CAN-based monitoring in refrigerated transports

Luis Ruiz-Garcia, Laboratorio de Propiedades Físicas y Tecnologías Avanzadas en Agroalimentación (LPF-TAG). Universidad Politécnica de Madrid
Pilar Barreiro, LPF-TAG. Universidad Politécnica de Madrid
José I. Robla, Centro Nacional de Investigaciones Metalúrgicas (CENIM-CSIC)

Perishable food products such as vegetables, fruit, meat or fish require refrigerated transports. As a consequence effective cold management is fundamental for maintaining the quality of these products along the supply chain.

The use of standardized CAN technology can improve monitoring transports, ensuring the inter-operability of the system. A variety of sensors and actuators can be integrated in the CAN. Information provided by sensors has to be processed in order to check the adequate status of settings. In case of anomaly data, alarms should be triggered. Also actual devices for fleet management, such as Global Positioning System (GPS), tachograph and satellite communications, can be a part of whole system. And, in near future, more emergent technologies like Wireless Sensor Networks (WSN) or Radio-Frequency Identification (RFID) will be ready to implement in an on-line monitoring environment. Thus, the challenge today is interconnecting these heterogeneous systems and the harmonization of the different interfaces.

1. Introduction

Perishable food products such as vegetables, fruit, meat or fish require refrigerated transports. The quality of these products might change rapidly, because they are submitted to a variety of risks during transport and storage that are responsible for material quality losses. Among them, intrinsic biological and chemical processes that undertake the fresh produce are related to a lack of appropriate control on duration, temperature and humidity, which causes senescence and rots. As a consequence effective cold management is fundamental for maintaining product quality along the supply chain.

Quality control and monitoring of goods transportation and delivery services is an increasing concern for producers, suppliers, transport decision makers and consumers. It is of particular interest for the refrigerated transport industry, where the major challenge is to ensure a continuous ‘cold chain’ from producer to consumer in order to guaranty prime condition of goods (Ruiz-Garcia *et al.*, 2007). It is essential to ensure that temperature inside the transport units is correct; local temperature deviations can be in almost any transport situation present. Reports from literature indicate deviations of 5°C or more (Tanner and Amos, 2003; Rodriguez-Bermejo *et al.*, 2007).

The transport is done by refrigerated road vehicles and containers equipped with embedded cooling systems. Some of them include monitoring systems, but they do not bring complete information about the cargo, because they typically measure in a single or very limited number of points.

The use of standardized CAN technology (ISO 11898-1/2) can improve monitoring transports, ensuring the inter-operability of the system. A variety of sensors and actuators can be integrated in the CAN. Information provided by sensors has to be processed in order to check the adequate status of settings. In case of anomaly data, alarms should be triggered. Actuators connected in the CANbus system will be responsible for controlling forced air flow, cold generation and defrosting.

But not only sensors and actuators can be part of the CAN. Also actual devices for fleet management, such as global positioning systems (GPS), tachograph and satellite communications, can be a part of whole system. And in near future, more emergent technologies like Wireless Sensor Networks (WSN) or Radio-Frequency Identification (RFID) will be ready to implement in the on-line monitoring of perishable goods.

The challenge is the interconnection of the different subsystems, with different interfaces and profiles, being the CAN the backbone of the system.

Thus, the concept of "Smart Container" is emerging. The system should comprise multiple types of sensors, with distributed measures depending on location. Authorized supply chain participants will track a container's progress as it journeys from the point of stuffing to the point of unloading. Logistics personnel will obtain this information for their shipments from the information network and can use it for supply, factory and route planning (Ruiz-Garcia *et al.*, 2007).

2. CAN-based in-vehicle networks for trucks/trailers

A few fieldbus systems have evolved to be dominant the facto standards, being the most relevant are AS-I, Ethernet, WorldFIP, Profibus, Interbus, P-Net and CANbus. From these, CAN based systems (Fig. 1) are the basis for road vehicles (SAE J1939 and ISO 11992) and also for ships, with the NMEA 2000.

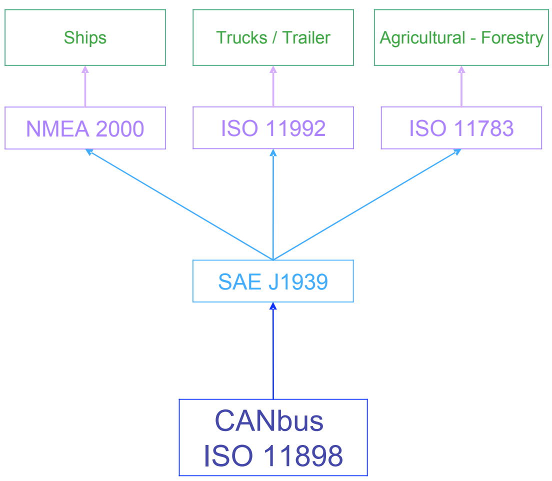

Figure 1: CANbus standards evolution

The CAN protocol was internationally standardized in 1993 as ISO 11898. The conformance test for the CAN protocol is defined whitin ISO 16845, which guarantees the interchangeability of CAN chips. It comprises the data link layer in accordance with a seven layer ISO/OSI (Open System Interconnection) reference model (ISO 7498, 1997).

The last version of the ISO11898: Road vehicles -- Controller area network (CAN) -- has 5 parts: 1) Data link layer and physical signalling, 2) High-speed medium access unit, 3) Low-speed, fault tolerant, medium dependent interface, 4) Time-triggered communication while 5) High-speed medium access unit with low-power mode (ISO11898, 2007).

CANbus is one of the most commonly used field buses in application domains that have real-time requirements like: passenger and cargo trains, maritime electronics, aircraft and aerospace electronics, factory automation, industrial machine control, lifts and escalators, building automation, medical equipment and devices. CAN is implementing fixed-priority scheduling (FPS) using a bit-wise arbitration mechanism in the medium access control (MAC) layer, This mechanism resolve collisions in a deterministic way and is amenable for timing analysis (ISO 11898; CiA, 2007).

CAN hardware implementations cover the lower two layers of the OSI reference model (Physical layer and Data Link Layer) while higher layer protocols cover the rest of the layers (Network layer, Transport layer, Session layer, Presentation layer). Examples of CAN-based higher layer protocols are CANopen, DeviceNet, CANKingdom, SAE J1939, etc. (CiA, 2007).

SAE J1939

The SAE J1939 application profile defines the CAN-based in-vehicle communication for trucks and buses. It was developed by the American Society of Automotive Engineers (SAE). A J1939 network connects electronic control units (ECU) towards a truck or trailer system SAE J1939 specifies, e.g., how to read and write data, but also how to calibrate certain subsystems. The maximum bus length of SAE J1939 is 40 m, with a maximum number of 30 nodes and data rate about 250 kbps, 1850 messages per second (SAE J1939, 2000, Johannsson, 2003).

Other industries have adopted the general J1939 communication functions, in particular the J1939/21 and J1939/31 protocol definitions, which are required for any J1939 compatible system (CiA, 2007; SAE J1939, 2000; Johannsson, 2005).

ISO 11992

The ISO 11992 Road vehicles – Interchange of digital information on electrical connections between towing and towed vehicles – is presently integrated by 4 parts, as separated documents: 1) Physical layer and data link layer, 2) Application layer for brakes and running gear, 3) Application layer for equipment other than brakes and running gear, & 4) Diagnostics

This standard specifies a J1939 - based application profile for the communication between truck and trailer. The ISO 11992 standard is also suitable for road trains with multiple trailers (up to five). The address assignment procedure is initiated by the commercial vehicle and automatically assigns addresses to the towed vehicles (ISO 11992, 2003).

Part 1 defines the physical layer and the data link layer. The physical bus consists of unscreened twisted pair (CAN_H and CAN_L) for the transmission of the differential signals. These conductors may be part of a multi-core cable. For the physical layer the characteristic impedance has no significant influence. The total length of the bus cable is split into three parts. The signal voltage levels are different from ISO 11898-2. The voltage levels for a dominant bit are specified as 2/3-supply voltage for CAN_H and 1/3-supply voltage for CAN_L. A recessive bit is represented by 1/3-supply voltage for CAN_H and 2/3-supply voltage for CAN_L.

Part 2 specifies the parameters and messages for electronically controlled braking systems including ABS (Anti-lock braking systems) and for running gear equipment (i.e. systems for steering, suspension and tires). The analog parameters are specified by data length, resolution including engineering units and offset, data range and type (measured or status). Part 3 specifies the parameters and messages for all other electronically controlled systems.

Part 4 of this standard defines the diagnostics services that are divided into basic and enhanced diagnostic applications. The purpose of the basic diagnostics is to provide vehicle independent identification and information. The enhanced services are truck-specific (CiA, 2007).

A Special Interest Group within the CAN in Automation (CiA) is working in the development and maintenance of CANopen gateway profile for trucks. Thus a set of CANopen interface profiles has been developed, specifying gateways to J1939 in-vehicle networks for trucks, buses, trailers and other commercial vehicles. Also interface compliant to ISO 11992 (truck/trailer point-to-point network), SAE J1939-71 (truck power-train network), or ISO 11783 has been established (CiA, 2007).

3. Wireless/wired communication to fleet management systems

There are several possibilities to achieve wireless communication for intermodal transport: Wireless Wide Area Network (WWAN), Wireless Local Area Network (WLAN) and WSN (Fig. 2).

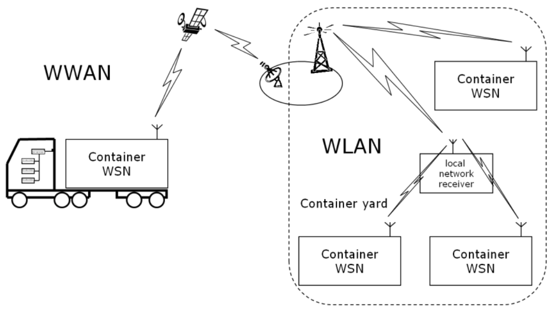

Figure 2: WWAN, WLAN and WSN in intermodal flow

WWAN

Wide area network enable long-range communications between the container and the central servers and are facilitated by satellite and cellular systems. Satellite is quite expensive compared to cellular systems, but has virtually ubiquitous coverage, so it can relay status messages and GPS data from nearly anywhere in the world. Satellite messaging systems are utilized in developing regions that lack cellular infrastructure. Low-Earth Orbit (LEO) satellites are most likely to be used for sending short data messages because of their relative low cost compared to traditional satellite services (ABI Research, 2004).

The use of satellites for monitoring refrigerated containers generally fails when antennas of the containers are shadowed, making data transmission impossible. The same fact applies when containers are stowed inside a deck. In future, however, it will definitely be possible to send data transmitted via satellite from the ship to receiving stations on land, to enable the refrigerated containers to be accessed online. Cellular devices make use of surface antennas for transmission (GDV, 2005).

Global System for Mobile-communication (GSM) and General Packet Radio Service (GPRS) modems are widely used in commercial solutions in vehicle tracking and fleet management. Recently 3G technology have emerged, 3G wireless services offer packet data enhancements to applications such as increasing speed and capacity for voice and data services together with high quality of service facilities. The two main 3G technologies under standardisation are UMTS (Universal Mobile Telecommunications System) and CDMA2000 (Code Division Multiple Access 2000). UMTS is being considered as a good option for container tracking, as nearly ubiquitous coverage is available in Europe (Baghaei and Hunt, 2004).

WLAN

Wi-Fi (Wireless-Fidelity) is a set of product compatibility standards for wireless local area networks based on the IEEE 802.11.x specifications (Wi-Fi, 2007). Wireless LAN (IEEE 802.11) is a flexible data communication protocol implemented to extend or substitute for a wired local area network, such as Ethernet. The bandwidth of 802.11b is 11 Mbits and it operates at 2.4 GHz frequency.

Wi-fi may provide intermediate range data transfers at ports, in marine vessels, and in container yards and terminals. Wi-fi already has a large role locating assets in a yard, such as heavy equipment and crane. The role is expected to expand in order to provide rapid data access. Wi-fi enables RFID readers, handheld or in a fixed location for data storage and verification (Ruiz-Garcia *et al*., 2007).

WSN

At current stage there are two available standard technologies for WSN: ZigBee and Bluetooth. Both are within the Industrial Scientific and Medical (ISM) band of 2.4 GHz, which provides license free operations, huge spectrum allocation and worldwide compatibility. ZigBee is more suitable for WSN, mainly because of its low power consumption derived from its multi-hop communication. The power consumption in a sensor network is of primary importance and it should be extremely low. The ZigBee protocol places primary importance on power management since it has been developed for allowing low power consumption and years of battery life. The suitability of this standard for WSN in transports has been proposed for various authors (Qingshan *et al*, 2004; Jedermann *et al*. 2006; Ruiz-Garcia *et al*., 2008)

Bluetooth works better in applications where large data rates are important, though it requires more energy consumption (Shih *et al*., 2001).

In comparison ZigBee provides higher network flexibility than Bluetooth, allowing different topologies like star, cluster tree or mesh network. ZigBee allows a wider number of nodes, above 65.000 according to specification. Also transmission range is longer (1-100 m) for ZigBee than for Bluetooth (1-10 m) (Baronti *et al*., 2007).

The ZigBee standard is built on top of IEEE 802.15.4 standard. The IEEE 802.15.4 standard defines the physical and MAC (Medium Access Control) layers for low-rate wireless personal area networks (IEEE, 2003). The physical layer supports three frequency bands with different gross data rate: 2450 MHz (250 kbps), a 915 MHz (40 kbps) and 868 MHz (20 kbps). It also supports functionalities for channel selection, link quality estimation, energy measurement and clear channel assessment. ZigBee standardizes both the network and the application layer. The network layer is in charge of organizing and providing routing over a multi-hop network, specifying different network topologies: star, tree and peer to peer. The Application Layer provides a framework for distributed application development and communication.

It is possible to add a gateway that changes wired CAN signals to wireless ZigBee signals. The gateway must convert CAN packets to wireless packets, and viceversa. The development of this interface was faced by Byrnes *et al.*, (2006), using a small canbus network with two CAN development boards and two wireless transceivers.

4. External interface for data recorder/monitor

The ISO 16844 is an International standard defining the CAN-based tachograph specifications to be used in trucks and buses.

It specifies the CAN interface for the interchange of digital information between a road vehicle's tachograph system and vehicle units, and within the tachograph system itself. It specifies parameters of, and requirements for, the physical and data link layers of the electrical connection used in the electronic systems (ISO 16844-4, 2004).

Also this standard specifies the parameters and the secured interchange of digital information between a road vehicle's tachograph system and vehicle units, and within the tachograph system itself.

5. RFID interface for goods to loaded and off-loaded

RFID has been increasingly used in logistics and supply chain management in recent years. RFID technology can identify, categorize, and manage the flow of goods and information throughout a supply chain and also it provides automatic vehicle and equipment identification. RFID has the ability to allow energy to penetrate certain goods and to read a tag that is not visible. It is thereby able to identify those goods without scanning a barcode.

The system is made up of three components: a remote device called the tag (transponder), a reader and a host interface (Finkenzeller, 2004).

There are many distinct protocols used in various RFID systems, from the lower ranges of the spectrum 135 KHz to the super high frequency (SHF) range at 5.875 GHz. Multimodal shipping containers use tags operating at 433 MHz or 2.45 GHz (Finkenzeller, 2004; Dobkin and Wandinger, 2005).

New RFID semi-passive hardware recently available, instrumented with sensors, can extends the range of application beyond the areas mentioned, because it gives new features like temperature or shock measurement. This represents a new type of wireless sensor which can be very useful for cold chain monitoring.

The RFID readers can be connected to a CAN converter, enabling the use of large quantity of RFID readers. We can find in the market devices that allow the integration of RFID in CAN. These devices are able to read and write to transponders according to ISO 14443 (50 mm) and ISO 15693 (90 mm).

The CiA has released the CiA 445 CANopen device profile for RFID readers/writers. The objective of the profile is to enable easy system integration of RFID readers into CAN networks. The device profile will make CiA 445-compliant RFID readers from different manufacturers interchangeable with a minimum of time and configuration effort (CiA, 2007).

6. Interface to GPS or other navigation systems

Electronic monitoring of the location during transport can be achieved with two different methods: Automatic vehicle identification versus GPS. The former involves the detection of the conveyance at various critical waypoints along its normal route being ratter inexpensive since it involves a relatively small number of active systems reporting to a central data processing site. Time between waypoints can be monitored for compliance with regard to expected travel times, though conveyance can be lost when the vehicle changes its normal route (Transcore, 2003).

Another way for vehicle location are the so called global positioning systems. The most extended one is NAVSTAR-GPS (Navigation System with Time and Ranging-Global Positioning System) developed and maintained by the US Department of Defence and the US Department of Transportation. NAVSTAR-GPS coexists with the Russian GLONASS (Globaluaya Navigatisionnaya Sputnikovaya Sistema).

Europe is developing his own system under the designation "Galileo", it is expected to be completely operative in the year 2010. For the location of containers the accuracy, availability and integrity of the stand-alone these system is not enough. In order to obtain the required performance augmentation systems are used, like EGNOS (European Geostationary Navigation Overlay Service) or LAAS (Local Area Augmentation System) (Lechner and Baumann, 2000).

GPS is currently integrated with RFID in order to locate vessel position as well as those containers that arrive on it. The system does have drawbacks, including the limited coverage in remote areas of the world, signals blockance when containers are stored, battery dependence, reliance on human intervention, and requirement of extensive maintenance. The remote coverage limitation is the main drawback that prevents GPS from tracking individual container positions on land. GPS offers significant prospects in the future as its area of coverage is increasing and effort are placed to promote system flexibility (Balog *et al*, 2005).

7. Conclusions

The next generation of reefer containers are required to have higher performance than those of today. The innovations in wireless and digital electronics enable applications which will become very common in future transport vehicles.

The container unit becomes the target for monitoring instead of the tractor. Thus monitoring system is located in the container though optimized to reach as much information as possible from external sources in order to rationalize the amount of sensing units to be installed.

Intelligent transport systems must be compatible with the SAEJ1939 and ISO 11992 standards, allowing connection between different subnetworks, as well as filtering and processing messages from sensors. The use of standardized, open network is essential for ensuring the inter-operability of the system. The advantage of having a standard is considerable, since it enables independent development of individual networked components, also allowing manufacturers to use components from different suppliers.

The trouble-free exchange of information between individual sub-systems is one of the prerequisites for a rational design and operation of the total system. A European or world-wide harmonization of different interfaces is necessary. The interconnection of these heterogeneous systems is a challenge that should be faced.

Acknowledgements

Thanks to the SENSOFRIGO research program supported by the Ministry of Education and Science of Spain (Ref: AGL2003-06073-C02-01) and TAGRALIA project funded by the Comunidad de Madrid.

Luis Ruiz-Garcia

LPF-TAG. Universidad Politécnica de Madrid

ETSI Agrónomos. Edificio Motores. Avda. Complutense. 28040 MADRID

Tel: +34 913 365 862

Fax: +34 913 365 845

luis.ruiz@upm.es

www.lpftag.upm.es

Pilar Barreiro

LPF-TAG. Universidad Politécnica de Madrid

ETSI Agrónomos. Edificio Motores. Avda. Complutense. 28040 MADRID

Tel: +34 913 365 862

Fax:+34 913 365 845
pilar.barreiro@upm.es
www.lpftag.upm.es

Jose I. Robla
Centro Nacional de Investigaciones Metalúrgicas (CENIM-CSIC)
Avenida Gregorio del Amo, 8. 28040 MADRID
Tel: +34 915 538 900
Fax:+34 915 347 425
jrobla@cenim.csic.es
www.cenim.csic.es

References

Abi Research, 2004. Electronic container tracking white paper. Available in www.abireserach.com [3 Feb, 2006].

Baghaei, N., Hunt, R., 2004. Review of quality of service performance in wireless LANs and 3G multimedia application services. *Computer Communications*, Volume 27, Issue 17, 1 November 2004, Pages 1684-1692

Baronti, P., Prashant, P., Chook, V. W.C., Chessa, S., Gotta A., & Fun Hu, Y. (2007). Wireless sensor networks: Wireless sensor networks: A survey on the state of the art and the 802.15.4 and ZigBee standards. *Computer Communications*. Article in press

Balog A., Lim J. J., Nettleton K., 2005. Riding the wave on ship container seal and tracking systems. 2005 Symposium on the Global Commercialization of Environmental Technologies. University of Washington.

Byrnes, C., Farmer, L., Marks, M., Ferens, K. 2006. CAN-to-ZigBee Gateway for Automotive applications. ECE 4600 Group Design Project Proposal.

CIA, 2007. Homepage of the organization CAN-in-Automation. Available in www.can-cia.de, [14 Dec, 2007].

Dobkin D. M., Wandinger T., 2005. A Radio-Oriented Introduction to RFID-Protocols, Tags and Applications. High Frequency Electronics 4, 32-46.

Fellmeth, 2002. CANopen gateway for commercial vehicles add-ons. CAN Newsletter 4/2002

Finkenzeller K., 2004. RFID Handbook Radio-Frequency Identification Fundamentals and Applications (2nd edition), John Wiley & Sons, Ltd., England.

GDV (Gesamtverband Der Deutschen Versicherungswirtschaft E.V.), 2005. Container Handbook - Cargo loss prevention from German marine insurers. German Insurance Association. www.containerhandbuch.de

ISO Standard: ISO 7498, 1997. Information technology -- Open Systems Interconnection -- Basic Reference Model.

ISO Standard: ISO 11992, 2003. Road vehicles – Interchange of digital information on electrical connections between towing and towed vehicles –

ISO Standard: ISO 16844, 2005. Road vehicles -- Tachograph systems --

ISO Standard: ISO11898, 2007. Road Vehicles -- Controller Area Network (CAN) --

Johansson, K. H.; Törngren, M;, and Nielsen, N., 2005. Vehicle Applications of Controller Area Network. Royal Institute of Technology. Stockholm. www.md.kth.se/RTC/Papers/VehicleApplicationsCan2005.pdf

Jedermann R., Behrens C., Westphal D., Lang W., 2006. Applying autonomous sensor systems in logistics – Combining sensor networks, RFIDs and software agents. *Sensor Actuat A-Phys*. Volume 132, Issue 1, 8 November 2006, Pages 370-375.

Lechner W., Baumann S., 2000. Global navigation satellite systems. *Comput Electron Agr* 25, 67-85.

Qingshan S., Ying L., Gareth P, Brown D., 2004. Wireless Intelligent Sensor Networks for Refrigerated Vehicle. IEEE 6th Symp. on Emerging Technologies: Mobile and Wireless Communication. Shangai, China.

Rodríguez-Bermejo, J., Barreiro P., Robla, J.I., & Ruiz-Garcia, L. Thermal study of a transport container. *Journal of Food Engineering*, Volume 80, Issue 2, May 2007, Pages 517-527

Ruiz-Garcia, L., Barreiro, P., Rodríguez-Bermejo, J., & Robla, J.I. (2007). Monitoring intermodal refrigerated fruit transport using sensor networks: a review. *Spanish Journal of Agricultural Research*, Vol. 5, No. 2- June 2007

Ruiz-Garcia, L.; Barreiro, P.; Robla, J. I.; Rodríguez-Bermejo, J., 2008. Performance of ZigBee-Based Wireless Sensor Nodes for Real-Time Monitoring of fruit Logistics. *Journal of Food Engineering*. Accepted.

SAE J1939, 2000. Recommended Practice for Control and Communications Network for On-Highway Equipment. The Engineering Society for Advancing Mobility Land Sea Air and Space.

Shih E., Cho S., Ickes N., Min R., Sinha A., Wang A., Chandrakasan A., 2001. Physical Layer Driven Protocol and Algorithm Design for Energy-Efficient Wireless Sensor Networks, ACM SIGMOBILE Conference on Mobile Computing and Networking, July 2001, ROME, Italy

Tanner, D.J.; Amos, N.D., 2003. Temperature Variability during Shipment of Fresh Produce. Postharvest Unlimited. Acta Hort. 599

Transcore, 2003. Electronic Container Seals Field Operational Test Project. Task # 2. Technology Review Report. Northwest International Trade Corridor Program. September 15, 2003. Available in http://depts.washington.edu/trac/freight/descript.html [22 Dec, 2005]

Wi-Fi, 2007. Website of the Wi-Fi Alliance. Available in www.wi-fi.org [12 Dec, 2007]