A BLUETOOTH SENSOR NETWORK BASED ON THE IEEE 1451 STANDARD

A Sensor Network Solution to Evaluate the Wellbeing of the Passenger and Improve Safety in Cars

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Abstract: The use of sensors is very widespread in a lot of different environments and applications. Each situation needs a different solution and for that reason the use of a scalable and easily manageable sensor network is a must as applications are becoming increasingly complex. In many cases the perfect solution is the one based on a wireless sensor network; it provides flexibility, ease of management of the system and expandability. But in order to provide interoperability between different sensor manufacturers and to give a transparent and independent interface, the use of a standard is mandatory. This standard system is provided by the IEEE 1451 family of standard protocols. In this project a Bluetooth based sensor network has been implemented using the IEEE 1451 family of standard protocols. The goal of this network is to aid data acquisition from a number of sensors within a car, in order to monitor the wellbeing of the passengers and improve safety and comfort.

1 INTRODUCTION

The Bluetooth sensor network that is presented in this paper has been developed for an automotive environment in order to increase the safety and the passengers' comfort and to monitor their wellbeing. For this purpose several sensors installed within a car have been controlled using an IEEE 1451 standard based sensor network.

The sensor network has been implemented within a Medea+ project known as Caring Cars, with satisfactory evaluation.

As a result, several electronic boards have been developed based on the HCS08 microcontroller family, which are provided with Bluetooth capabilities. The firmware of these devices has been implemented using the APIs and data structures defined in the IEEE 1451.0 standard.

In parallel, several software libraries and their respective APIs have been created in order to control these devices from a Linux based PC.

2 CARING CARS

The main goal of the Caring Cars project was to increase car safety by enabling wellbeing applications in an automotive environment.

The main target was in-car safety and wellbeing to address the huge indirect costs of transportation in the EU. Reports by the European Environment Agency estimate the indirect costs of transportation at about 8% of GDP, a substantial part of which is caused by accidents. Each year an estimated 127 thousand people are killed and about 2.4 million are injured on roads in Europe.

So, the main goal of project was to address these costs by turning the car into a safer environment.

To achieve the previously mentioned general goal, the project designed an open automotive infrastructure, mainly based on a sensor network in cooperation with a car gateway. This sensor network consists of the sensors already available in vehicles augmented with new sensors.

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The Car gateway manages and coordinates in-car devices and establishes a connection with the external world signalling for enriched information exchange. In this way it will be possible to improve car safety and thus reduce the costs of transportation activity.

By adding external communication to the infrastructure envisioned by the project it will also become possible to use the same infrastructure to support health care applications.

This project had partners from both industry and academia to form a well balanced consortium that has experience in providing car manufacturers and manufacturing cars while possessing technical expertise in the relevant technical fields. The consortium used this experience and knowledge to raise car safety to the next level.

3 IEEE 1451

The IEEE 1451 family of standard protocols is aimed at giving a standard set of commands and data structures to facilitate the self-management of sensor networks and transducers. It provides the application layer not only with a transparent interface to handle sensors and actuators but also a communication interface that is independent to the communication protocol used in the physical layer.

The standard defines two main entities; the Network Capable Application Processor (NCAP) and the Smart Transducer Interface Module (STIM).

In order to achieve this, the standard family is divided into different subfamilies: IEEE 1451.0, IEEE 1451.1, IEEE 1451.2, IEEE 1451.3, IEEE 1451.4, IEEE 1451.5, IEEE 1451.6 and IEEE 1451.7.

The following figure shows an overview of this family of IEEE international standards and how each previously mentioned sub-family is related to each of the others, mainly the IEEE 1451.0 and IEEE 1451.5, which are the only ones that have been used within this work.

One key feature of the IEEE 1451 is the Transducer Electronic Data Sheet, TEDS. This kind of file is used to help to implement plug & play features for the management of the transducers and the transducer network itself.

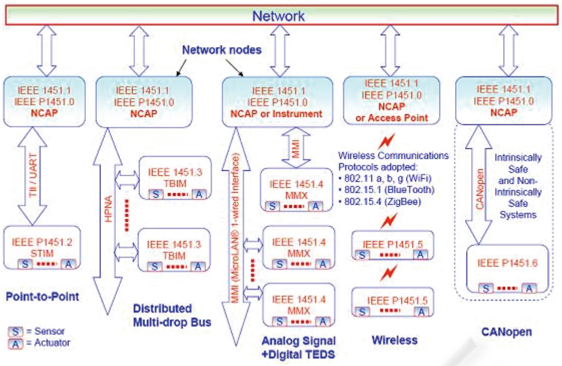

Figure 1: IEEE 1451 family of protocols.

In this project only the 1451.0 and 1451.5 subfamilies have been used. The first one defines all the data structures, commands, TEDS and communication, transducer services and HTTP access APIs and the second one defines the interface for IEEE 1451 wireless communications (802.11.x, 802.15.1, 802.15.4).

4 BLUETOOTH SENSOR NETWORK

The sensor network that has been implemented, consists of three main elements. At the highest level of the hierarchy is the car-gateway which is in charge of collecting all the data from the sensor network and storing it in the data base.

One step below in the architectural hierarchy is the sensor manager, which is focused on collecting all the data from the sensor nodes using a Bluetooth communication and then sending the collected information to the car-gateway via Ethernet.

Finally, there is one more element at a lower level of the architectural hierarchy, the sensor node. This works as an interface to the sensors themselves. It is able to control eight different sensors and send the gathered information to the sensor manager via Bluetooth using the IEEE1451.0 TransducerServices API and ModuleCommunication API.

4.1 Network Architecture

The network architecture which has been used is illustrated in figure 2.

Figure 2 shows the main elements of the system: the car-gateway, the sensor manager and the sensor nodes.

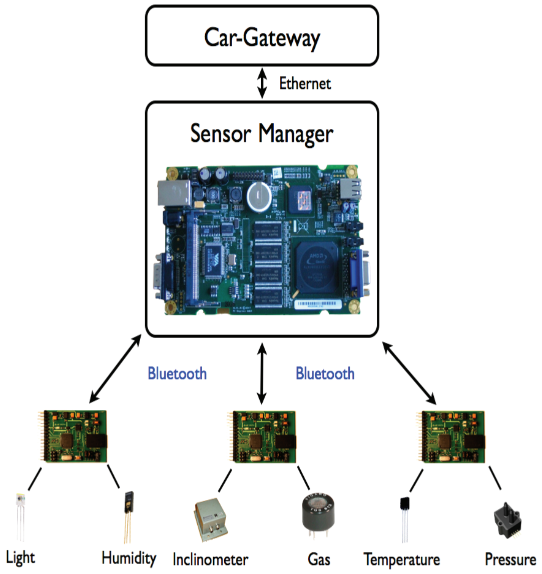

Figure 2: General architecture of the sensor network.

For the Caring Cars project, seven different transducers have been used: gas detection, temperature, pressure, inclination, humidity, light plus a special ECG signal sensor.

All these transducers have been distributed within a car, making three different groups each controlled by a sensor node (STIM). The data acquired by the nodes is sent to the sensor manager using a previously established Bluetooth connection while the communication parameters and the connection itself are established by the sensor manager.

4.2 Car-Gateway

The Car-Gateway is the top element of the architecture and it is a Linux based Car-PC. Its responsibility is to run the main application, storing the information sent by the Sensor Manager via Ethernet and evaluating the information of the sensors in the system, and finally taking the right decision in order to help to increase car safety and passenger comfort.

Thus, an interface based on HTTP protocol between Car-gateway and NCAP is used to provide the 1451.0 functionality to any particular application requiring sensor data.

4.3 Sensor Manager, NCAP

The Sensor Manager is a mini-PC (alix 3c3) with Linux operative system. It uses the created libraries and APIs to manage the sensors and the communication with the sensor nodes in a transparent way, as defined in the IEEE 1451.0 and IEEE 1451.5 standards.

In order to have an overview of functionalities provided by the implemented solution (first version), the following table summarizes some of the most important of these:

Table 1: Some of the implemented functions.

Function name	Description
TedsManager_readTeds	Reads TEDS files
TimDiscovery_reportTims	Reports available STIMs
TransducerAccess_open	Opens the access of the specified channel
TransducerAccess_startStream	Starts the data stream from a specified channel
Comm_init	Initializes the communication parameters and establishes the Bluetooth connection
NetComm_open	Opens the communication interface of the IEEE 1451 layer

Several others have also been completed for this functional solution, e.g. to report available channels in a STIM, close the access of the specified channel, stop the data stream of a specified channel, or read a message that is in the bluetooth layer from the IEEE 1451 layer.

The NCAP current hardware device (alix 3c3) selected is based on one “AMD Geode LX800” CPU (500 MHz) and 256 MB DDR DRAM. Although nowadays this device is working correctly and is considered a good option at this development stage, because of certain new features and corresponding performance it should be evaluated prior to a more consolidated version, and it is planned to design a new NCAP hardware device which is more adjusted to the final constraints and which features only the necessary interfaces in order to obtain cheaper market solutions. From this point of view, hardware architecture options based on ARM are being considered for the future.

4.4 Sensor Nodes, STIM

The sensor nodes are eight bit microcontrollers based on the Freescale HCS08 family. The current

STIM version is able to control eight different transducers and they have a Bluetooth chip, the LMX9838, connected to the microcontroller by a serial communication interface, and it has the Bluetooth protocol stack implemented until the SDP layer.

The firmware in the microcontroller sends the information via serial lines in messages defined by the Bluetooth chip manufacturer (national semiconductor).

The established Bluetooth connection uses the RFCOMM protocol to emulate a serial point to point communication between the sensor nodes and the sensor manager using radio signals.

From the point of view of the protocol between NCAP and STIM (Bluetooth), it has to be mentioned that some problems related to connection time have been detected. Therefore the current version of the overall network requires more than the previously expected time for all of the transducers' data to reach the NCAP and be monitored. This time sometimes exceeds 30 seconds. It has been checked and some interesting results have been obtained, in that the connection time increases significantly when more wireless devices, e.g. mobile phones, are working in the surroundings.

As Bluetooth communication protocol was selected because the transducers involved for CaringCars project were related to wellbeing evaluation within the car, this means that time constraints for connection between STIMs and NCAP were not very strict, the obtained results were sufficient. Otherwise, this issue is being tested in order to make improvements to future versions.

In any case, the IEEE1451 standard enables easy changes to be made from one communication protocol to another more convenient one, if this is required due to time constraints or any other requirement, using the same transducer descriptors (TEDS). This is because the 1451.0 is providing a common interface to manage every different type of STIM, although it should also be mentioned that only this Bluetooth STIM type has been fully tested up to now.

4.5 Sensors and TEDS

The IEEE 1451.0 standard defines the so called Transducer Electronic Data Sheet or TEDS. These files are data structures divided in perfectly defined different fields. The information within these fields describes the sensor itself.

Using the information of these files the application layer can easily know every parameter of the sensor that is controlling, for instance calibration information, the sensor's measuring ranges or the maximum working temperature of the sensor.

One of the most useful characteristics of these files is that they can store the information for the conversion from the sensor's output voltage value to its corresponding physical units. These characteristics make the management of the transducers easier, providing the application with a transparent interface to work with, regardless of the physical characteristics of the transducer in question.

Some of the data provided by a calibration TEDS for the LM35 temperature sensor used in CaringCars project were as follows:

```
/* Total Length */
/* TEDS identification header */
/* Length of TEDS */
/* --------------- */
/* Last calibration date */
/* Length of field */
/* --------------- */
/* Calibration interval */
/* --------------- */
/* Linear conversion */
/* --------------- */
/* Set of coefficients */
/* --------------- */
/* Checksum */
```

The strangest sensor used in this project was the ECG signal sensor. It is not very usual to obtain the ECG signal in a car environment but on the other hand this signal could give a lot of information about the wellbeing and comfort of the passengers.

To obtain this signal three conductive material stripes have been added to the surface of the steering wheel. These stripes are placed in a manner that ensures that the necessary signals can be obtained in order to achieve the ECG signal which is so desired.

The use of such an unusual sensor in an automotive environment has been facilitated thanks to the sensor network and the IEEE 1451 family of standard protocols.

4.6 Results

As a result of this project, some IEEE 1451 standard compatible electronic boards have been manufactured which are able to communicate using the very well known Bluetooth protocol. Thus, a functional sensor network has been implemented based on Bluetooth communications and IEEE 1451 family of standard protocols.

A common API and its respective libraries have been developed in order to be able to control the sensor nodes in a transparent way not only for the management of the sensors, but also for the communications used in the physical layer.

Finally a functional sensor network has been implemented in a car environment satisfactorily controlling a number of sensors between which the ECG has been the most unusual but also the most valuable sensor to monitor the wellbeing and comfort of the passenger.

The following image shows the demonstrator panel, formed by one NCAP and two STIMs where each STIM module is able to connect to two transducers, fabricated in order to explain the main feature provided by this technology, which is the easy way to interchange transducers connected to different channels in any sensor node hardware module (STIM), simply by downloading the proper descriptor (TEDS) from the NCAP to the corresponding STIM.

On the other hand, some limitations, problems and/or disadvantages have been detected too. Firstly, the current development is able to connect just two channels per STIM physical node, although this is only due to RAM memory space constraints. This problem will be solved for the next version.

Figure 3: Demonstrator panel.

Furthermore, a longer delay to establish Bluetooth connection in order to start communications has been detected, mainly for environments with more wireless technologies working at the same time. This was detected because when mobile phones were switched off this connection time was reduced.

Another limitation related to Bluetooth protocol is that one NCAP is able to connect a maximum of seven STIMs. As the fabricated STIM can be connected to eight transducers, nowadays one NCAP would be able to provide data from up to 56 transducers. Obviously, any sensor network based on this technology could have as many NCAPs as required.

Finally, it should be mentioned that current NCAP hardware is a commercial device and, although the corresponding firmware will be easily portable, new hardware devices based on a more suitable hardware will be designed in the future.

5 CONCLUSIONS

From the functional point of view, and taking into account that this is the first fabricated version, the goals of this sensor network have been satisfactorily achieved although with certain limitations to be resolved in the future.

This solution applied to this project has helped to implement an application that is able to control and manage a number of sensors in a transparent way, regardless of the physical communication used in the lower layers and regardless of the physical characteristics of the sensors.

The use of Bluetooth communications has helped to implement the sensor network in a car environment easily due to the wireless characteristic of the communication. The bandwidth and data transfer rates provided by Bluetooth have been sufficient to satisfactorily measure all the required sensors for wellbeing evaluation, once the first connection has been established.

On the other hand the use of IEEE 1451 family of standard protocols has been very useful. The data structures, the transducer access interface and the transparent communication interface provided by the standard family have been the key features for the success of the entire sensor network.

Some days in connecting several STIMs and NCAP by Bluetooth protocol have been detected mainly when more wireless technologies are working at the same time.

Besides, due to some limitations related to not having enough RAM memory space in the current STIM version, a new STIM hardware version will be proposed.

Therefore, future improvements for the next version will aim at improvement according to the main two aspects: providing more RAM memory in order to be able to connect more transducers per STIM node (at least eight channels), and reducing connection time using Bluetooth protocol when any STIM and NCAP are switched on.

A new hardware device based on a more suitable hardware will be also designed for NCAP in the future.

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