IoT Intelligent Sensor System based on Fuzzy Inference for Efficient Resource Management System in Residential/Commercial/Industrial Smart Buildings

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IoT Intelligent Sensor System based on Fuzzy Inference for Efficient Resource Management System in Residential/Commercial/Industrial Smart Buildings

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Abstract — **Intelligent sensor systems constitute the essential element for automatic control in residential/commercial/industrial smart buildings. For the environment, the use of intelligent sensor systems within buildings implies an efficient management of resources. Beside environment advantages, for the end users, intelligent sensor systems contribute to the improvement of the quality of life by enhancement of comfort, safety, and security, buildings becoming more adaptable for the users' individual needs. Energy consumption, which is generally reduced by using insulating materials in building structure is better managed by intelligent sensor systems [1] by reducing the waste of energy through demand-controlled heating and ventilation processes. Different technical requirements depending on the specific application should be fulfilled regarding the necessary precision, resolution, reliability, and dynamic behavior. The production and operating costs of the systems should also be critically considered - especially a long lifetime and high reliability are indispensable for the reduction of maintenance costs and to relief the user of any problems during operation. A solution to this problem would be the use of less expensive new wireless-related technologies enabled "smart" sensors. Smart sensors are based on built-in microprocessors and wireless communications, which fundamentally change the way civilian infrastructure systems are monitored, controlled, and maintained. The paper describes a new application for the development and implementation of a reliable intelligent system using a network of intelligent wireless sensors for measurement and diagnostics which integrates dedicated applications related to safety, security, convenience, and comfort.**

Keywords - monitoring, wireless measuring, smart sensors, automatic control, environment, fuzzy, IoT

I. INTRODUCTION

The applications for intelligent sensor systems can be classified in four categories, according to their benefits for the user (Figure 1):
1. *monitoring* important data for the user;
2. *control* of the basic systems of building;
3. *security and safety* for both persons, and buildings.
4. *comfort and convenience* for residents (Figure 1).

Monitoring conditions using sensors integrated by a microcontroller (raspberry pi) and Ethernet shield: notification via message was set up as a warning system for owner if uncommon or unusual activity appears. [2]

For the security of residents and of buildings, sensor systems represent key components for dangerous situations detection (the detection of definite concentrations of combustible gases or gas mixtures is indispensable for the prevention of explosion risks, for simultaneous detection

of smoke and increase in temperature. The system could signal an alarm for a fire in its early stages, so that major damage can be avoided).
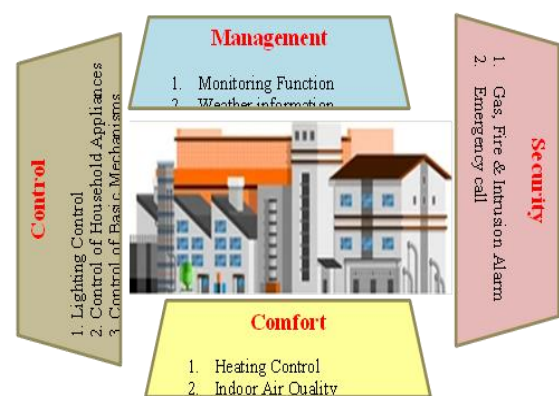

Figure 1. Applications for sensor systems in intelligent buildings

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The health and well-being of the residents of smart residential/commercial/industrial buildings depend significantly on the quality of the air and climate inside the building. Sensor systems contribute significantly to the achievement of inhabitants' comfort by controlling the room occupancy-driven heating and ventilation.

Emphasis is placed on sensor types, topology of the networks used and identification of sensor node configurations; it integrates measurement systems, data transmission, and signal processing. Such a wide spectrum of applied technologies enables a fully integrated approach to the design and operation of various technical facilities.

Special sensor systems could be employed outside and inside the building to alarm on intrusion or to manage the access of persons in the building which increases the feeling of safety for users. Also, sensor systems for monitoring weather information via user-friendly interfaces are important. The paper is organized as follows: second section describes the requirements for intelligent sensor systems within buildings, third section presents the features wireless measuring systems should have, section four describes our proposed solution to integrate adaptive, intelligent sensors with self-diagnosis and self-calibration capabilities within a monitoring, control, and diagnosis system, and the last section concludes the paper.

The development of intelligent sensor systems for special applications requires the proper choice of sensors (as devices), technology, signal processing, network system and should generally fulfill many requirements, such as:

- low investment costs
- small dimensions and ease of installation (plug and play)
- easy operation
- ease of retrofit in existing houses;
- reduced power consumption
- high reliability and long-term stability;
- independence from specific manufacturers.

Several sensors are simultaneously needed in order to realize one main function. Therefore, it is preferable to gather integrable sensors in *multi-sensor modules* (MSMs), which could be realized in microsystem technology, so that both manufacturing and installation costs could be significantly reduced [3].

The power consumption of sensor systems during operation can be significantly reduced by using microsystem technology, an intermittent operation mode and management of operating modes of individual system units [4]. Table 1 describes different types of sensors and their capabilities, from the perspective of software applications. We give some examples in order to assess the way they could be integrated within a software architecture.

Example 1: sensor systems dedicated to people safety and health. Figure 2 shows an example of a scenario of technical alarms within a home [5]. Therefore, the sensors for different applications could be *further integrated in MSMs, which help to reduce significantly the total costs of components, installation and overall system maintenance* [3], [6].

Example 2: fire detection. Sensor systems installed in a building could provide information related to the presence of persons and their health status, so that rescue measures could be more effective.
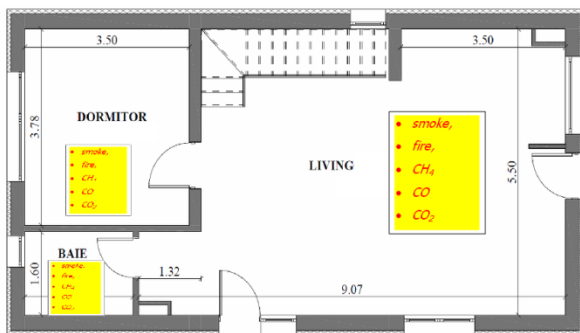
Figure. 2 Scenario of technical alarms

Table. I Sensors for different applications in smart buildings [7]

Sensors for/ applications	Air temperature	Air humidity	IR radiation	Gas detection
Heating/air condition	x	x		x
Presence/intrusion			x	
Early fire detection	X	x	x	x
Gas monitoring	x	x		x

Example 3. Gas detection is nowadays performed using different types of gas sensors based on different physical principles.

The additional use of sensor arrays in early fire detection systems requires a signal-processing method that is more sophisticated and difficult than the usually used simple threshold-based algorithms [8]. The signal processing should be able to discriminate between fire, non-fire, and disturbing event situations by identifying fire signatures from measured sensor responses (Figure 3).

With the neural network in Figure 3, the signals were mapped to three possibilities characterizing the situations: fire exists, no fire, and disturbing event.
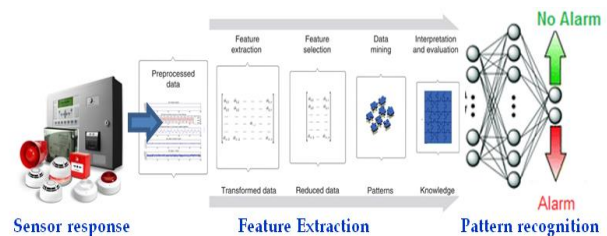
Figure. 3 Structure of a sophisticated fire detection algorithm [9]

The concentration of toxic and flammable gases should be continuously monitored in order to alarm the user in case of danger situations and to reduce the risk of health damage or explosions. Appropriate measures could include switching off the power supply in order to avoid sparks or opening windows in order to reduce the concentration of some gases.

In certain places within a building, toxic gases such as CO (carbon monoxide) resulting from an open fire and higher concentrations of CO_2 (carbon dioxide) are expected. These gases need to be measured and to be critically considered in ventilation processes.

Although metal oxide sensors have good sensitivity, the problem of cross-sensitivity makes the determination of the concentration of only one gas difficult. Electrochemical cells, in contrast, are selective, but they have problems concerning long-term stability. They have a relative short lifetime and must be frequently calibrated. Figure 4 shows the different effects influencing the properties of gas sensors. Because of the fluctuation of several factors during the production process, semiconductor elements show a certain specimen scattering. Temperature, humidity, and aging processes influence the behavior of most gas sensors. Aging processes affect the sensor properties such as the sensitivity in the case of electrochemical cells.
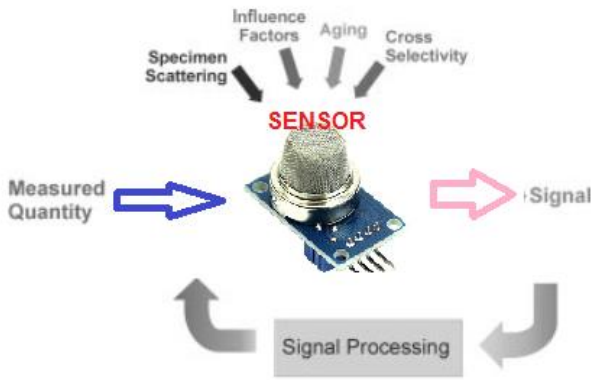
Figure 4. Importance of signal processing in the case of gas sensors

Example 4. Intrusion and person detection - in public buildings, such as in companies, access management is generally needed to allow only authorized persons to enter particular sectors.

Besides passive IR detectors, ultrasound and microwave devices can be employed, which have a very good resolution. The Doppler effect on which these methods are based can be explained as follows: a reflector or an object moving with velocity ν causes a frequency shift f_D between the transmitted and the received signal, which is inversely proportional to the wavelength λ of the signal (Equation 1).

$$f_D = \frac{1}{2\pi}\frac{d\varphi}{dt} = \frac{2}{\lambda} v \cos \alpha$$

(1)

The reliability of Doppler-based sensors depends largely on the capability to dis¬tinguish target signals from an event produced by noise or other disturbances. The confidence level of Doppler-based detectors was improved by a combined microwave-ultrasonic multi-sensor system [10] (Figure 5).
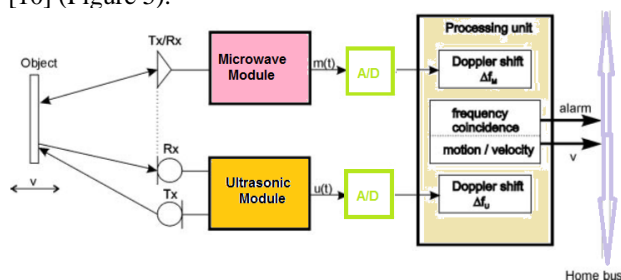

Figure 5. Block diagram of the ultrasonic-microwave multi-sensor system for motion detection [10]

Figure 6. Ultrasonic sensor module

Example 5. Thermal comfort - is one of the most important factors for the well-being of inhabitants of a building. A large number of parameters are responsible for the perception of comfort inside buildings [11].

Example 6. Indoor air quality - (IAQ) is relevant for well-being. Inadequate ventilation in buildings can lead to serious problems, such as the sick building syndrome (SBS), building-related illnesses (BRI) and mildew [12].

In order to realize safety, convenience, and comfort for the users of intelligent/smart buildings (SB), many sensor systems distributed all over the building are necessary (Figure 7). The main feature of the total system is its individuality. The total system should therefore be maintained flexibly changeable, because the users' requirements change with time. In the future, users will probably look after this new market sector in order to be able to adapt buildings to their new requirements.
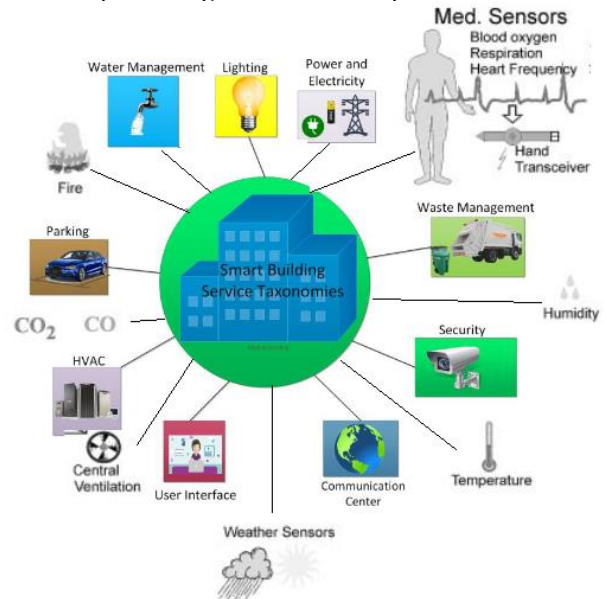

Figure 7. Example scenario in an intelligent/smart building (SB services taxonomy)

In the future, many goals could be aimed for the development of sensor systems for intelligent buildings, such as:
- reduction of energy consumption
- reduction of installation and maintenance costs
- widespread use of wireless sensors
- use of sensor systems allowing self-monitoring and self-calibration increasing integration of sensors and actuators with the building matter.

III. WIRELESS MEASURING SYSTEMS

Wireless measuring system should have the following features:
- 100% synchronization of signal sampling between individual measuring sensors,
- useful measuring band within the range 100 to 1000 Hz,
- minimum amount of energy for functioning,
- small size.

The complete synchronization of data from multiple sensors is technically difficult [13]. Our solution is focused on two of the available solutions. The first one is characterized by the use of multiple radio frequency channels for synchronous data transmission from sensors, described in figure 8.
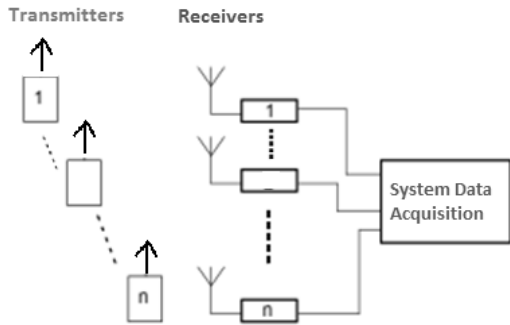
Figure 8. Wireless multichannel transmission of measurement signals

Wireless data transmission systems based on this solution are offered by a certain number of companies, (eg. MicroStrain with Agile-Link system which offers the possibility of parallel data acquisition from 28 different sensors). This solution, thanks to channels multiplexing technique (Time-Division Multiplexing - TDM), through combining various signals onto a single transmission media, increases the number of signals at the expense of increasing the time delays in collecting data.

The second solution consists in the construction of advanced measurement modules equipped with non-volatile memory, in which measurement data are collected. The data measured after a filter and validation are marked with time stamp, then transmitted to the base station where they are saved in the database, archived for processing and subsequent analysis. (figure 9).
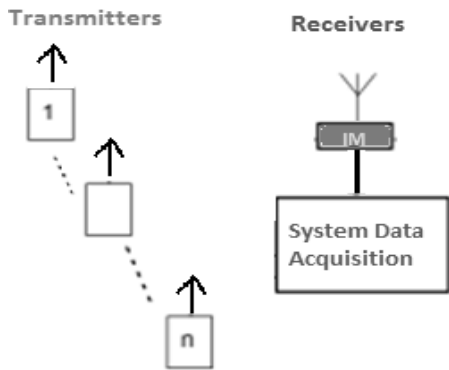

Figure 9. Wireless measuring system using intelligent modules (IM)

An important issue of this solution is the synchronization of the individual measurement modules, and also the influence of temperature on the frequency stability of the oscillators that generate the clock signal for the processor. Despite this inefficiency, systems based on intelligent modules are one of the most commonly commercial solutions within wireless measuring systems domain.

Our proposed solution provides adaptive, intelligent sensors with self-diagnosis and self-calibration capabilities, reducing the amount of information that needs to be via the network. Kiremidjian [13] highlighted that data acquisition, computation and processing is fundamental to intelligent monitoring systems, but also a radical deviation from the conventional design of computational tools and strategies for monitoring.

IV. APPLICATION

The system architecture we proposed is further summarized. Figure 10 describes the diagram of interaction and dependencies between the interfaces used in the developed program. Use case scenarios can be further derived.
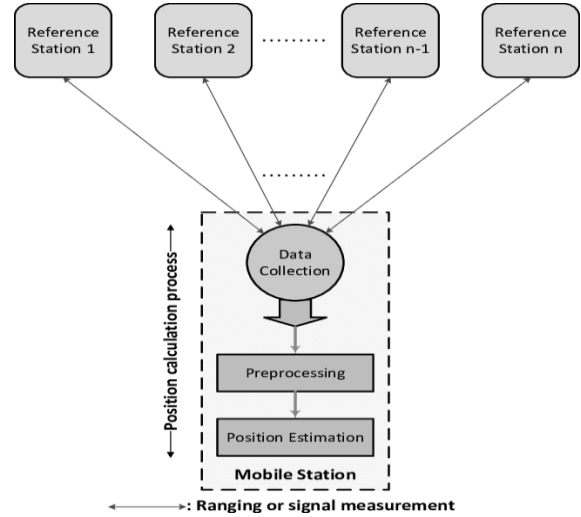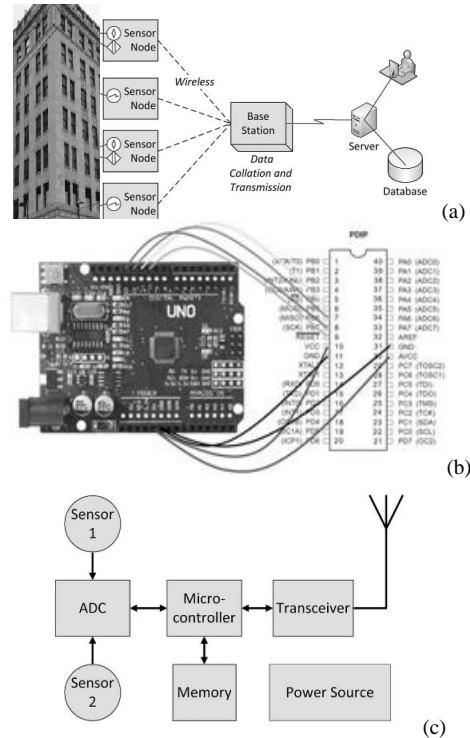

Figure 10. Diagram of interaction of components in the developed measurement application.

The analog sensor collects the analog data, transmits it to the base station where it is converted to digital, and the "smart" sensor filters, validates and converts the analog signal into digital signal before RF transmission. (RF). (fig 11a).
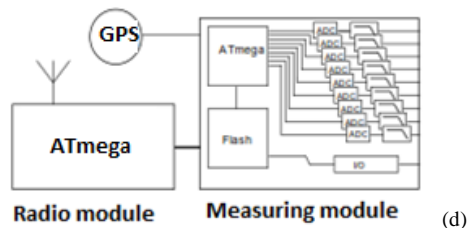
Figure 11. (a) typical WSN setup for building condition monitoring (b) Programming using uC IDE. Prototype Smart Sensor. Wireless sensor node can support bidirectional, peer-to-peer communications.(c) The structural configuration of a typical sensor node with multiple sensors and the ultralow-power microcontrollers. (d) Block diagram of the developed measurement system (module measuring & radio) with external synchronization of modules by PPS signal (pulse per second).

Monitoring can be achieved by integration of big data to the Google Cloud via web servers, then analysis of the big data is simplified thereby enabling ease of monitoring and alerts can be triggered in case of exceeding the limits of the monitored resources. Modern signal transmission technologies and cheap and available electronic components allow the construction of measuring modules with high technical parameters. Soon, the use of new technology satellite will allow simple and accurate deployment of sensors on large buildings. Reliable and performance wireless systems are evaluated in terms of hardware, software stability and functioning reliability. The data from wireless sensors must first be filtered and validated to ensure they are accurate and error-free (sensor faults, noise, null values, communication errors, etc.) saved in the databases and then be interrogated, analyzed by multi-agent system and transformed into useful information. This process can also be performed by the microcontroller of the sensor node; so only valid data is transmitted at base station for reducing bandwidth. Data from the database is then analyzed using robust algorithms based on artificial intelligence and multi-agent system technology. These contextual data along with multi-agent system suggestions can be included in models to improve model coverage and precision and provide suggestions for making decisions about monitor conditions. Based on implementation and validation process of designed system, all sub-systems can successfully work. In the security part, the system can detected RFID card that integrated with notification system by sending an email to manager. While, in the monitoring system, room temperature and humidity, the flame on the stove, rain conditions, the presence of intruders and also controlling the AC bulbs and solenoid valve as actuators can be monitored on the smartphone screen remotely via the internet network. The goal is that the proposed system is fully autonomous, as cheap as possible [15], allowing the creation of networks with a large number of sensors based on four basic components: computing power, energy supply, communication and bandwidth of the wireless links connecting sensor nodes. This system benefits from the advantage of a reduced physical size, low cost, minor energy consumption, flexibility in design and use, which can bring substantial social and economic advantages.

CONCLUSIONS

The Internet of Things (IoT) is a newly emerging field with a vision of connecting `things', human and machines together, making them an integral part of internet. This paper deals with the development of resource monitoring & management system with deployment of intelligent sensors system.

Possible further improvement of the proposed research can be the inclusion of more input parameters (e.g. gas leakage level, temperature and humidity, the flame on the stove, rain conditions, the presence of intruders and also controlling the AC bulbs and solenoid valve as actuators, pollution) to take into account the real scenarios in order to decide how much energy consumption is required. This system can be expanded by applying the same fuzzy controller to large number residential/commercial/industrial buildings and can be integrated into a micro grid. As the amount of data increases when dealing with a large number of residential/commercial/industrial buildings, this system can be further integrated with cloud/fog computing. Big data analysis is used to improve the scalability of the smart grid component and can be added to the existing technique because of an increase in the system data when dealing with a large number of residential/commercial/industrial buildings.

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