Dust Monitoring Systems

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Abstract— **In order to monitor dust in a city or on a large plant, we have designed a distributed network of nodes, which consists of smart sensors that detect dust. Such a network design must be scalable, to allow additional nodes to be added at any time. Each node should operate as a Plug-and-Play device, in order to provide minimal downtime for the network. With the help of microcontrollers embedded in each node it is possible for each sensor to upload measurement results directly to a server within the network. In order to keep a high compatibility of the sensor network and the associated network protocol requirements, an IEEE 1451 standard should be used, to provide a generic interface between a sensor and the outer network, regardless the network protocols. We have obtained new practical results, which we show as comparison between different dust measurement methods.**

Keywords- dust monitoring system; smart sensor; wireless network sensors

I. INTRODUCTION

Dust measurement has considerable significance and applications in modern life, depending on each field of application. Dust has impact on the environment, climate control, aviation, and health. We need to monitor the presence of dust in these fields and trigger an alarm system based on the specific levels of dust, in order to prevent accidents or malfunctions. Dust from outer space has a big effect on the climate of the planet. Ambient radiation heats dust and re-emits radiation into the microwave band, which may distort the cosmic microwave background power spectrum. In industrial applications for various plants and factories, where combustible dust or dust containing goods are produced, processed or stored, dust explosions may be expected if dust is not put under control.

To monitor dust in a city in particular or in any area in general, we have designed a distributed network of nodes, which consists of smart sensors that detect dust. Such a network design has to be scalable to allow additional nodes to be included at any time. Each node should operate as a Plug-and-Play device used to provide minimal downtime for the network. Through microcontrollers embedded in each node, each sensor can upload measurement results directly to a server within the network. In order to keep high compatibility between the sensor network and the associated network protocol requirements, an IEEE 1451 family of standards [4] should be used to provide a generic interface between a sensor and the outer network, regardless of the network protocols.

By networking and deploying an array of sensors, we obtain several benefits such as area coverage and connectivity. A distributed network incorporating sparse network properties will enable the sensor network to span a greater geographical area without adverse impact on the overall network cost. We will use wireless sensor networks and connect them together at sink nodes. The clustering of networks enables each individual network to focus on specific areas and shares only relevant information with other networks, enhancing the overall knowledge base through distributed sensing and information processing.

All the nodes shall transmit information through the network to the main server to process and record into a database the monitoring information. Based on the configured dust acceptance levels on the server, an alarm can be triggered from the server and sent back through the network to the corresponding devices.

The rest of the paper is structured as follows: Section 2 presents the state of the art in dust measurement, Section 3 describes the architecture of the system we propose, Section 4 analyses some experimental results, and Section 5 draws the conclusions of this work.

II. STATE OF THE ART IN DUST MEASUREMENT

Several measurement principles for dust detection are used, among which we can mention: the Gravimetric measurement [1], Triboelectric measurement [2] and Optical measurement [10]. Each of these enumerated measurement principles is suitable for a specific application based on the intensity of dust pollution, water vapor proportion and dimensions of the measurement zones [1, 2].

The gravimetric principle describes a set of methods in analytical chemistry for the quantitative determination of an analysis based on the mass of a solid. A simple example is the measurement of solids suspended in a water sample: A known volume of water is filtered, and the collected solids are weighed [2, 9].

The triboelectric effect (also known as triboelectric charging) is a type of contact electrification in which certain materials become electrically charged after they come into contact with another different material and are then separated (such as through rubbing). The polarity and strength of the charges produced differ according to the materials, surface roughness, temperature, strain, and other properties. We can use this effect to measure the quantity of dust [2, 9].

The optical measurement of dust implies measuring the light transmission using optoelectronic techniques. The measuring principle is based on the attenuation of the intensity of a light beam, penetrating a cloud with solid particles, by absorption and dispersion. The ratio between the resulting and the initial intensity is defined as transmission [1, 8, 9].

There are several applications implying the measurement of dust in liquids, and the most suitable method to be used is the gravimetric principle. The triboelectric dust measurement devices can be used for bag, ceramic and cartridge filters or cyclones where indicative monitoring is required. Dust detectors using the optical measurement principle are usually used for continuous measurement of medium and high dust concentration on industrial plants as well as for monitoring limited values, as required by the applicable directives and regulations. The optical principle is also used to measure the concentration of dust in saturated gas downstream of desulfurization plants, downstream of wet scrubbing plants and wet exhaust gas. This last method of dust measurement is used in the development of the wireless monitoring system described in this paper. Figure 3 shows the advantage of using this system compliant sensors and devices to communicate wirelessly, eliminating the monetary and time costs of installing cables to acquisition points. This document explains not only how to setup system, but also how to compare the dust sensor according application and dust type. Also the user of this system can make configuration threshold according to the specific application for which the dust detection sensor network is used.

III. SYSTEM ARCHITECTURE

To measure and monitor the dust level in a city or on a plant, we propose the distribution of several nodes, from N_1 to N_n. Each node is a smart sensor operating in a Plug-and-Play mode and each node communicates to a server, over a wireless network by using the IEEE 1451.5-802.11 standard [4].

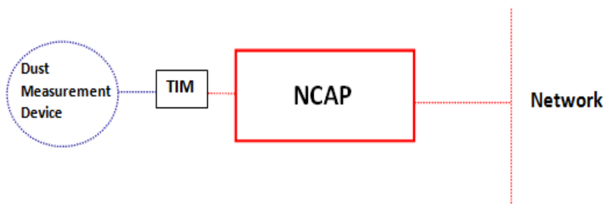

Figure 1. Dust Smart Sensor.

This standard will enable 1451 compliant sensors and devices to communicate wirelessly, eliminating the monetary and time costs of installing cables to acquisition points. IEEE is currently working on three different standards, 802.11, Bluetooth and Zigbee [4].

The server acquires the monitoring information from the distributed network of smart sensors and processes this data via specialized software. Based on the user configured thresholds, the server will either take no action, but to record the data for statistic purposes, or send a signal to other devices for specific tasks, such as air trap shutdown or activating air recirculation systems, in case the configured thresholds have been surpassed to a critical level. This depends on the specific application for which the dust detection sensor network is used.

Each node connects with a smart sensor, namely: a dust detection device, transducer interface model (TIM) and Network Capable Application processor (NCAP) as shown in Figure 1.

A TIM (Transducer Interface Module) is a module that contains the interface, signal conditioning, Analog-to-Digital and/or Digital-to-Analog conversion and in many cases, it also contains the transducer. A TIM can range in complexity from a single sensor or actuator to a module containing many transducers including both sensors and actuators.

An NCAP is the hardware and software that provides the gateway function between the TIMs and the user network or host processor (the transducer channel). The IEEE 1451 standard defines the communications interface between an NCAP or host processor and one or more TIMs. An NCAP or a host processor controls a TIM by means of a dedicated digital interface medium. The NCAP mediates between the TIM and a higher-level digital network. The NCAP may also provide local intelligence.

Figure 2 shows the implementation of a Wireless Sensor Network (WSN) based on IEEE 1451.0 and 1451.5-802.11, using IEEE 1451.2 sensors. This WSN consists of one NCAP node and one WTIM node. An IEEE 1451.2 sensor is connected to the WTIM via a serial port.

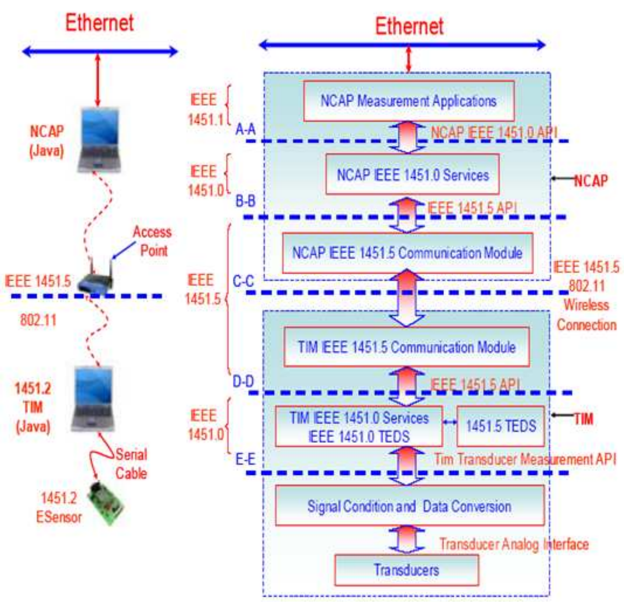

Figure 2. WSN based on IEEE 1451.0 and 1451.5-802.11.

The NCAP can communicate wirelessly with WTIM through IEEE 1451.0 and 1451.5 protocols using the client-server and publisher-subscriber communication models. The client-server and publisher-subscriber communications between the two nodes can be implemented using

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Transmission Control Protocol / Internet Protocol (TCP/IP) and Transmission Control Protocol / User Datagram Protocol (TCP/UDP), respectively.

We can integrate a dust smart sensor node into a network of smart sensors, as shown in Figure 3, from Node 1 to Node N, according to the application requirements and the number of sensors needed.

The Server monitoring software can be implemented with the Java programming language, for full flexibility and compatibility.

By using Java, we will also have the advantage of portability, having standardized libraries that provide a generic way to access host-specific features such as threading, network access and automatic memory management.

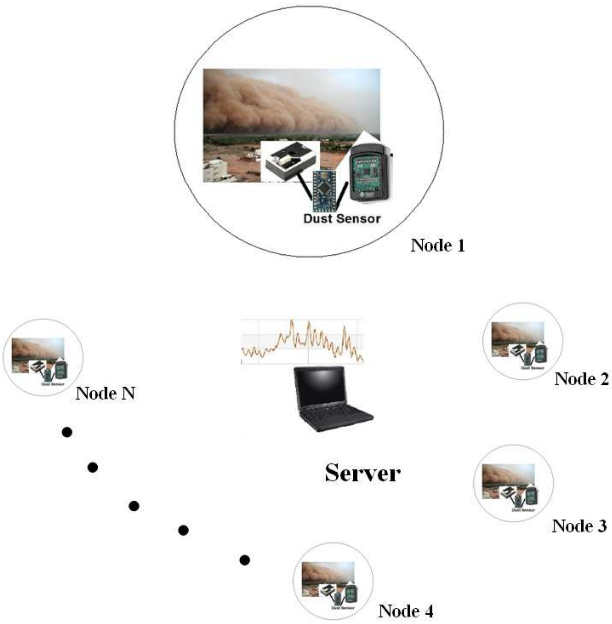

Figure 3. Dust monitoring network.

IV. EXPERIMENTAL RESULTS

Each node was implemented using a Sharp GP2Y1010AU0F dust sensor that is based on the optical principle [8]. The sensor was tied to a Sun SPOT (Sun Small Programmable Object Technology) device, which is an open source wireless sensor network (WSN) mote developed by Sun Microsystems. The device is built upon the IEEE 802.15.4 standard and on the Squawk Java Virtual machine [7]. This allowed us to use the Java programming language to control the data acquisition from the Sharp sensor. The connection from the Sun Spot to the server was assured by a standard wireless connection.

The following lines of code were used to acquire data from the Sharp dust sensor:

```
"byte[] buffer = new byte[64];
try {
demoBoard.readUART(buffer, 0, buffer.length); returnString = returnString +
new String(buffer, "US-ASCII").trim();
dustLevel = Integer.parseInt(returnString);
}
```

The first line of code in the try clock reads the serial port of the dust sensor and returns the value as an array of bytes. .

The results are sent to the server through the following simple lines of code:

```
"System.out.print(dustLevel);
System.out.println(", " +String.valueOf(dustLevel)); leds.getLED(0).setOff();"
```

The experimental results were obtained by using several types of dust: sand dust with high granularity, plaster dust and smoking ash. Another dust detector has been used as a reference, based on the gravimetric principle "D-RC80 Automatic sampling device for Gravimetric Dust measurements", used as reference measuring system. The output of the sensor is sent through the Sun Spot to the server, where we used the LiveGraph program to plot the results. During the experimental phase, modern test methods were taken in to account, such as they are described in the dedicated literature [5, 6].

For the smoking ash, we obtained a fluctuation in the results, as shown in Figure 4, but with a solid average, which was within the values obtained by using the dust detector with gravimetric principle.

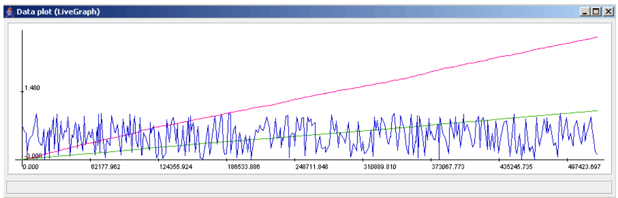

Figure 4. Live Graph plot of smoking ash measurement.

TABLE I. MEAN EXPERIMENTAL RESULTS

Type of dust	Mean measurement with our setup	Gravimetric measurement
Sand	3.2 mg/s	3.6 mg/s
Plaster	2.4 mg/s	4 mg/s
Smoking Ash	1.23 mg/s	1 mg/s

The experimental results depicted in Table 1 are encouraging regarding the accuracy of the optical measurement, compared to the ones made with a gravimetric device. The mean values were calculated based on 20 measurements.

We also conducted tests with two sensors sending data simultaneously to the server and we obtained satisfactory results. The server was configured with a service, programmed in Java, which allowed multi threaded communication. Our tests were made only at a distance of maximum 30 meters, between the node and the server, due to the wireless technology limitations, but this could be easily improved for higher distances by using a signal repeater.

V. CONCLUSIONS AND FUTURE WORKS

By using a smart sensor network we can monitor and measure the dust in any environment: urban or industrial. The area coverage of a dust monitoring network can be expanded depending on the needs, without any adverse impact to the overall network cost.

Each dust sensing device can focus on a specific area and by managed as a single entity or in turn it can be used as only one point of presence in an area, contributing to the overall accuracy of the measurement. The more nodes we will use for a dust monitoring network, the greater the accuracy of the gathered information will be.

The human interaction will be greatly reduced by using such a network. Also, compared to human observation, the introduction of a smart sensor network is more flexible when it comes to dangerous and hostile environments where humans can't penetrate, allowing access to information previously unavailable from such close proximity.

Sensor scheduling can be obtained by enabling the sensor nodes to modify communication requirements in response to network conditions and events detected.

The optical sensor that we used can easily become a node in a multi node network, and connect to a server over a wireless network.

From the experience of already existing devices, we can expect that in the coming decade a large number of monitoring systems for all physical phenomena will emerge, with great application in the human health sector, industrial sector and the environment. The monitoring system gives excellent opportunities to design and configure many types of sensors to monitor and control all physical phenomena for many applications based on people demands. Like example use similar systems to compare the accuracy and application by use tripoelectric device and compare with optical sensor and gravimetric sensor. Due to the large dust in Iraq, there is an intention to set up a system for monitoring the dust in Baghdad and I am now on the agreement with the relevant authorities.

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