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"Design of a Smart, Survivable Sensor System for Rapid Transit Applications"

J. R. Hogan and J. L. Mitchell
Sandia National Laboratories
Livermore, California

Abstract -- An application of smart sensor technology developed by Sandia National Laboratories has been proposed for real-time monitoring and tracking in the transportation industry [1]. Its primary purpose is to reduce operating costs by improving preventative maintenance scheduling, reducing the number, severity and consequence of accidents and by reducing losses due to theft.

The concept uses a strap-on sensor package, the *Green Box*, that can be attached to any vehicle. The *Green Box* is designed as a valued-added component, integrated into existing transportation industry systems and standards. The device, designed to provide advanced warning of component failures, would be capable of surviving most typical accidents. In an accident, the system would send a distress signal notifying authorities of the location and condition of the cargo; permitting them to respond in the most effective manner.

In addition, the *Green Box* is adaptable for use as a notification/locator system to enhance the security of operators and passengers for various modes of public transportation. The modular architecture which facilitates system integration in a number of different applications is discussed. A test plan for evaluating performance in both normal and abnormal operating and accident conditions is described.

INTRODUCTION:

An efficient transportation system is vital to economic health. Loss of revenue resulting from unscheduled maintenance or accidents are a major concern. Breakdowns during peak periods of operation can disrupt traffic, produce long delays, and increase cost of operation. Real-time monitoring of critical components could significantly reduce these problems by identifying declining capability before failure occurs. The *Green Box* sensor module described in this paper can perform this monitoring task and transmit information critical to the safe operation of transit vehicles.

Advances in sensor micro-electronics and digital signal processing permit us to produce a class of smart sensors which interpret raw data and transmit inferred information. Using these new technologies, Sandia National Laboratories has developed a strap-on sensor package, the *Green Box*, that could be attached to any transportation vehicle or container. As applied to rapid transit systems its primary purpose is maximize operating efficiency and minimizing operating costs. The system would be capable of numerous activities including: controlling system braking and vehicle acceleration, active noise cancellation, recognizing component failure conditions, and logging sensor data.

During normal operations, the module's sensors will continuously monitor the performance of safety critical components and report deteriorating conditions to the operators (Figure 1). Based on these reports, maintenance requests can be scheduled to resolve the deficiencies. To avoid communications gridlock only information packets, not raw data, would be transmitted. In addition, the *Green Box* would be capable of surviving most typical accidents. In an emergency, the system would send a distress signal notifying authorities of the location and condition of the vehicle; thereby enhancing rapid and efficient response.

Figure 1. *Green Box* used in an automated maintenance scheduler mode.

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BACKGROUND:

To accommodate increased demand for service, the number of vehicles in a transit system can be increased and the inter-vehicle spacing decreased. At some point as the number of vehicles in the traffic pattern increases, however, a fundamental design limit is reached, component failure rates begins to dominate and system performance degrades. To resolve this situation by either decreasing the time between component exchanges or increasing the frequency of preventative maintenance may be impractical. As an alternative we propose a Just-in-Time maintenance approach based on real-time information acquired by onboard sensors.

We propose the use of the Green Box technology to provide this maintenance scheduling function. Based on sensors and telemetry developed for data acquisition and remote monitoring of weapon systems we propose a concept for a strap-on sensor package, the *Green Box,* that could be attached to any transportation vehicle. This intelligent sensor system would be capable of recognizing component failure, notifying the operator and logging the sensor data for use in scheduling preventative maintenance.

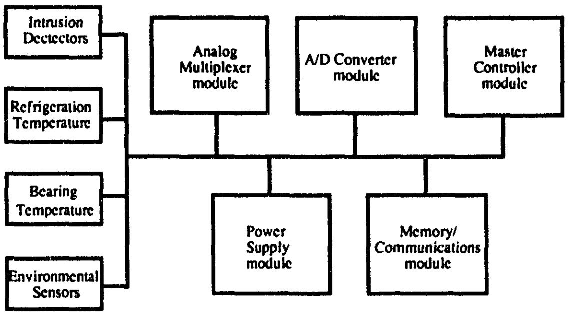

Figure 2. Modular architecture of the *Green Box* control system and sensor module.

DESIGN APPROACH:

To facilitate implementation and to accommodate different customer requirements, the smart sensor is designed as a modular system. A typical system (Figure 2) might consist of microcontroller-based module, a communications module, a sensor suite, a memory module and if required a geographic position locator (e.g., global positioning system). Each component can be individually matched to the specific application. The only requirement is that every component satisfy the interface specifications established for the system. With this modular architecture as the foundation, newer editions can be delivered at minimal cost and with minimal disruption to operations.

EVALUATION TESTING:

The objective is to produce a component (housing and electronics) that will survive the initial accident event and immediately report critical information to the response team. To establish the design specs one must first identify the combination of environments encountered in a typical accident. In the absence of definitive (Table I) were developed from a combination of sources. These sources include the Federal Aviation Administration (FAA) flight recorder (Black Box), a report prepared for the U.S. Dept. of Energy titled "Severities of Transportation Accidents" and private discussions with experts in the transportation safety industry.

TABLE I
Green Box General Structural Requirements.

Requirement	Specification
Weight	Entire system to weigh 60 lbs or less.
Size:	Not to exceed 12" x 12" x 12".
Electrical Connections	All external connectors to be female. Minimum pin size TBD.
Mechanical Fasteners:	Lids and components: 160,000 psi UNF series hex screws. Attachment to vehicle: 160,000 psi UNC series Hex bolts.
Manufacturing:	Avoid exotic materials and fabrication processes. Allow for modularity.

To date, the principal *Green Box* modules have been functionally tested at the component and subsystem level. A prototype strap-on module and base station have been built. The basic functions of the *Green Box* automated monitoring and tracking system have been tested in both laboratory and field demonstrations. In these concept validation tests, ac/dc converters, and rechargeable batteries supplied the necessary system power, and a cellular telephone simulated the communication link. To verify component integration with existing transit communication and power system interfaces, a full scale functional test in an operational scenario is planned. Both maintenance and simulated emergency conditions will be examined.

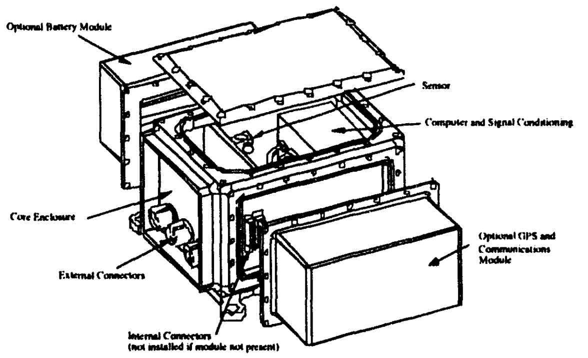

Figure 3. Prototype *Green Box* housing.

Mechanical System Testing

The mechanical testing program for the *Green Box* is in the planning stage. For normal environments the prototype structure shown in Figure 3 will be fabricated and loaded with mass mocks of the electronics. This assembly will be subjected to the normal environment thermal, vibration and shock conditions to establish the natural responses and to refine the initial design features. This unit will also be used to assess human engineering design features such as *Green Box* maintenance, mounting, connectors, etc. A second assembly with functional electronics will be subjected to both static and dynamic environments to assess the mounting and packaging features of the design.

To validate the survivability of the *Green Box* a series of single environment laboratory tests stressing the design in fire, shock, static crush and high vibration are planned. These tests will be used to match the design with the requirements and to establish the parameters for a fully instrumented, simulated accident involving combined shock, crush and fire.

APPLICATION TO TRANSIT SYSTEMS:

The goal of the project is to use field testing and analysis to demonstrate the benefit of this concept in terms of enhanced public safety and reduced operational costs to the industry. The micro-controller based sensor system has the flexibility to monitor the operation of both vital (brakes, lighting, propulsion) and non-vital (air conditioning, ride quality) components and report the condition to the operators for optimum management of the maintenance operations.

In complex systems where accurate analytic models are very difficult or impossible to develop, an intelligent system is particularly useful [2]. The *Green Box*, for example, might use "learned information" to evaluate acceptable system performance in circumstances in which the exact interpretation of deteriorating performance is uncertain. If statistical data on the performance of equipment is available, the smart sensor can use historic data to establish a baseline, then establish new trends as additional data are logged.

To evaluate potential commercial benefit of this maintenance scheduling option, Sandia will draw from our experience investigating advanced railroad technologies [3]. In this demonstration project, for the New Mexico State Transportation Authority, sensors will be mounted on a railcar placed in service on a freight train. This self-contained sensor package will monitor the railcar's safety critical components and cargo state of health. The information will be telemetered to a receiving station. The data will be correlated with the preventative maintenance requirements and the preventative maintenance schedule for the railcar.

Intra-Urban Bus:

A second project is designed to evaluate the utility of using the *Green Box* sensor system aboard a municipal bus system servicing the inter and intra urban community (Figure 4). In this project the use of a position locating system has been incorporated into the test plan. A base station which monitors the information generated by the onboard sensors and displays the real-time location of the vehicle overlaid on a map of the area has been prototyped. The sequence of test events, reporting cycles, message content, etc. are all controlled from the base station.

Figure 4. *Green Box* in an intra or inter urban transportation system application.

Rural Transit:

The *Green Box* technology is also being considered for use in rural transportation systems. In response to a request by New Mexico Governor Bruce King, Sandia National Laboratories proposed to demonstrate a system that could respond to accidents/emergencies in the rural areas of the state quickly and effectively (Figure 5). The demonstration will use a school bus driving through a remote area of the state [4].

On a much larger scale the same technology could play a role in the Intermodal Surface Transportation Efficiency Act's congressionally mandated program requiring all 50 states to improve the nation's infrastructure for moving people from one place to another. To assist the states in meeting these requirements, Sandia's Transportation Systems Center is developing a prototype system keyed on geographic information systems. In the future, individuals might even be equipped with sensors and transmitters that give their location and condition in the event of an accident or if their car is stolen or the driver kidnapped.

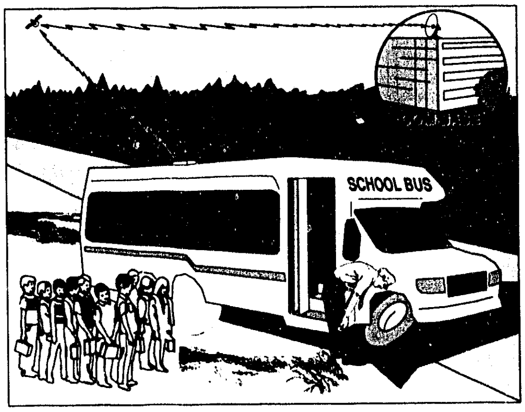

Figure 5. *Green Box* in rural transit system.

CONCLUSIONS:

An accident resistant, strap-on electronics module has been proposed for use in the transit industry. The device can autonomously track and monitor the condition of the vehicle and its safety critical components. This information can be used in routine reports to schedule maintenance, expedite routing and, in an accident, automatically transmit information vital to the emergency response teams.

The primary purpose is to minimize the number, severity and consequences of accidents and to reduce losses due to theft. The system would also be capable of recognizing component failure conditions, notifying the operators and logging sensor data for use in directing preventative maintenance. Taken together, these two features suggest a device that can assist the industry in reducing operating costs and streamlining the flow of traffic by making use of real-time information from the moving vehicles.

REFERENCES:

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