SAS 2007 – IEEE Sensors Applications Symposium
San Diego, California USA, 6-8 February 2007

Controller Area Network for In-Vehicle Law Enforcement Applications

Anthony Marino, *Member, IEEE*, and John Schmalzel, *Senior Member, IEEE*

***Abstract*—Based on requirements for an advanced law enforcement vehicle demonstrator, in-vehicle Controller Area Network (CAN) architecture has been implemented. In an effort to reduce the amount of point-to-point wiring in law enforcement vehicles and centralize communications between devices, CAN is suggested as a means to serialize data communications within the vehicle environment. The benefits of this CAN net-centric approach to in-vehicle law enforcement applications over traditional point-to-point schemes will offer increased flexibility and expandability for future technology insertions and provide the user access to information from a set of interoperable CAN enabled sources.**

***Index Terms*—Controller Area Network (CAN), In-Vehicle Network, Communication Protocols, Network Technology**

I. Introduction

THE New Jersey State Police (NJSP), with the support of the New Jersey Department of Transportation (NJDOT) and the Federal Highways Administration (FHWA), have made a commitment to improve cockpit integration and expand the suite of technology available in their fleet of patrol cars.[1] It is the intent of the NJSP to use this commitment to create an advanced technology law enforcement vehicle that improves the effectiveness of the fleet and provides safety for the entire force. The requirements for the advanced technology vehicle effort include the following:

1) capture existing requirements to identify the current functions, physical attributes, and user interactions of the patrol car.
2) capture future requirements to identify the desired changes to current design.
3) assessment of new candidate technologies to be integrated with the existing technology suite.
4) definition of ergonomic requirements for effectively and safely integrating technology suite.
5) design, development, and validation of a cockpit layout that includes the suite of existing and new technologies while meeting ergonomic requirements.

The impetus to implement CAN architecture within the vehicle environment evolved during the capture of existing requirements. A survey of the current technology revealed that stock patrol cars that are purpose-built for high performance are retrofitted with an array of technologies, which include multi-band voice and data communication, radar, video, location via global-positioning system (GPS), and an on-board computer system, which provides integrated data management. With increasing technology inside automobiles, especially law enforcement vehicles, there is a growing need for centralized wiring and device interconnection methods. Each new technology, such as GPS units and in-vehicle video systems, includes a corresponding wiring harness that requires installation. The summation of all these hardwired technologies leads to large volumes of wire that negatively affect safety, power demands, ergonomics, and future design opportunities. In the end CAN satisfied the requirement of a new technology, relative to the existing NJSP technology suite, while satisfying ergonomic needs for effectively and safely integrating technologies.

Aspects of the in-vehicle CAN architecture have been implemented. The initial application to be migrated to the CAN bus is the NJSP pursuit light package. Our intent is to show that if the wiring involved with such a system can be reduced, then other systems can follow suit. Transforming the vehicle environment from point-to-point to serial communications will provide law enforcement agencies with such benefits as, but not limited to, greater installation flexibility and opportunities to easily expand technology suites. Preliminary results support our hypothesis and provide a foundation that will assist with in-vehicle technology modernization and eventually lead to a completely integrated law enforcement technology suite with a common communications backbone. Additional opportunities have been identified to sustain the development of CAN designed in-vehicle networks for law enforcement applications, which should be of interest to others working in the field of vehicular technology.

Various protocols, such as CAN protocol [1], have been developed and introduced as a solution to hardwired schemes by providing a net-centric approach to connect the multitude of electronic systems in automobiles. Other protocols including J1850, Local Interconnect Network (LIN), Media-Oriented Systems Transport (MOST), and FlexRay have been developed to control vehicle features from non-critical, comfort electronics, window motors and seat adjustment controls, to critical, real-time controls such as braking and steering [2-5].

This work was supported in part by the New Jersey Department of Transportation, New Jersey State Police, and Federal Highways Administration.

A. Marino was with the Electrical and Computer Engineering Department, Rowan University, Glassboro, NJ 08028 USA. He is now with Lockheed Martin, Moorestown, NJ 08057 USA (phone: 856-359-3488; fax: 856-359-3461; e-mail: anthonymarino@ieee.org).

J. Schmalzel is with the Electrical and Computer Engineering Department, Rowan University, Glassboro, NJ 08028 USA (e-mail: j.schmalzel@ieee.org).

[1] The opinions expressed herein are those of the authors and are not to be construed as those of NJSP, NJDOT, and/or FHWA.

Since there is no common protocol, the selection of a protocol is dependent upon the specific application, availability of parts, and economics. For the purpose of this paper, we have adopted the requirements, as defined by Krug and Schendl [6], of an in-vehicle network as the following:

1) to integrate subsystems with the goal of creating a more complex system;
2) to manage the increasing number of electronic components;
3) to reduce the costs caused by increased wiring.

The CAN protocol satisfies the requirements above and was selected since it has been widely applied to automotive applications, thus making it readily available and economical, and it is ideal for non-critical controls.

II. Overview of CAN

The CAN protocol, defined by Bosch [1], was developed to allow connection of sensors, actuators, and various control units in vehicle and industrial applications. CAN is a priority-based, broadcast bus that allows for messages with the highest priority to gain access to the bus in a non-destructive, bit-wise process. While the bus is idle or free, the bus is said to be in a recessive state. Arbitration is initiated with a change from recessive to dominant via a start of frame bit transmitted by a node. Every successive identifier bit transmitted is compared with the bus level as shown in Fig. 1. If the transmitted level matches the bus level, then the next bit is transmitted. If the bus level does not match the transmitted level, then the node concludes that another node is transmitting a message of higher priority. Once a node has completed the arbitration process, the rest of the message is transmitted. In general, when multiple CAN nodes attempt to access the bus concurrently, messages are not loss during collision; instead once the highest priority message wins access successive messages follow without destruction.

In addition to the CAN access method other appealing aspects of this protocol include [7-8]:

- cyclic redundancy check (CRC) and bit stuffing for error detection;
- EMC and EMI resistance;
- expanding and converting to different configurations is simple;
- content-based addressing, implying that each message packet has a unique identifier according to its content;
- latency time is short for high priority messages;
- variable data length, 0-8 bytes.

Perhaps the two most appealing aspects of CAN are the supported data rates ranging from 5 kb/s to 1 Mb/s and the robustness of a CAN network. There are two data lines defined by CAN, which transmit the same data. If one line is damaged or grounded, the network is not hindered but operates under degraded noise immunity. The CAN protocol also has the ability to limit bus access for defective nodes in the network.

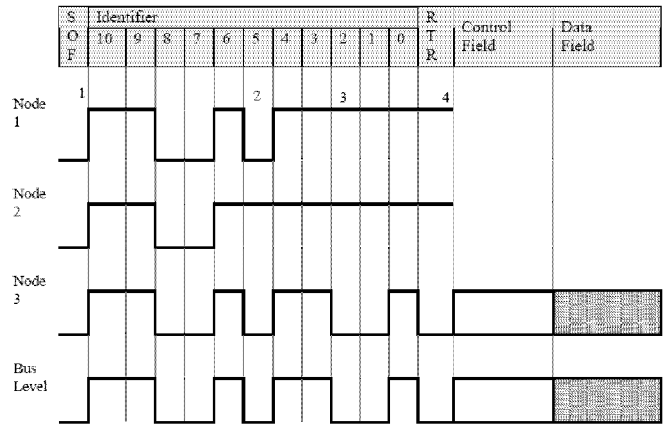

Fig.1. CAN bus arbitration process.

III. Approach

The approach employed for this paper, pursuit light package control via CAN communications, can be divided into functional blocks as shown in Fig. 2. At the lowest level, the CAN bus lines, CAN high and CAN low, are connected to a CAN module via a CAN transceiver.

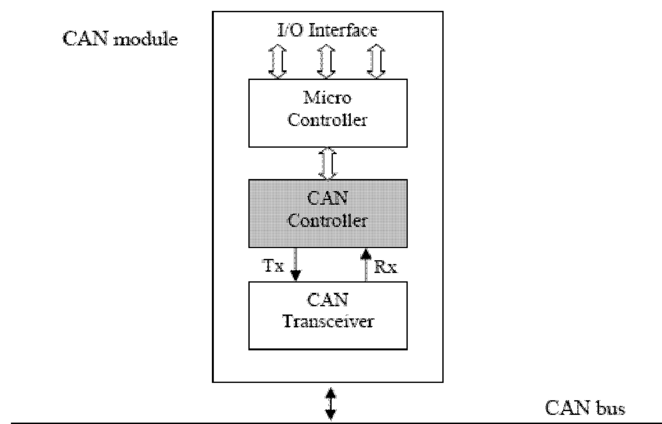

Fig. 2. Generalized CAN module configuration.

The transceiver controls both the transmission and reception of messages to and from the CAN bus. The next level up from the transceiver is a CAN controller. The CAN protocol is implemented inside the CAN controller. The controller is oftentimes connected to a microcontroller that handles the overall application. Finally, the highest level is the application level, which can have a variety of inputs and outputs. For this work, the intended platform for the CAN network is the NJSP pursuit light package. The application aspect of this platform would be the "intelligence" of the respective functions of the light package; for instance, turning on the front strobe lights for 30 seconds and then switching to the rear strobe lights for another 30 seconds.

A. Pursuit Light Package

The NJSP pursuit light package includes an overall combination of 14 LED, strobe, and halogen lights in different positions as shown in Fig. 3. In the front of the car, there is one

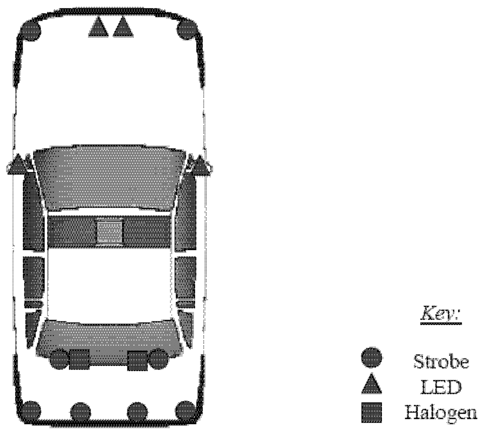

Fig. 3. Diagram of NJSP pursuit light package.

strobe light in each headlight as well as two LEDs in the front grille. There are also LED lights in the two side view mirrors. In the rear of the vehicle, there are two strobe lights and two halogen lights in the interior positioned on the rear deck, and four strobe lights in the brake and reverse lights.

The current user control points for the light package are located in the cockpit of the car, separated from the electronic, switching control unit in the trunk. For the light system, there is a dedicated cable that connects each light to the control unit in the trunk. The control unit then communicates with the cockpit user interface via another cable. The combination of these dedicated cable installations is an example of the increasing problem of excessive wiring.

B. CAN Applied To Light Control

The proposed architecture consists of three major components, a user interface attached to a CAN module, the CAN bus, and the light package attached to a CAN module as shown in Fig. 4. Commanding a light pattern is initiated by the user via a switch interface. For this approach, the activation of a switch generates a CAN message. Embedded in the CAN message are two key components, the intended address of a light, and the data to be transferred to that address. In the complete light package, each of the 14 lights could be individually addressed or a combination of lights could be addressed together. The data transmitted to a CAN enabled controlled light can vary, but in the simplest form, a logic level 1 would turn on a light and logic level 0 would turn off a light. Translating logic levels to operate a light is accomplished by using a transistor as a switch to turn on and off the current through a load.

Implementing the proposed architecture is accomplished with the use of an 8-bit microprocessor[2] interfaced with a SJA1000 CAN controller[3] which is attached to a PCA82C251 CAN transceiver[4] as shown in Fig. 5. At the command of the user, a CAN frame is generated upon activation of basic I/O provided by the microcontroller. The CAN message will contain the intended address of a light or group of lights to be controlled and an associated data field defining an on or off state. From the cockpit of the car a transmitting CAN node will broadcast the message over the CAN bus to receiving CAN cores via an attached CAN transceiver. CAN nodes with the matching destination address receive and filter the message and subsequently pass along the data field to the host microcontroller. The embedded message is interpreted by the microcontroller and the corresponding lights are turned on or off in a sequence driven by the knowledge programmed into the microcontroller.

IV. Discussion

A. Results

In the implementation described in this paper a transmitting CAN module, which emulated the user control point, located in the cockpit of the car, generated and transmitted a pre-defined CAN message over the CAN bus to a receiving CAN module. The microcontroller of the receiving CAN module deconstructed the message and was able to control a representation of the NJSP light package. Using a standard CAN frame format with one data byte, or eight bits, and by defining each bit position as a light, our representation consisted of 8 lights. For example, a received bit stream of 00000001 reflects that all lights are off except for light 1. The microcontroller was able to receive messages from the CAN controller and examined the bit positions of the data byte(s) and determined if a light in the light package should be turned on or off according to the logic level present at each bit position using a bit inspection process as shown in Fig. 6.

The methodologies and results presented in this paper suggest a promising approach for achieving integrated control of in-vehicle electronics in conjunction with reduced cabling in a law enforcement application. The proposed network, CAN, offers a net-centric approach providing a common data bus that would eliminate the need for point-to-point wiring of the current systems. Furthermore, this network provides the capability to control applications such as the NJSP light package. When the user selects a light combination, a CAN message is generated that contains the address of the target CAN receiver node. The receiver node filters the CAN frame and decodes the embedded data field, which contains the instruction for turning on or off the selected lights.

In addition to proving that CAN is a suitable technology to carry out the control of the light package, the inherent two-wire bus associated with the CAN implementation automatically presents an opportunity to reduce and centralize wiring. In view of the fact that the CAN bus is centralized, the

[2][Online]. Z-World, Davis, CA. Available: www.zworld.com

[3,4][Online]. Philips Semiconductors, Eindhoven, The Netherlands. Available: www.semiconductors.philips.com

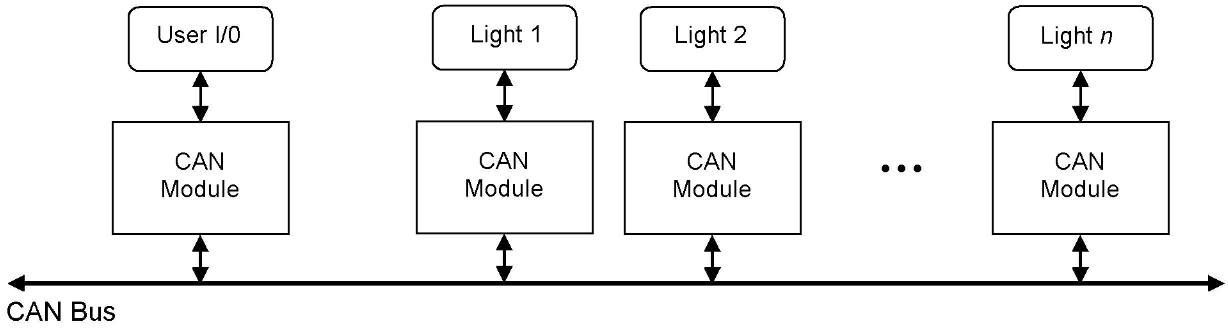

Fig. 4. Generalized diagram of proposed CAN architecture.

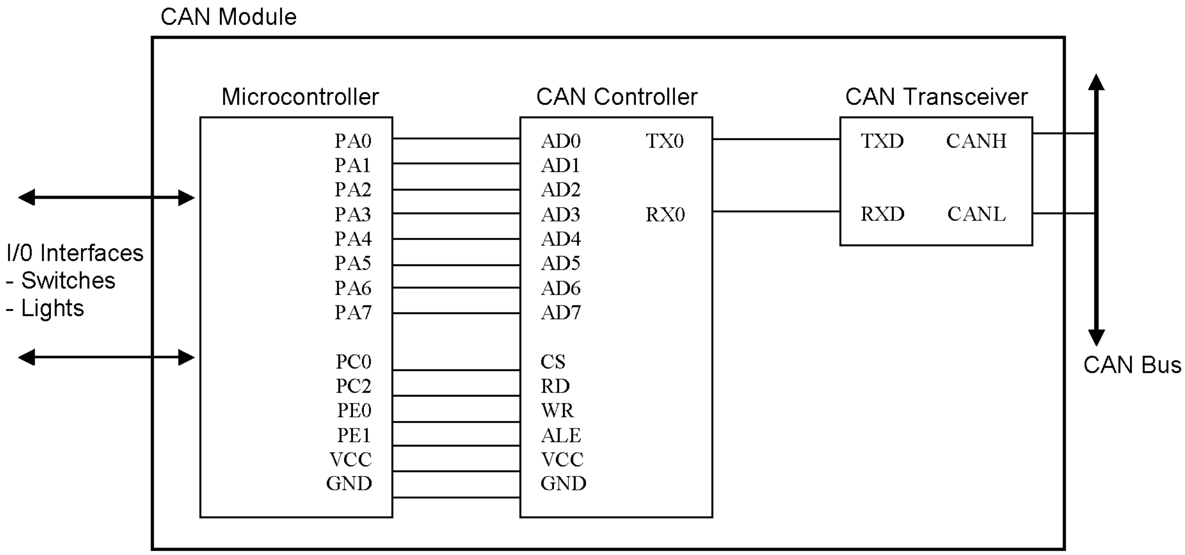

Fig. 5. Prototype CAN module.

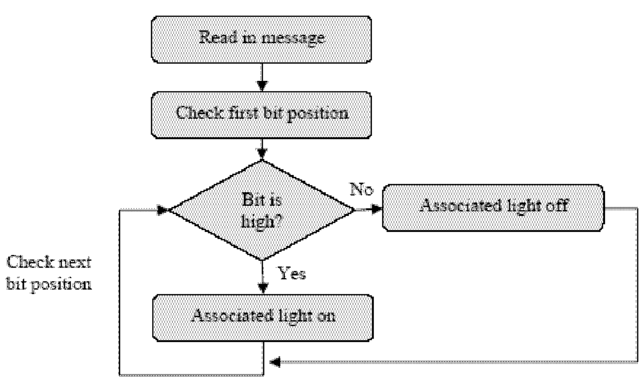

Fig. 6. Flow diagram for bit inspection of received data byte.

wire required to connect the CAN nodes to the bus is minimum. With an efficient layout that minimizes the amount of CAN nodes implemented and maximizes the amount of lights controlled, it is possible to reduce the amount of currently installed wire by half. The CAN nodes are designed to be able to control more than just one light and hence each light in the light package does not require an attached node. Instead, the car can be viewed as three sections; front, middle, and rear, with a CAN node controlling each section.

For a relatively low cost, a CAN implementation of the light package offers economic advantages over the current installation method. In addition to the impending savings in installation costs CAN provides greater flexibility and versatility over point-to-point wiring. Not only does the CAN implementation reduce wiring but it provides a communication channel that can facilitate other technologies and systems in the future. In short, the benefits of a CAN implementation outweigh any shortcomings.

B. Future Development Considerations

Although the design demonstrated the control of a modified light package; CAN is versatile enough to accomplish more than just control. An entity with CAN capability can report diagnostic information obtained from other elements on the shared network, thus supplying the user with a "smart" technology suite.

CAN is not without shortcomings. As mentioned earlier, CAN is ideal for non-critical controls and is predominantly applied to sensors and actuators. Applications such as in-vehicle video systems would be best suited to communicate through a network designed for multimedia. In fact, it is not uncommon for a vehicle to have segmented networks operating at different transmission rates.

Additional future development considerations in line with this work and the overall objective to improve cockpit integration for law enforcement include the following:

- Define further law enforcement applications to operate on a CAN network.
- Mature the CAN architecture to include smart modules for in-vehicle networks [9].
- Modify CAN modules to include health monitoring capabilities.
- Investigate additional in-vehicle protocols that can overcome limitations in CAN.

V. Conclusion

Based on the requirements for an advanced technology law enforcement vehicle, CAN was presented as a new technology to the existing technology suite currently deployed by the NJSP. In addition, the CAN protocol fulfilled the requirement to effectively integrate technologies by providing a common communications medium for device interconnection. We have implemented a prototype CAN network applied to the NJSP pursuit light package. The preliminary results lay the foundation for a highly integrated police car that provides greater functionality to the user and makes the vehicle more flexible to facilitate additional technology growth in the future. Further benefits include reduced wiring costs and weight.

References

[1] R. Bosch GmbH, CAN Specification, Version 2, Sept. 1991.

[2] LIN Consortium, LIN Specification, Version 1.3, Dec. 2002.

[3] MOST Cooperation, MOST Specification Framework, Version 2.2, Nov. 2002.

[4] G. Leen, D. Heffernan, A. Dunne, "Digital Networks in the Automotive Vehicle," *IEEE Computer and Control Eng. Journal*, pp. 257-266, Dec. 1999

[5] N. Navet, "Controller Area Network," *IEEE Potentials*, vol. 17, no. 4, pp. 12-14, Oct.-Nov. 1998.

[6] M. Krug, A. Schendl, "New Demands for In-Vehicle Networks," *Euromicro: Proc. of the Euromicro Conference*, vol. 23, pp. 601-605, 1997.

[7] J. M. Lee, S. Lee, M. H. Lee, and K. S. Yoon, "Integrated wiring system for construction equipment," *IEEE/ASME Trans. Mechatron.*, vol. 4, pp. 187–195, June 1999.

[8] W. Xing, H. Chen, and H. Ding, "The Application of Controller Area Network on Vehicle," *Proc. of the IEEE Int. Vehicle Elect. Conf.*, vol. 1, pp. 455-458, Sept. 1999.

[9] K. C. Lee, M. H. Kim, S. Lee, and H. H. Lee, "IEEE-1451-Based Smart Module for In-Vehicle Networking Systems of Intelligent Vehicles," *IEEE Trans. Industrial Electronics*, vol. 51, no. 6, pp. 1150-1158, Dec. 2004.