The TDCU works in conjunction with the traverse motor to control the turret azimuth. The resolver is part of the control system of the traverse motor. It senses the position of the traverse motor shaft. The resolver interfaces to the TDCU as shown here.

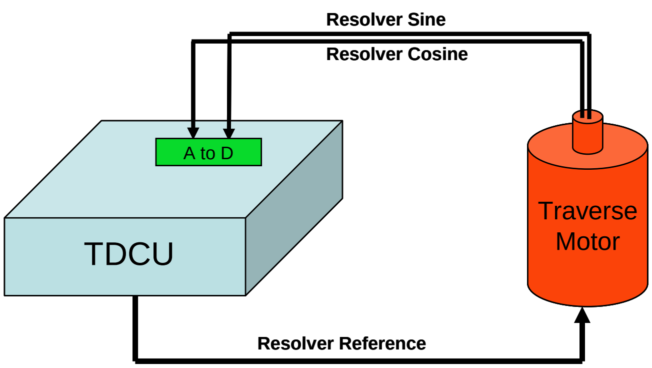

Figure 3: TDCU and Traverse Motor.

Analysis and the Problem

CPU Tech received a traverse motor that was removed from a vehicle in which the motor chatter condition was reported. The motor was installed into the TDCUII Automated Test Equipment (ATE) stand. A traverse low rate test was conducted, and the chatter was observed. Using the data capture capabilities of the TDCUII RTNI port and CPU Tech’s SystemLab tool suite, data was recorded for the sine, cosine, and traverse current as processed by the Motor Controller processor in the TDCUII.

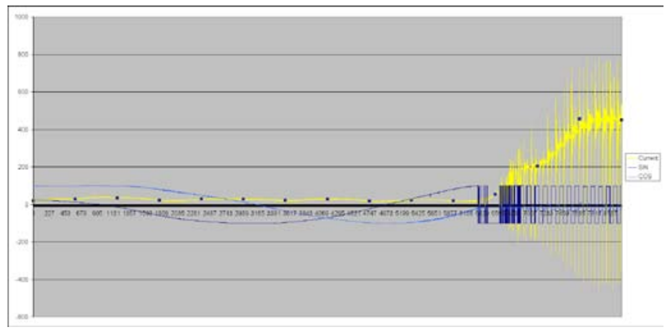

Figure 4: SystemLab Data Capture during Traverse Low Rate Test

The violent oscillations of the sine and cosine waveforms correspond to observed spikes in the positive and negative current to the turret motor. The oscillations of the current from positive to negative command the motor to switch directions rapidly and this causes the audible and visual ‘chatter’.

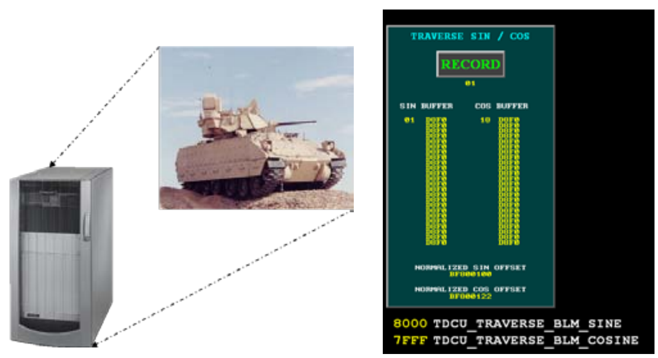

Figure 5: Software Processing of SIN Input 0x8000

Using CPU Tech’s SystemLab PS real-time model of the Bradley vehicle, we were able to verify that the software’s response to specific inputs of sine and cosine were consistent between the observed responses on the vehicle and that of the real-time HW/SW model on the SystemLab PS.

The analysis shows that when the raw resolver signal achieves the max negative value (saturation) the motor control software negation operation overflows the encoding capability and without proper software saturation math, the data appears to change instantaneously from the maximum negative value to the maximum positive signal value. This is a classic problem in DSP and control software and is typically addressed by overflow detection and data saturation and or by data scaling.

CONSIDERATION OF ALTERNATE SOLUTIONS

A software solution would appear to be the most appropriate solution since the behavior was caused by a software calculation error but this is not the case. A software change cannot be isolated to localized resources and structures, instead, it overlays the same memory and register resources as the rest of the tactical software thereby creating the potential to induce inadvertent errors. While the intended change in behavior can be validated easily enough, the unintended consequences and time-sequence impacts to the control algorithm make the verification and validation magnitudes more complex. Therefore, a software change is typically the method of last resort for dealing with ongoing production issues.

Another possible solution would be a sub-system change such as a motor replacement. In this case, the motors are within specification and the failing behavior is due to variations within the specified tolerances of the motor.

Lastly, component changes within the signal scaling circuitry of the resolver or analog to digital conversion would be a reasonable and traditional approach to a solution. This could offset or scale the data away from the processing 'hole' in the software. However, this would require defining, validating and processing an ECO that would involve removing LRUs from each vehicle. The LRUs would have to be sent to the vendor for component changes and retest. The modified LRUs would have to be reinstalled in vehicles and retested. This solution would ripple through the production and the field for quarters.

THE SOLUTION

In lieu of modifying the existing TDCU software to correctly handle this condition, CPU Tech prepared a firmware logic change to prevent the scenario from occurring in the first place. This solution detects if the resolver signal value from the analog to digital converter is equal to the maximum negative value. If it is, the value is adjusted by 1 unit. This represents a change of 0.0015% of the original value of the signal, which is well within the accuracy rating of the analog to digital converter device and avoids the erroneous software sign conversion. Figure 6 shows the resulting behavior of the system when the firmware logic change is applied.

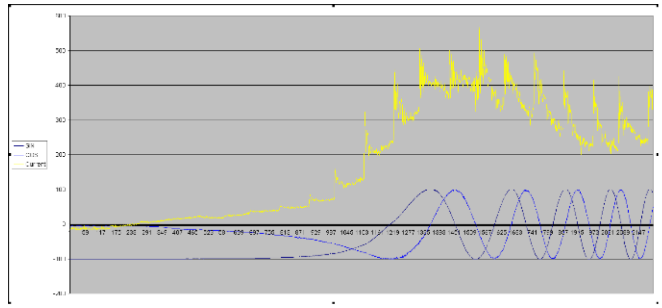

Figure 6: Normal Waveform Resulting from Firmware Change

As can be clearly observed, the spikes in the sine and cosine waveforms are completely eliminated. The current waveform is normal for this traverse operation. With the firmware logic change in place, the system operates as intended and the motor chatter is eliminated.

The solution was evaluated on the SystemLab PS vehicle model and then verified and validated in BAE Systems engineering test facility in Santa Clara, CA. The change was downloaded to production vehicles in York, PA and previous erroneous behavior was eliminated. BAE Systems and CPU Tech engineering teams installed the change in vehicles at Yuma, AZ where the Army exercised the vehicles against mission profiles and approved the modification.

PRODUCTION UPGRADE

CPU Tech was requested by BAE Systems production facility in York to assist in the upgrade of the vehicles with the validated logic firmware fix. CPU Tech Field Service Representatives and BAE Systems production and engineering personnel assembled a rapid response team that was able to update over 150 vehicles in four days. This was done by downloading the new logic firmware into the TDCUII LRU's from a standard laptop PC and an Ethernet connection. This was accomplished without removing any LRUs or boards from the vehicles, allowing the production units to be upgraded, tested and to ship with no production disruption. Following the upgrade effort at York, CPU Tech continued to train BAE Systems Field Service Representatives in the firmware update procedure and together, upgraded the population of vehicles at various Army depots and installations around the country.

Figure 7: Fast Response Team: Slim Linton, BAE Systems in the Turret. Left to Right: David Osborne, David Sherwin, CPU Tech and J.R. Rexroth, BAE Systems.

CONCLUSION

BAE Systems has developed significant capability in whole-vehicle modeling and simulation within the Bradley Vehicle simulation and modeling team in Santa Clara, CA. CPU Tech has developed and applied critical systems modernization, validation and modeling technologies and practices for the sustainment of long-lived electronics systems. The combined resources and capabilities of these teams have been applied to the compatible modernization of the TDCU. Straightforward engineering processes were applied to eliminate current obsolescence issues and reduce future obsolescence issues with the TDCU LRU. Tools and processes were applied to validate that the modernized TDCUII is 100% binary executable code compatible with the legacy TDCU. Techniques and tools were applied to recreate and validate obsolescent COTS-bound logic functions to technology-portable soft IP. The techniques employed provide great value for the cost-effective long-term sustainment and capability upgrade of any mission-proven electronics systems. Revolutionary improvements were realized in LRU fault-location, system visibility and repair-in-place capabilities. Revolutionary improvements have been realized in the time and cost required to field repairs. Significant capabilities have been provided to enable remote diagnostics, remote repair and remote upgrade of electronics systems.

Comments

On the subject of the recent and ongoing upload of a firmware modification to the TDCUII boxes at York, Yuma, Ft. Carson and Ft. Hood, BAE management made the following comments: *If the vehicles still had the original TDCU I boxes installed, it would be very difficult to find the root cause of the chatter and time-consuming to troubleshoot the problem with approaches such as switching out an electric motor; but CPU Tech tools and models alone have made a significant difference in solving system level issues like this that have and will continue to arise. Secondly, the built in SystemLab ports and the combination of these ports with the analysis of the SystemLab environment make a significant difference in fielding changes to firmware and software.*