GUARDIANS

D2.1.2 Reference guidelines for implementing a standard interface in a set of modular sensors

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Abstract.
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This document proposes standard guidelines to be used in the implementation of smart modular sensors to be used in the GUARDIANS system. The guidelines proposed follow the recomendations of IEEE 1451 standard for smart sensors and actuators.
Keyword list: smart sensors, IEEE 1451 standard, fire detection sensors.

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Executive Summary

This report proposes guidelines to implement smart sensors into the Guardians system. Smart sensors are sensors with internal data acquisition, data storage and processing capabilities. These sensors can be interfaced with other smart systems through a data communication network. An advanced smart sensor can provide plug-and-play and self-diagnosis capabilities. With these capabilities, the system setup times will be shorter and its reliability will be increased.

Considering the heterogeneity of sensors used by the Guardians system, the authors of this report propose that IEEE 1451 standard for smart sensors and actuators be followed. This standard can be adapted to transducer array-based sensors or to more common single transducer sensors; to analog output sensors (dot4) or to multiple types of physical communication interfaces (RS232, USB, CANopen, WiFi, Bluetooth, ZigBee, etc).

The use of IEEE 1451 in a Guardians modular sensing system is exemplified with kheNose, an olfactory smart sensing system that interfaces with a khepera III mobile robot.

Contents

Chapter 1

Introduction

This report describes how to adapt IEEE 1451 standard to the sensors developed in the framework of the GUARDIANS project. This description is illustrated by a set of guidelines and an example of a smart sensor for gas concentration and airflow measurement.

1.1 Smart sensors

A smart sensor is a sensor version of a smart transducer, which converts a physical, biological or chemical parameter into an electrical signal [1] and then pre-processes this signal into standardised data before sending it to a controller or to another system component.

1.2 IEEE 1451 standard

While the IEEE 1451 family of standards [2, 3, 4, 1, 5, 6] were created to serve the needs of the sensor and measurement industries, the Transducer Electronic Data Sheet (TEDS) concept has profound implications for other industries [7]. The TEDS stores transducer's manufacture-related information, such as manufacturer identification, measurement range, accuracy, and calibration data, similar to the information contained in the transducer data sheets normally provided by the manufacturer [8]. The information, belonging to a Transducer Interface Module (TIM) will be sent through a serial bus to a Network Capable Application Processor (NCAP). The basic TEDS contains the minimum required information that characterises a transducer. It shall be comprised of the Manufacturer ID, Model number, Version letter, Version number and Serial number in a total of 64 bits is included for each node of the Smart Transducer [5].

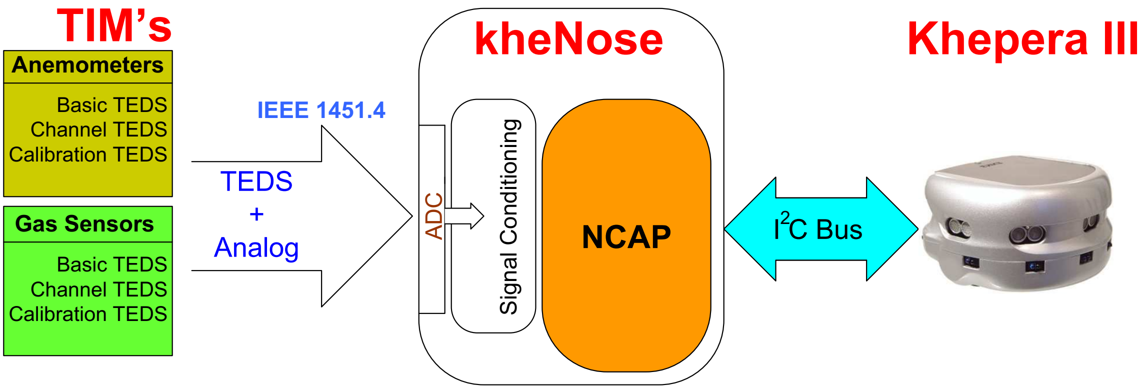


Figure 1.1: System organisation of the kheNose smart transducer.

Previous works from Postolache and Ramos [9, 10] used gas, temperature and humidity sensors for air quality monitoring, Pardo [11] developed a gas measurement system based on IEEE 1451.2 standard and Wobschall [12] a wireless gas monitor with IEEE 1451 Protocol. The work presented here expands the previous works insofar as it will be used in mobile platforms, using thermal anemometers for odour tracking and for human injuries prevention in particular.

The developed system will be used in hazardous environments - especially in fire fighting applications where the air is contaminated - monitoring and acquiring information about that environment and sending it to an external control unit that will inform the fire-fighters about the conditions they will face. To overcome the fact that the sensors may be easily poisoned, transducer modules are made easy to exchange and keep the system working, guaranteeing a low operational cost. This is accomplished by the storage of the basic transducer information in a local memory that is read each time a new module is inserted into the system.

Fig. 1.1 depicts the implemented system. Using this type of sensor, which contains the previously mentioned problems, such as sensor poisoning or replacement and that require important features like self-identification, configuration and calibration, reveal the key importance of a new approach regarding the traditional sensors, the smart sensors. A smart sensor is a sensor with built-in intelligence, self-diagnostic, local processing and data communication interfacing capabilities. Along with the common sensor response, some information about the measurement is presented inside the sensor. The IEEE 1451 smart sensor family of standards intends to overcome this shortcoming in the current technology scenario. IEEE 1451.4 (also known as dot4) is particularly useful for olfactory systems. This part of the standard defines a Mixed Mode Interfacing (MMI) for transducers, allowing for an analog gas sensing output along with the digital calibration table specific to each transducer.

1.3 The motivation for smart sensors

Smart sensors are becoming very common in robotics mainly due to their usefulness in a variety of areas. Despite the great number of works and research attempting the release of the entire IEEE 1451 standard, a lot of discussion surges everyday, presenting new possibilities and new ideas on the standard. However, some parts of IEEE 1451 standard are already finished and published, which encourage and stimulate their use. Of these, IEEE 1451.4 [5] is perhaps that which is most widely used nowadays, mostly due to a private company (National Instruments) putting some efforts into this standard, including the release of some commercial products [13]. Using the TEDS defined by this standard, the plug and play capability is real, allowing the smart sensors to be automatically detected and configurable by the acquisition system, reducing configuration time, simplifying system management and improving accuracy due to a detailed calibration information provided electronically [14].

1.3.1 The plug and play ability

The plug and play ability is a key feature related to smart sensors, sometimes referred to as "hot swap" capability. Hence, this plug and play ability - which describes the entire process: from inserting a new sensor in the system until the time the system has the possibility to acquire correct and formatted data from the sensor - has a huge importance. In order to accomplish all these requirements, the plug and play process can be divided into a number of minor parts such as the detection (scanning for the presence of a new sensor), the addressing/identification (knowing which sensor is connected and how to deal with it), the configuration/calibration (establishing a connection, allowing both sides to exchange information) and at last sharing data (the real sensor data, with all the parameters recognised). Figure 1.2 shows the self-detection process.

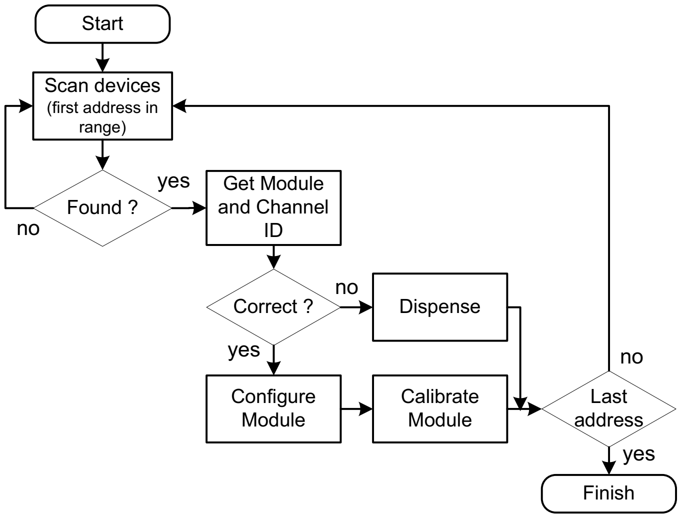


Figure 1.2: The self-detection schematic after a new module insertion.

Chapter 2

Guidelines for a standard interface with modular sensors

This chapter describes a set of guidelines to follow in order to implement smart sensors or smart sensing modules.

1. Identify the sensor structure (single or multiple transducers; analog or digital interface between the transducer(s) and the processing nodes)

2. Identify the physical interfaces to be used (i.e. select the proper part of IEEE 1451 standard)

3. Select the proper TEDS if it exists or define a new one according to the rules defined by IEEE 1451.0

4. Implement drivers to support the general model for transducer data, control, timing, configuration, and calibration.

5. A basic software driver running in the NCAP should be able to periodically scan the hardware ports in order to check if are there new transducers connected. If a new transducer was found, the driver should read the basic TEDS and start the proper transducer specific software driver that will be responsible for the basic operation of the system (reading and updating the full TEDS, reading data, etc.)

Chapter 3

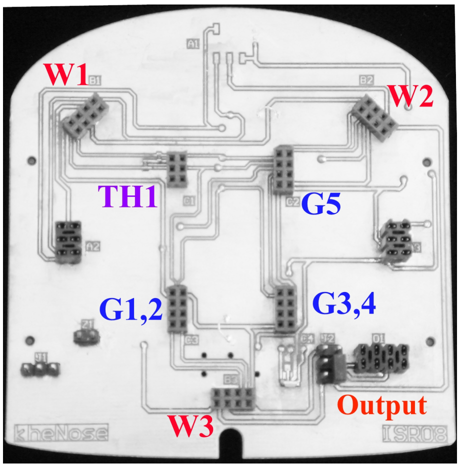
kheNose smart sensor

This chapter presents the development of a smart transducer, which includes five gas sensors, three anemometers for air flow estimation and one sensor capable of measuring the temperature and the humidity of the environment. It is able to actuate four output ports for general purpose actions. Previous research in this area, like RoboNose from the University of Coimbra [15], worked with gas sensors to gather olfactive information, specially gas concentration measurements. The goal was to upgrade it and develop a smart transducer, following IEEE 1451 standards - Smart Transducer Interface for Sensors and Actuators guidelines, modular, plug and play and capable of including calibration information, to firstly interact with a Khepera III mobile platform [16] and in the future, be compliant with other devices that will be used by the GUARDIANS project [17].

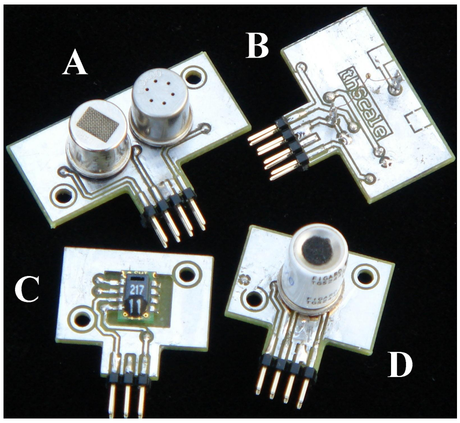
3.1 The kheNose

The kheNose (Fig. 3.1(a)) is a device developed to sense olfactive information through the use of gas sensors (G1-G5), anemometers (W1-W3) and a temperature and humidity sensor (TH1). A Microchip dsPIC33F controller acquires all the analog and digital information from the sensors, processes that data and sends it to the Khepera III KoreBot Extension board [16]. This extension board supports several communication protocols, like I^2C, used to physically connect the kheNose to the Khepera III.

The system is composed of six TIMs: An eCO, three thermal anemometers, and two eNostrils. The eCO and the anemometers are single channel IEEE 1451.4 compliant boards and the eNostrils are double channel boards. All the functions related with the transducers, namely signal conditioning, data acquisition and processing and calibration management are performed by the kheNose board. The calibration data for each sensing module is stored in a local EEPROM located in the module.



(a) kheNose main board and modules location.



(b) kheNose sensing modules.

Figure 3.1: kheNose overall system.

3.1.1 The modules

kheNose is a modular system composed of IEEE 1451.4 based gas sensing modules (see Fig. 3.1(b)). Each module is composed of a gas sensing transducer, basic signal conditioning and an EEPROM memory that contains the relevant information to identify the transducer, its output characteristics, and a calibration table made with a set of target gases. Designing the system in this manner provides several advantages to its future operations, such as:

- The user of the system can have a large set of different transducers that can be employed selectively depending on the target environments.
- When a transducer becomes damaged, by poisoning or other aging effect, the user can buy a new calibrated one and use it inside the system.

eNostril

A setup with two different gas sensors (see Fig. 3.1(b), (A)) from Figaro Engineering is used to make the eNostril. It is modular, since we are able to have different sets of different sensors for a broader sensing capability.

Since the module has two sensors, the TIM has two channels that were configured in the EEPROM.

This I^2C EEPROM holds the Basic, the Channel and the Calibration TEDS's from the sensors that composes the eNostril.

thScale

Thermal anemometers (see Fig. 3.1(b), (B)) are used in the system for measuring the air flow and to track odour plumes, with NTC thermistors from EPCOS. Since the hardware is previously calibrated, this board has an EEPROM, as the previous modules, with the corresponding TEDS's.

eTempHum

eTempHum is another module (it can be seen in Fig. 3.1(b), (C)) installed on the board which measures the temperature and humidity, using a Sensirion Inc SHT11 sensor, that will help to compensate the data from the eNostril. This bus was driven using 2-wire interface, and using two digital Input/Output (I/O) ports from the kheNose controller, it is possible to measure the humidity with an absolute RH accuracy of $\pm 3\%$ RH and the temperature with an accuracy of ± 0.4℃@25℃.

eCO

The eCO board can be seen in Fig. 3.1(b), marked with (D). This board is composed of a Carbon Monoxide sensor from Figaro Engineering (TGS2442) and an EEPROM with the respective TEDS. The aim of this board is to sense the monoxide carbon in the test area.

Actuators

Four digital output ports can be switched through an I^2C register, to control the state of a pump, an electronic valve or other actuators for other purposes.

3.1.2 The kheNose plug and play

As mentioned previously, the plug and play ability is a main aspect in our smart system, allowing for the exchange of modules or the connection of a new sensor without requiring manual configuration and/or calibration.

After the physical connection of the new module to the base board, the kheNose should detect the presence of a new (inserted) module and this task can be done by scanning the bus (I^2C bus) for new devices. After the detection and the identification of the new module, the interchanging of information can occur between the module and the host. These exchanges can involve information concerning the sensor operation, the proper signal characterization and/or processing (when required), the configuration or even the calibration of the sensor. All this TEDS information is stored in a non-volatile memory (EEPROM), present in each TIM (more detailed information below).

Therefore, in the case of the gas sensor module, dealing with smart sensor that include plug and play capability take the overall system to a higher level when compared to traditional sensors. Hence, the desired outputs of that sensor module are no longer single signals (e.g. voltage) but some certainly high level information (gas identification, gas concentration estimation). This kind of response can only be obtained when the calibration and/or configuration of the module is performed previously, using the presented TEDS information.

3.2 kheNose software organisation

The developed software for the smart sensor, as metioned before, runs under a RTOS, a real time kernel operating system. This is a pre-emptive real time operating system that allows software to perform the required actions in real time. Since kheNose needs to process several actions at the same time, this type of operating system is an important advantage. Each action is performed by a specific task that has it is own running period, when it is a periodic task, or it is own processor time, in interrupt based tasks. The main function initialises all the important modules (ADC, I^2C and RealTime Scheduler). Fig. 3.2 shows the RTOS existing tasks, as well as the data flow between sensor modules, tasks, buses and actuators. The blocks representing the tasks have their own function, as described below:

Process Task: this is the main task, responsible for configuring and initialising the hardware modules, the TEDS and the calibration data, as well as ensuring the program control and stability.

Acquisition Task: this task performs data collection of ADC channels from gas sensors and anemometers, dealing with timing constrains and channel selection.

SHTxx Task: this task acquires and stores the temperature and humidity values from a proprietary 2-wired serial bus.

Sensor Detection Task: this task detects the presence of a new module, reads the TEDS data and sends this information to the Process Task that will call the corresponding function, according to the sensor module connected. This is one of the most important tasks in the smart sensor concept.

I^2C Task: the communication task, responsible for dealing with data requested and sent. This task exchanges information (requests and answers) mostly with the Process Task.

Along with these function blocks, the Data Container is also important in relation to the smart sensor feature since it holds all the information that characterises the kheNose, including the TEDS from all the modules.

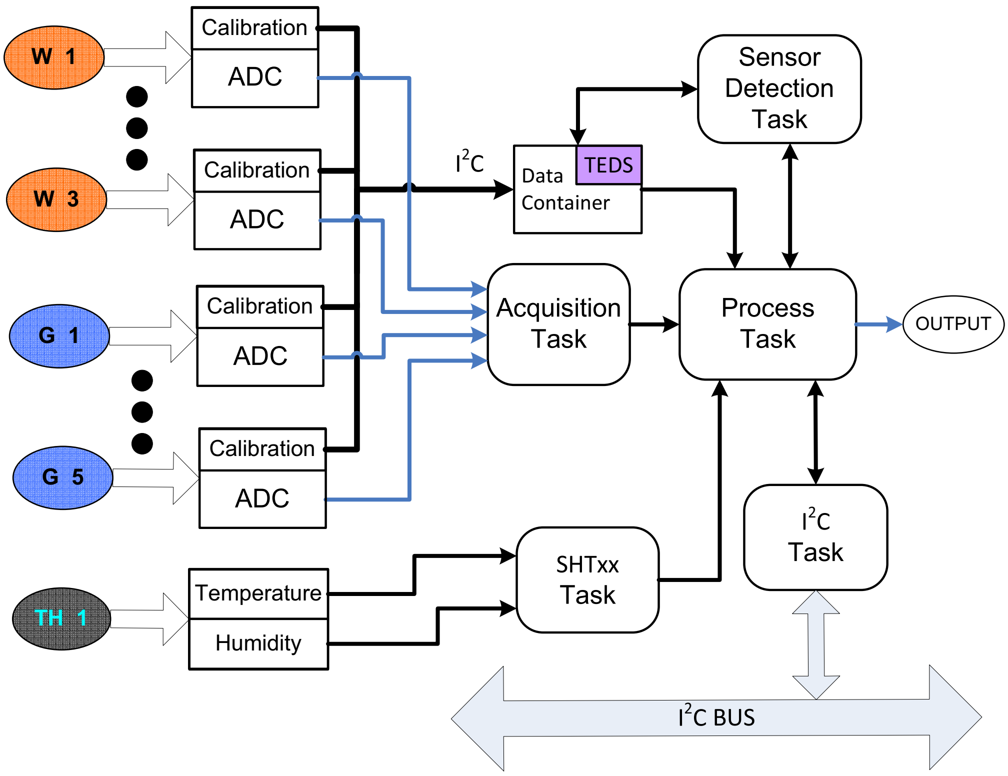


Figure 3.2: kheNose software organisation. Representation of the tasks block, the tasks priorities (at lower right corner of each task block), the data flow between functions and the main bus.

Table 3.1: kheNose implemented Basic TEDS.

Basic TEDS	Bits	Type	Data
Basic TEDS length	16	int	80
Model Number	15	int	3
Manufacturer ID	14	int	16382
Version Letter	5	char	A
Version Number	6	int	3
Serial Number	24	int	062008
Total	80	–	–

Table 3.2: kheNose implemented Channel TEDS.

Channel TEDS	Bits	Type	Data
Channel TEDS length	32	unsigned long int	480 (60 bytes)
Lower range limit	32	float	0.660
Upper range limit	32	float	3.143
Physical units	16	unsigned int	1
Unit warm up time	32	float	600
Uncertainly	32	float	8.07e-4
Channel model significant bits	16	unsigned int	12
Channel sampling period	32	float	1.0e-4
Manufacturer's identification	128	string	Figaro
Model number	128	string	TGS2600
Total	480	–	–

3.2.1 kheNose TIM

As mention before and shown in Fig. 1.1, kheNose has a specific TIM organisation. TIM is responsible for analog conversion and signal conditioning, as well as communication and data transfer functionalities. In a dot4 smart sensor, the TIM also stores the TEDS information, mostly Basic and Channel TEDS, as presented in Tables 3.1 and 3.2. This Basic TEDS information is comprised of 64 bits where the Manufacturer ID was set to 16382 since this is the identification number normally used for academic purposes [18].

For instance, the physical units of the Figaro TGS2600 sensor Channel TEDS are set to 1, since voltage is being measured instead of concentration, the ranges depend on the implemented circuitry used in the kheNose and the extra data belongs to the kheNose and to the TGS2600 sensor [19].

Chapter 4

Conclusions

This report described the advantages of following a smart sensor-based approach in the development of sensors for the GUARDIANS system.

In order to demonstrate the proposed concepts, a kheNose prototype was implemented and basic tests like plug and play detection and data acquisition were performed. This system is being employed in Khepera III mobile robots to develop and test navigation algorithms involving chemical detection in small scale scenarios. A set of IEEE 1451.4 compliant sensing modules were implemented and the respective TEDS for gas sensors and thermal anemometers were designed and successfully implemented (see Fig. 4.1).

The characteristics found in the kheNose system are easily ported to other highly advanced smart sensing systems that can be used in normal sized robots used in the framework of the GUARDIANS[1] project (e.g. Era-Mobi [20] and Rescuer [21]).

Deliverable 2.1.2 has been produced on schedule. It is, however, expected that enhancements and improvements will arise when the work related to this deliverable is being implemented in the GUARDIANS system.

[1] `http:www.guardians-project.eu`

Figure 4.1: Khepera III and kheNose with sensing modules

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