Improving safety with on-board monitoring and control systems using CAN technology

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The Office of Research and Development of the Federal Railroad Administration (FRA) is sponsoring a revenue service demonstration of Advanced Train Systems featuring new technologies for improving safety and efficiency in freight train operations. The project, which commenced in 1999, is part of the Rolling Stock Program Element in FRA's *Five-Year Strategic Plan for Railroad Research, Development and Demonstrations.* The demonstration system, referred to as the On-Board Monitoring and Control System (OBMCS), features an integrated package of sensors and actuators for monitoring and controlling mechanical components on freight trains. The OBMCS includes sensors to monitor bearings, wheels, brakes and trucks and actuators (referred to as advanced components) for remotely controlling parking brakes, angle cocks, cut levers and a cushion unit lockout system to eliminate slack. The demonstration of the OBMCS with advanced components will commence in 2005.

An *open system architecture* based on CAN technology provides the framework for integration and control of the advanced components. The CAN bus network is also employed to monitor bearing temperatures and the status of brake piston travel sensors. A communication protocol based on a subset of CANopen Draft Standards DS301 and DS401 has been developed to provide a standard architecture for integration of sensors and actuators into the OBMCS.

Introduction and Background

The Federal Railroad Administration Office of Research and Development is sponsoring a project to develop and demonstrate onboard condition monitoring systems for freight trains. The project commenced in 1999. The objective of the project is to improve operational safety and efficiency of freight trains through continuous monitoring of mechanical components to detect defects and alert train crews before breakdowns and accidents occur. A prototype onboard monitoring system was developed in 2000 and tested during the period Nov 2000 – Nov 2001 on a test vehicle provided by Norfolk Southern Corporation.

In September 2003 the monitoring system was installed on five coal hopper cars owned by Southern Company. The system is presently being tested in a revenue service operation on a Norfolk Southern route in Alabama between a coalmine and an electric power plant. Figure 1 shows a diagram of the onboard monitoring system concept currently being tested. Figure 2 shows details of the monitoring system hardware installed on the Southern Company hopper cars.

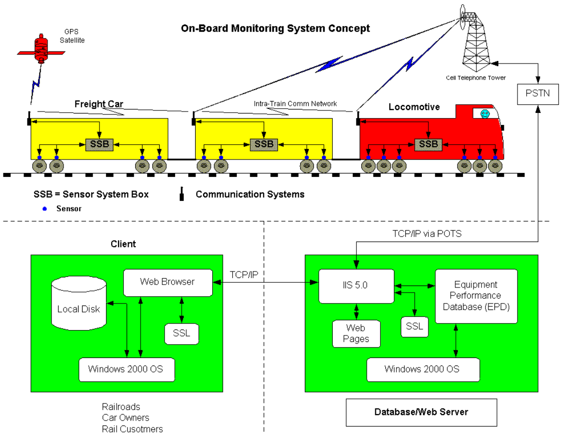

Figure 1. Monitoring system architecture

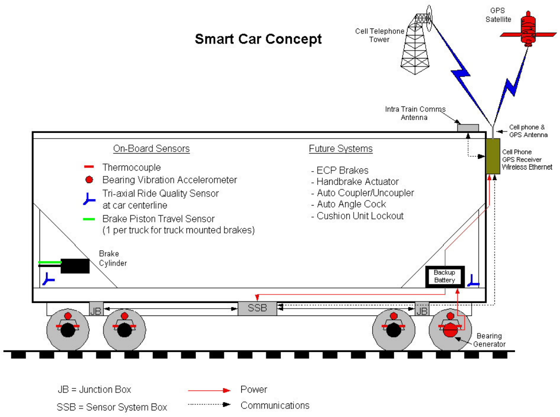

Figure 2. Monitoring system components

The capabilities of the onboard monitoring system are currently being expanded to enable remote control of coupling and uncoupling operations and other functions. Automation of these operations offers an opportunity to save time and reduce injuries to the brakeman charged with these tasks, since they can be performed inside the locomotive from a console. CAN technology is being used to seamlessly integrate the Advanced Components with the onboard monitoring system. The augmented system is referred to as the On-Board Monitoring and Control System (OBMCS). Figure 3 shows a diagram of the OBMCS.

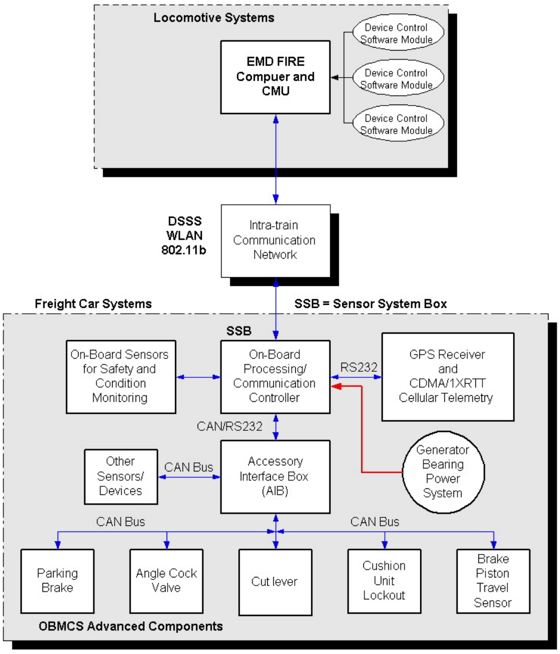

Figure 3. New OBMCS architecture using CAN technology

Rationale for Onboard Monitoring Systems

Development of onboard monitoring and control systems is motivated by the desire to improve freight train safety and efficiency. For example, the current approach for hot bearing detection (HBD) is to use a wayside detector mounted in the rail bed. These units cost approximately $50,000 USD each. They are typically spaced at 20-mile intervals. The HBD counts the number of axles observed starting at the locomotive. When a hot bearing is detected, the locomotive operator stops the train, counts the axles and performs a physical inspection. This activity takes up to 45 minutes. The false alarm rate for HBD systems can be as high as 80%. A bearing can appear normal to the detector and burn off 3 minutes later...well before the train reaches the next detector.

The On-Board Monitoring and Control System (OBMCS) solves this problem by inserting thermal sensors in each inner and outer bearing adapter. In the present system shown in Figure 2 sixteen sensor cables are wired to a PC104 Analog to Digital Converter. Measurements are taken on a regular interval and logged. Exceptions are reported via an 802.11b wireless link to the locomotive operator. The exact car ID, axle number, and bearing location are precisely identified. There is no lapse of monitoring between fixed detector installations associated with wayside HBD systems

Transition to CAN Technology

Bearing temperature is one of many items monitored by the OBMCS. The system currently deployed in revenue service in Alabama uses direct analog signal cables from each sensor to an op-amp buffer board that connects to a Diamond Systems DMM32 PC104 analog to digital I/O board. It is a simple approach that was easy to prototype. However, it was fairly costly. The low loss analog cables were expensive and long runs opened the door for signal degradation. The DMM32 board was selected for its ability to provide high frequency sampling of the vibration signature on each bearing adapter. Using 16 channels to perform a one-shot A to D for temperature measurement is a poor use of such an expensive device. In an effort to reduce cost and increase system monitoring system performance and reliability the OBMCS project is transitioning several existing sensor systems from dedicated wiring to use of CAN controllers. CAN solves cabling problems and is easily implemented on low cost micro-controllers. The Microchip PIC18F6585 has been selected as our platform for a custom CAN controller. The bearing temperature measurements and brake piston position sensors will be monitored via CAN instead of direct wiring to an embedded PC104 data acquisition system.

Concurrent with the development of onboard monitoring systems, FRA sponsored development of several advanced freight car components under Small Business Innovation Research (SBIR) projects. These devices have reached the stage of development where they are ready to be integrated with the onboard monitoring system and showcased in a revenue service demonstration. The advanced components being integrated with the OBMCS include a tri-couplers (for coupling cars, pneumatic air line and Electronically Controlled Pneumatic brake power bus), remote controlled angle-cock valves, cut-levers, parking brakes and a cushion unit lockout device to remove slack between cars. Integration of these devices provides further rationale for utilizing CAN technology in the project. The requirements for integrating these devices into the OBMCS have been derived and a CAN network architecture to support this effort has been developed. CAN controllers to integrate these devices with the OBMCS are being developed. To facilitate this integration, a standard interface for connecting the advanced components to the CAN bus and providing power to operate them has been developed and is currently being tested.

The custom CAN controllers will employ firmware patterned after the CANopen standards. The CAN identifier allocation strategy is based on DS401. The first pass of this firmware is intended to demonstrate “proof of principle”. Assuming the implementation functions as desired, there will be a subsequent effort to make the firmware fully conformant with standardized CANopen protocol tests.

The Electronically Controller Pneumatic (ECP) brake systems impose another task on the brakeman. The brakeman ordinarily handles the coupler, connects the air brake hoses, opens the angle-cock valves and releases the handbrake. ECP requires coupling the ECP power/control bus as well. The Sharma tri-coupler automates the ECP bus/coupler/air brake pipe connection tasks. The auto-angle cock automates the task of opening the air brake pipe connection to the next car. The automatic handbrake allows releasing the parking brake without need of climbing aboard the car to perform this operation. The coupling tasks can be fully automated using CAN controllers to operate the angle-cock and handbrakes.

The uncoupling task is equally important. In the new OBMCS architecture, the CAN controllers will set the handbrakes, close the angle-cock valves and release the coupler. All of these operations are commanded from the locomotive over the 802.11b wireless link to the OBMCS. The OBMCS provides the authorization, authentication and translation of commands before passing them to the CAN bus. CAN sensor traffic is aggregated at the OBMCS and selected items are passed back to the locomotive operator.

The Locomotive Operator’s View

The locomotive operator will see an integrated graphical user interface provided by the General Motors Electromotive FIRE computer display. Setting the parking brakes on a given car will be initiated by clicking on a graphic element. Under the covers, a message is encoded in EMD proprietary NetCore communication protocol and conveyed over an 802.11b wireless network to the OBMCS on a specific freight car. The 802.11b interface on the car receives the packet and passes it to the PC104 computer. The command is decoded, authenticated, authorized and passed to the CAN gateway process. Attached to the serial port of the PC104 computer is a Lawicel CANdip outfitted with the CAN232 firmware. This interface passes the command to the CAN bus where it is received and processed by the handbrake CAN controller. A status message traces the reverse path to indicate successful completion.

The effort to integrate these systems into a cohesive whole is fairly well understood. Getting the set of processes to work in a lab environment is not expected to be difficult. Making the system work in the context of a revenue service train adds a new set of challenges.

CAN On A Freight Car Is A Challenging Task

In the laboratory a prototype CAN system has access to continuous power. One can easily ensure that all message processing takes place as expected. The situation changes drastically in the field.

A Timken generator bearing and a deep cycle 12-volt marine battery power the OBMCS. The embedded PC104 computer systems draw significant power, so they must remain off until they are needed to perform a task. A CAN controller in the “smart” battery box monitors the tachometer signals from the Timken bearing generator. The tachometer signal is a 50% duty cycle square wave at 12 pulses per axle rotation. At 18 pulses per second, the generator is producing enough power to charge the battery and operate the OBMCS. At 50 miles per hour, the Timken generator bearing produces about 24 watts of power. The pulse per second rate from the tachometer in the generator bearing is transmitted in a CAN message for use by speed sensitive elements of the system.

If the cars are idle, the computer systems will be powered down. The locomotive requires the computers to be powered up to initiate remote control operations. Currently we plan to monitor the ECP power bus to see if a locomotive has coupled. If the ECP bus is powered, the PIC controller in the “smart” battery box will initiate a power on condition to create a working system that responds to remote commands over the 802.11b wireless LAN.

The condition of the power system is transmitted over the CAN bus by the “smart” battery box CAN controller. The OBMCS must aggressively manage power consumption. If the battery voltage drops below 10.7 volts, the battery charger/regulator ceases to function. There is little “headroom” between a fully charged battery and a battery discharged to the point that it cannot recharge. Any power drain that is not necessary must be turned off to preserve the available power.

The reason for creating custom CAN controllers for this project centers around the need for aggressive power management. Reducing clock speed and dynamically controlling the MCP2551 CAN transceiver can yield a significant reduction in the OBMCS power requirement. To demonstrate this concept, a Microchip CAN/LIN3 development board was stripped to a single PIC18F6680, 25 MHz crystal, CAN transceiver and power supply. The “stock” configuration draws about 56 mA when powered from a 13.8 volt DC supply. Changing the crystal oscillator to 4 MHz and applying dynamic control of the Rs (slew rate) lead of the MCP2551 reduces the current requirement to 14.6 mA.

To further reduce power consumption the MCP2551 CAN transceivers on the two CAN controllers monitoring 16 channels of bearing temperature will be kept in standby mode 99.8% of the time. On 15-second intervals, the temperature sensors will be sampled, the CAN transceiver will be enabled and 4 CAN messages will be transmitted over the CAN bus to the embedded PC104.

The CAN controllers monitoring the brake piston position (Hall effect) sensors will provide updates on 15-second intervals in like fashion to the temperature controllers. However, they will also transmit a CAN message upon a change of state input from either of the two Hall effect sensors.

Action at a Distance

Improving the sensor system with CAN controllers represents an incremental improvement in the existing OBMCS system. The sensors represented a very safe “read only” operation. Operating angle cock valves, cut levers and handbrakes raises a new set of issues. This new set of CAN controllers can change the state of parking brakes, angle cock valves and couplers. The new capability also brings new responsibility. The wireless command links must include authentication to avoid “hacking” by a malicious party. The mechanical devices must include “fail safe” designs that work even if the CAN network fails.

Each of the Sharma & Associates advanced components (tri-coupler, auto angle cock and cut lever) retains normal functionality if the CAN controller ceases to function. The cut lever controller monitors the wheel speed messages from the smart battery box/tachometer controller. The wheel speed must be zero to accept a remote uncoupling request. The auto angle cock valve employs cams and micro-switches to monitor the state of the ball valve. The actuator motor safely completes a cycle independent of the CAN controller. Automation of these operations via the CAN bus is being performed with a full “safety net” in the underlying electromechanical design.

The UTD handbrake actuator employs an electro-pneumatic actuator. The CAN controller initiates operation of an air valve to set or release the handbrakes. The “safe” fallback condition for this subsystem is “brakes set”. Releasing the brakes requires brake pipe pressure. This subsystem will be permitted to operate on a moving railcar. The automatic handbrakes can be employed as an “emergency brake”. The handbrake is normally used to immobilize a car that is placed in an idle condition on an inactive section of track.

Future Migration of Current Sensors to CAN

The OBMCS includes some accelerometer systems to monitor ride quality (tri-axial accelerometers at each end of the car) and detect bearing defects. The lateral motion of a truck to stay within the rails is known as “hunting”. This motion has a frequency under 10 Hz. In the monitoring system currently being tested in Alabama this signal is cabled to the PC104 A to D converter for sampling and analysis. The low frequency of this motion can easily be monitored and analyzed by a PIC running CAN software. Moving this monitoring function to a CAN controller makes it a truly continuous process that leverages the distributed nature of the CAN network.

Another accelerometer candidate for transition to the CAN architecture is the vertical bearing channel. Continuous monitoring of this channel will enable detection of a wheel derailments and event reporting over the CAN bus. Swift detection and reporting can avert a major accident.

Summary

Moving to CAN based architecture offers an opportunity to reduce cost and improve the performance and reliability of the OBMCS. The distributed processing model of CAN allows truly continuous monitoring of bearing temperatures and truck ride quality instead of multiplexing these varied tasks on a single PC104 A to D converter. Active control of brakes, cut levers and angle cock valves can improve the safety and working conditions for the railroad brakeman. Detecting pending catastrophic failures of bearings or wheel derailments will improve safety for both the operating crews and the public areas exposed to freight train operations.

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