



## Network of Smart Sensors for Remote Electromagnetic Field Monitoring with a Fuzzy Alarm Reporting

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*Received: 1 June 2005    Accepted: 15 June 2005    Published: 20 June 2005*

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**Abstract:** The present paper proposes a network of mobile sensors in order to remotely measure concerning environmental parameters. Taking advantage of wireless technology, the system is able to exchange commands and data in numeric format with a querying remote client; displaced in a wide area to be monitored, each measurement module is equipped with an isotropic electromagnetic field smart sensor and a GPS module. Acquired data, according to a fixed sampling rate, are transmitted to a remote PC for processing stage, by GPRS networks. Several solutions have been undertaken for reducing noises and error contributes and the measurement system has been characterized in terms of uncertainty, in order to guarantee reliability and accuracy. Data processing optimization is performed by a fuzzy algorithm, previously tested, so getting the qualification of the decision-making stage with particular attention paid to the statistical features of monitored process.

**Keywords:** mobile smart sensors, wireless communication, remote environmental monitoring, decision-making, alarm reporting

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### 1. Introduction

Nowadays, modern technology in the Telecommunications sector allows exchanging information between clients separated from long distances. The opportunity of obtaining data promptly refreshed, with real time solutions, represents an important and sometimes an essential tool for application fields such as environmental monitoring, statistical control of critical processes and healthcare services. On

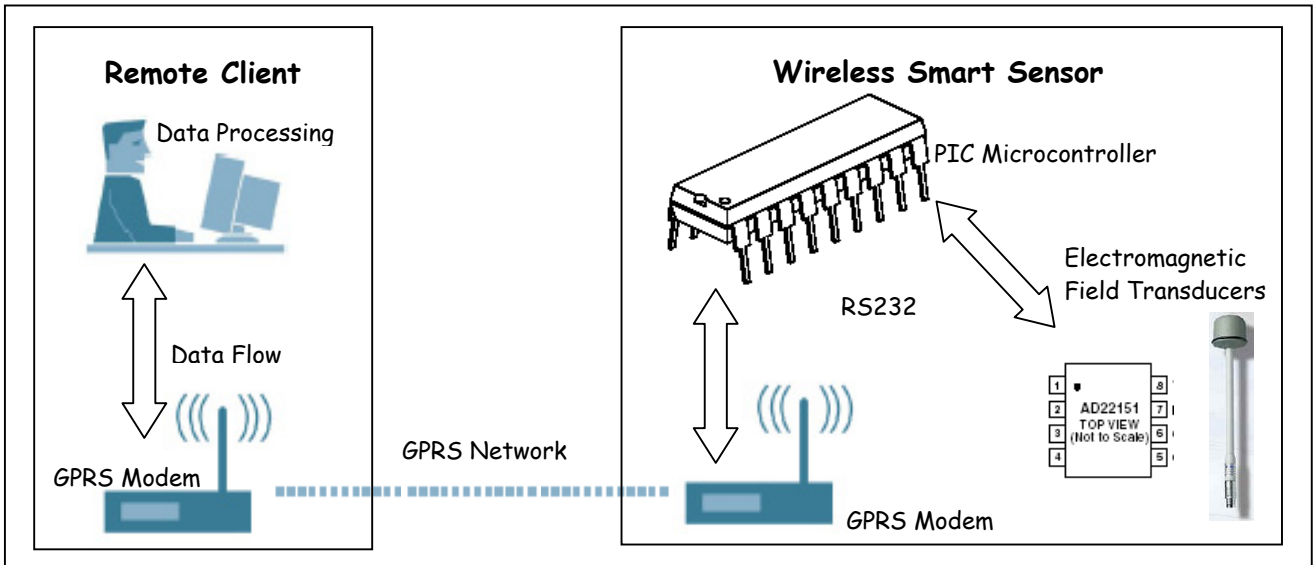
the other hand, a continuous increase in the number of systems and models in order to ensure a suitable quality of life has been registering. In this view, the authors have taken into consideration innovative solutions for environmental monitoring and control according to the actual Standards. Several laws and regulations have been issued to limit the exposition levels for environmental parameters, which are considered indexes of life quality, such as the electromagnetic field. The overcoming of these limits is an indication of a warning or alarm situation that requires the proper corrective actions to safeguard population health. It is worth noting that a limit overcoming could be an occurrence due to measurement uncertainty; so, reliability of acquired data cannot be guaranteed without an appropriate interpretation of them, which can be done by resorting to correct decisional rules and minimizing risks and costs of the decision. The authors propose a networked measurement process for the remote acquisition and processing of electromagnetic field levels, making use of a mobile architecture of smart sensors displaced in a wide area to be monitored [1-2]; the wireless communication allows remote client to collect data in 'real time' and to elaborate them by a fuzzy algorithm in order to estimate the observance or the possible overcoming of fixed limits. The measured data are carried out according to the statistical features of the monitored process. The sensing system includes two sensors for measuring magnetic or electric field. Three transducers, one for each orthogonal direction, are sensible to low frequency magnetic field. A further probe allows executing measures of electric field in high frequency range. By a serial I/O port the microcontroller exchanges information with the sensors. Each measurement system is a modular unit that mounts inside a PIC Microcontroller, whose main task is to control the data flow for properly synchronizing the communication between the electric/magnetic field probe and the GPRS modem. A GPS module provides constantly the geographical position of the measurement unit and the acquisition time. The inside implemented C-code allows the host processing unit to ask for the desired measure, obtaining the total electric/magnetic field or its value along one axe, according to a fixed sampling rate. The wireless data transmission between the measurement units and the remote workstation is performed by programmable GPRS modems with M2M technology, representing a suitable tool for wireless control applications.

## **2. The Network of Mobile Smart Sensors**

The timely execution of corrective actions if a warning or alarm situation event occurs, is possible only with a 'real time' monitoring process of the investigated area. It requires the possibility of remotely activating the measurement devices in reasonably short time with a prompt data processing system. In order to satisfy these requirements the adopted architecture is characterized by a networked measurement system with mobile wireless smart sensors. The mobile architecture allows the measurement system to monitor a wide area with a reduced number of sensors [3]. Each measurement unit is equipped with two isotropic sensors of electric and magnetic field. The former one, performing measures of electric field in high frequency, is a PMM EP-330 probe connected to a programmable optical repeater PMM OR-03; by an optical link and an optical/serial converter, the sensor exchanges information with the microprocessor unit. The latter sensor is realized by three linear transducers Analog Device AD-22151 displaced orthogonally along the Cartesian axes  $x$ ,  $y$  and  $z$ , each output is a voltage proportional to the magnetic field applied perpendicularly to the top surface.

The two sensors are alternatively connected to the controlling unit according to needs and desired measure. So, sensor exchanges data with a PIC microprocessor, which acts as controller of data transfer operations between a remote client asking for the measures and the same measurement module, the queries are performed by AT commands. The wireless communication has been made possible by a serial connection of an AT programmable GPRS modem (Sony-Ericsson GT47) to the microprocessor. By GPRS network the client can query the mobile measurement modules for a data package with a specific sampling rate. The integrated GPS information allows the workstation to localize each module. Subsequently data is processed with a fuzzy decision-making algorithm in order

to make a reliable decision about the possible overcoming of reference limits, as described in detail in the successive paragraph. In Fig.1 the Block Diagram of the measurement process and data collecting is explained.



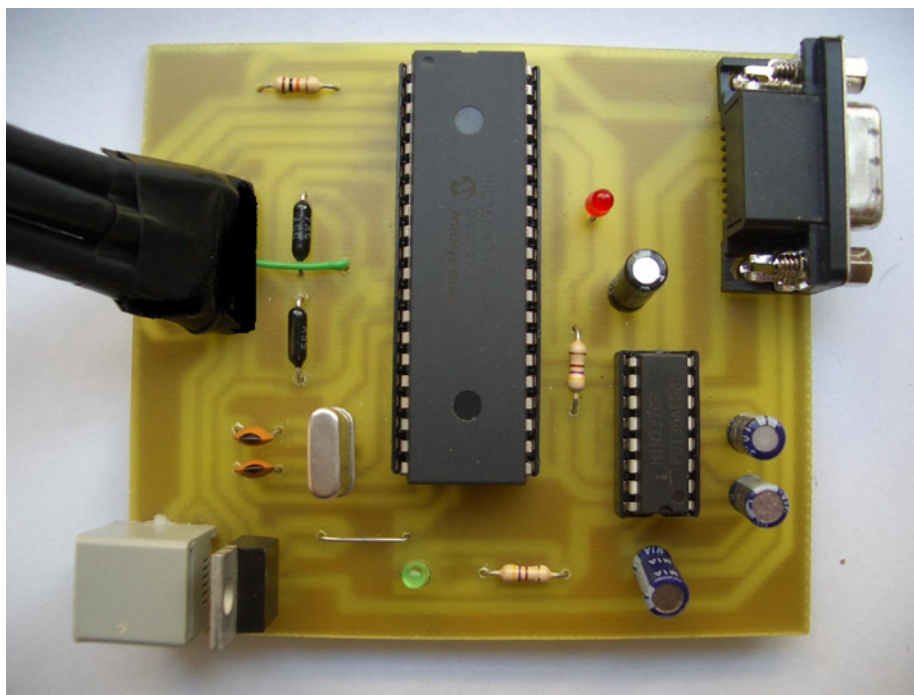
**Fig. 1.** Block Diagram of the measurement process.

In order to reduce noises and error contributes, the resort to an optical link, for the electric field sensor, has allowed to perform the measures transfer (by the optical repeater) from the probe to the control circuit, minimizing external interferences during RS-232 communication.

The magnetic field sensor, instead, combines the integrated bulk Hall cell technology and the instrumentation circuitry to minimize drifts related to temperature changes, associated with silicon Hall cell characteristics. In fact the device incorporates a “thermistor” transducer that detects the relative chip temperature. This function provides a compensation mechanism for the various temperature dependencies of the Hall cell and magnet combinations. Moreover the principal noise component in the sensor, represented by the thermal noise from the Hall cell, has been largely suppressed with the application of a bypass capacitor. Temperature compensation is performed by a suitable circuitry that, in addition, guarantees the conditioning of the transducer to be fully unipolar sensitive towards the field applied.

Each measurement unit has an interface circuit between the sensors and the modem; it mounts on board a Microchip® PIC16F877A as microcontroller, whose task is to manage the data flow by a RS-232 communication. Moreover, for the magnetic sensor, the microcontroller is able to evaluate the modulus of the total magnetic field along the three dimensions, and sends the value to the modem for transmission; the three transducers have been displaced on a Plexiglas support along the orthogonal Cartesian axes. In order to adapt the typical levels of RS-232 communication with the CMOS levels of PIC, a voltage regulator has been necessary. Serial connectors are used for connecting the microcontroller with the GPRS modem and the electric sensor, three analogical ports of PIC receive the signals of the magnetic sensor, instead a RJ12 port makes possible the power supply.

The serial transmission type is the Universal Asynchronous Receiver/Transmitter (UART). The PIC was programmed by a C-code which implements an UART controller conforming to the EIA RS232-C Standards specifications. An asynchronous transmission allows data to be transmitted without the transmission of the clock signal between the sender and the receiver. Instead, the sender and receiver must agree on timing parameters in advance and special bits are added to each word which is used to synchronize the sending and receiving units. In Fig. 2 is represented the circuit realized for each measurement module.



**Fig. 2.** *Interface Management and Transfer Control Circuit.*

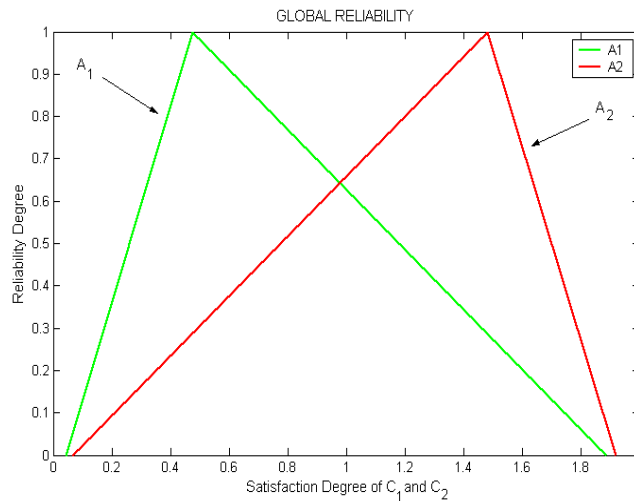
The whole measurement system has been characterized in terms of uncertainty [4]. In particular, the high frequency sensor has been tested in an anechoic room and the low frequency sensor's characteristics have been performed in a shielded room by a Helmholtz coil.

The M2M application was performed by a C software development tool, so programming the modems for the wireless transmission of data package to the host PC. The realized application is characterized by the implementation of a mobile distributed architecture of the measurement modules, where each smart sensor is mounted on a motor vehicle, as those used in the public transport service, using opportune screen against interferences. With the GPS support it is also possible to obtain aggregate information about the local position of the sensor and an indication about the acquisition time. The driver has the simple task of guiding the motor vehicle, with the measurement module, along a fixed path, by using a PDA with Navigator software according to a refreshed map sent from the remote client using GPRS communication. The 'mobile distributed architecture' allows the measurement system to explore a sufficiently large region by a reduced set of measurement modules, with a consequent money and time saving. The wide area is divided into several local areas, so that a measurement unit has to monitor an assigned zone with a specific detail level according to the fixed sampling rate and the desired information density. The monitoring map is a dynamic matrix of sampling points realized by an experiment design. According to the project requirements the map can be promptly refreshed and updated. The dimension of the sampling points' matrix depends from the desired confidence level about the final information consistency. The investigated area is an urban environment; in fact it represents the area with the greatest risk of exposure to high electromagnetic field levels, due also to the population density.

### **3. The Fuzzy Alarm Reporting**

A correct interpretation of data needs a complete characterization of the measurement system in terms of uncertainty, but in order to have information on data reliability it is also necessary to perform a statistical analysis of the monitored process [5]. This combined knowledge was the starting-point for

the development of a fuzzy decision-making procedure, according to the present Standards. The algorithm allows to determine if an acquired measurement value is conformance or non-conformance with a specification limit and so to grant an aid to the human decision maker. There are two possible alternatives:  $A_1$  indicates the conformance occurrence, which is the measured datum is below the limit; while  $A_2$  represents the non-conformance of datum, in other words it is beyond the specification limit. The procedure gives the erroneous decision probabilities  $P_\alpha$  and  $P_\beta$  associated with the process considered, these quantities weigh the decision criterion for guaranteeing the decision consistency, so conditioning the final choice. Therefore the decision criteria single out the final choice as the most suitable one according to the statistical features of process and measurement uncertainty, so qualifying in full the measurement process [6]. Moreover risks and costs of the decision alternatives are considered in a second criterion, improving the discernment properties of the algorithm in those situations in which it is difficult to make a plausible decision. Visual tools provide information about the confidence level on the decision to be taken and generate a graphical representation of the global reliability of the two possible alternatives (conformance or non-conformance with the specification); moreover the fuzzy approach allows modeling the vague aspects due to human behavior. Two fuzzy triangular sets represent the global satisfaction of the decision rules for the alternatives, see Fig. 3.



**Fig. 3.** Global Reliability of alternatives.

By a rapid visual analysis of Fig. 3 it is possible to single out the best reliable alternative with the highest satisfaction degree for decision criteria (in example  $A_2$ ), minimizing risks and costs associated with the eventuality that the assumed decision is erroneous because of the measurement uncertainty. A quality index of relative decision consistency DC provides a percentage level regarding the quality of decision. A final alarm report on measured data is obtained, with information about the confidence level reached. The developed decision rules are compliant with the Standard ISO 14253-1 [7], and in addition allow us to overcome its intrinsic limitations taking the most reliable and plausible decision also if vague information is available.

Moreover the risks and costs take part in conditioning the choice, as well as in valuing the possible consequences associated to an erroneous decision.

#### 4. General Remarks

In this paper a reliable application is proposed for remote environmental parameters monitoring. The adopted solution leads to the saving of time and money if the possible extent of investigated area and the amount of the obtained information are considered. The resort to mobile smart sensors, set up at a

distance from a remote client, involves great flexibility and autonomy, low cost of management and servicing, the possibility of varying the sampling rate according to need, and the easy update of the individual modules. The final qualification of the measurement system is executed by the fuzzy decision-making algorithm. A quality index values the consistency of the final decision alternative chosen. The realized measurement system represents a complete solution for monitoring, controlling and alarm reporting of a critical process such as the environmental one; in fact the strength of the developed project lies in its capacity to communicate remote alarm events, such as limit overcoming. The result is a practical tool that ensures a prompt control with low costs. Moreover the architecture used for measurement system makes it easily adaptive to the investigated area by the preliminary design of the monitoring map. The reduced dimension of each acquisition and transmission module allows its utilization in several environmental monitoring applications needing a small encumbrance. The embedded microcontroller allows us to manage the GPRS communication with a querying host PC in order to process the acquired data in real time. The programmed C-code permits the exchange of information between the host and the remote units by AT commands, in order to fix the desired measure and the sampling time. The developed application provides a powerful standalone tool for environmental quality control and a low cost telemetry. Furthermore, the power of the M2M communication provides a practical solution to minimize the project development time.

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