SMART SENSOR NODES FOR AIRBORNE PARTICULATE CONCENTRATION DETECTION

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This paper describes the design and deployment of smart sensor nodes for dust monitoring applications by using two types of dust sensors which can be deployed in indoor or outdoor conditions. Generic system architecture is proposed, by the integration of smart sensor nodes for dust detection by using two types of detectors Sharp GP2Y1010AU0F and Shinyei PPD4NS. The design is based on Memsic IRIS motes and specific considerations regarding the integration of two types of optical dust sensing devices with the sensor nodes. Finally, results are evaluated from both a data collection and the 2 types of optical sensor relation with a reference system, in order to assess the suitability of the proposed nodes to be used in a wireless sensor network (WSN).

Keywords: data acquisition interface, dust sensing, microprocessor, wireless device, environment monitoring

1. Introduction

Recent advances in computer science, telecommunications and electrical engineering have converged into the field of wireless sensor networks (WSN) [1]. These tiny embedded networked devices, which consist of processing units, low-power radios, various sensors and a power supply, usually in the form of batteries, can be deployed in an interest area and relay important data back to a base station. There, data is stored, processed and analyzed and can be made available to the user. In a broader view, wireless sensor networks can be seen as essential building blocks of the internet of things.

A large number of liquid and solid particles are contained in the air that we constantly breathe. They are known as aerosols and come from a combination of industrial sources and natural sources. Although most of these particles are so small that can't be visible for the naked eye, we can see the solid ones, generally called dust.

There are several measurement principles for dust and fine particles and among these the most commonly used in commercial applications are: the

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gravimetric principle, the triboelectric principle and the optical principle [2, 3]. Each of these principles is suitable for a specific application depending by the intensity of dust pollution, water vapor proportion and the dimensions of the measured zones.

The commonly used and precise principle is optical principle [4]. The measuring principle is based on the attenuation of the intensity of a light beam by absorption and dispersion penetrating a cloud with solid particles. Moreover there are many optical instruments designed to measure the dust particles (Fig. 1).

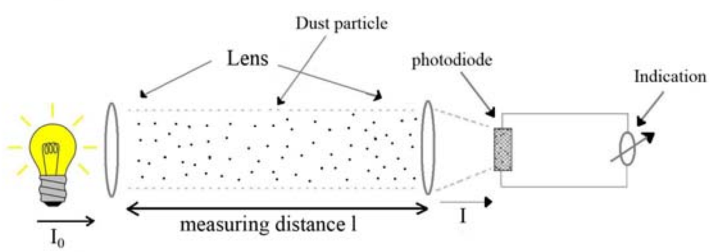

Fig. 1. Schematic diagram of the dust concentration optical measuring principle

Finally there is a Piezo Dust Detector which used to measure and monitoring for Hazard and System Degradation due to the impacts of Space Debris and cosmic dust are a major concern for satellite and human spacecraft missions in Earth orbit as well as for robotic and human exploration missions to comets, asteroids, planets and moons. Therefore NASA has declared Space Debris Hazard Mitigation as one of their Space Technology Grand Challenges.

Sensor nodes are devices that account with at least one sensor and may include actuators as well as having processing and networking capabilities to process data and use the wireless access, as shown in Fig. 2.

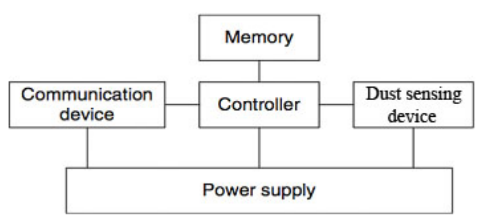

Fig. 2. Sensor node structure

Dust sensors are devices included in the sensor nodes. Sensors measure the particles concentration of an observation, converting the measurement into a signal that may be electrical (e.g. current, voltage, power, resistance, etc.), mechanical (e.g. pressure, flow, liquid density, humidity, etc.), chemical (e.g.

dust, oxygen, carbon monoxide, etc.), acoustic (e.g. noise, ultrasounds, etc.), or any other signal type.

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.

We can create a pervasive WSN for measurement and monitoring which 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.

2. Smart Sensor Network Architecture

The starting point in our scenario is to create 2 nodes in a WSN, by using IRIS Memsic. Each node has an optical detector, to obtain a high temporal and spatial resolution monitoring of the indoor or outdoor environment. Communication among devices in this WSN is enabled by many types of protocols: physical layer protocols, Medium Access Control (MAC) protocols, routing protocols, transport protocols, data encoding and aggregation protocols. The communication protocol IEEE 802.15.4 has a big effect for the facility of the nodes. IEEE 802.15.4 standard provides the physical and MAC layer. The physical layer deals with transmission and data reception services, radio interface management using the Energy Detection module (ED), Link Quality Indication module (LQI) and Clear Channel Assessment module (CCA).

The architecture of our proposed system consists of two wireless measurement nodes by using two types of dust sensor relaying data towards the sink as shown in Fig. 3.

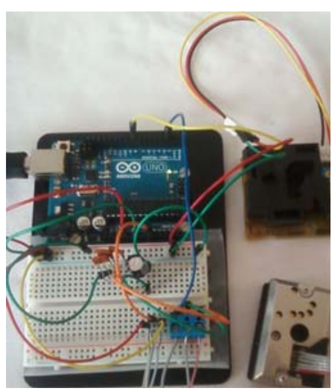

Fig.3. Laboratory picture for dust node with Sharp and Shinyei dust detectors

At the gateway level, the data is collected, stored and presented for interpretation or further processing.

The proposed wireless measurement node consists of the following devices [5]:

1) Microprocessor unit ATMega 1281 8 bit MCU

2) Radio device IRIS sensor nodes and an USB radio base station XM2110, IEEE 802.15.4 compliant RF230 radio transceiver operating in the 2.4GHz ISM band.

3) (MDA300 board) data acquisition board (design and manufactured in PUB)

4) Optical dust sensor interfaced with a microcontroller development board, we used two types:

a) Sharp GP2Y1010AU0F dust sensor [6]

b) Shinyei PPD4NS dust sensor [7]

The IRIS XM2110 is the main processing/radio board, which hosts an ATMega 1281 8 bit MCU and a IEEE 802.15.4 compliant RF230 radio transceiver operating in the 2.4GHz Industrial Scientific and Medical (ISM) band. The module is from Berkeley motes and is supported by the open- source community under TinyOS 1.x and 2.1 an event-based, low footprint operating system for resource constrained devices.[8] This module has a better performance in terms of radio coverage and improved energy efficiency. The 51-pin connector provides stackable expansion possibilities to connect to the MCU peripherals.

The MDA300 is a data acquisition board as shown in Fig. 4. The complete feature list is the following:

- 7 single-ended or 3 differential ADC channels;
- 4 precise differential ADC channels;
- 6 digital I/O channels with event detection interrupt;
- 2.5, 3.3, 5V sensor excitation and low-power mode;
- 64K EEPROM for onboard sensor calibration data;
- 2 relay channels, one normally open and one normally closed;
- 200 Hz counter channel for wind speed, pulse frequencies;
- External I2C interface. [9]

The Sharp GP2Y1010AU0F is a dust sensor with optical sensing system. An infrared emitting diode (IRED) and a phototransistor are diagonally arranged into this device.

It detects the reflected light of dust in air. Especially, it is effective to detect very fine particle like cigarette smoke. In addition it can distinguish smoke from house dust by pulse pattern of output voltage. The features that have recommended it are the compact size envisioned for integration in air purifiers or air conditioning units which is also suitable for our design. Very important for wireless embedded application is the low current draw of 20mA. I used a popular Arduino board to handle the interfacing of the sensor in this initial iteration.

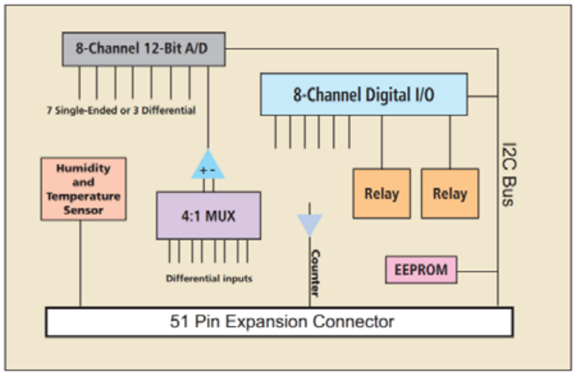

Fig. 4. MDA300 board (picture and electrical scheme)

The microcontroller board is based on the ATmega328. It has 14 digital input/output pins, of which 6 can be used as PWM outputs, 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button.

Basically, a digital output controlling the led of the detector has to be set to low for 0.32ms in a 10ms time period; afterwards an analog voltage output can be read. We place the dust sensor in our region of interest and air starts flowing naturally through the measurement space.

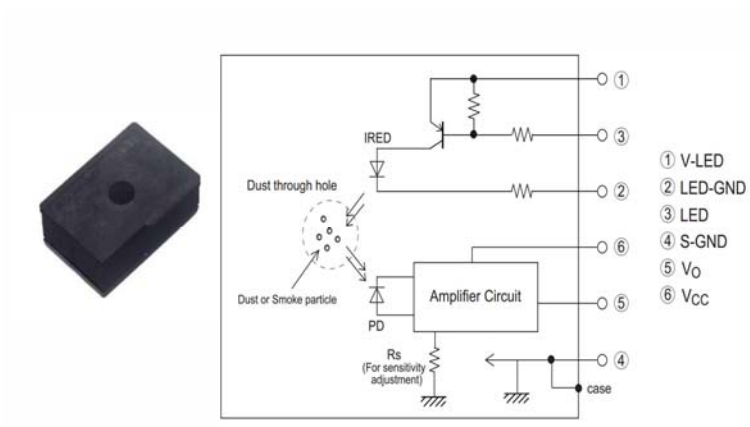

Fig. 5. Sharp GP2Y1010AU0F Dust sensor

The microcontroller board runs the embedded software loop to activate the light source and read the sensitive element processed output. Once a value has been read, it is output in the form of an analog signal captured by the ADC0 channel of the MDA300 board and interfaced to the appropriate input channel of the mote. The mote is tasked with broadcasting a radio message containing this voltage value. This happens either directly to the base station or, if the networking protocol decides that there is no direct or poor connectivity to the base station, via multi hop communication with neighboring nodes acting as relays for the source of the data.[10]

The Shinyei particle sensor PPD4NS is used to create Digital (Lo Pulse) output to Particulate Matters (PM). (Fig. 6)

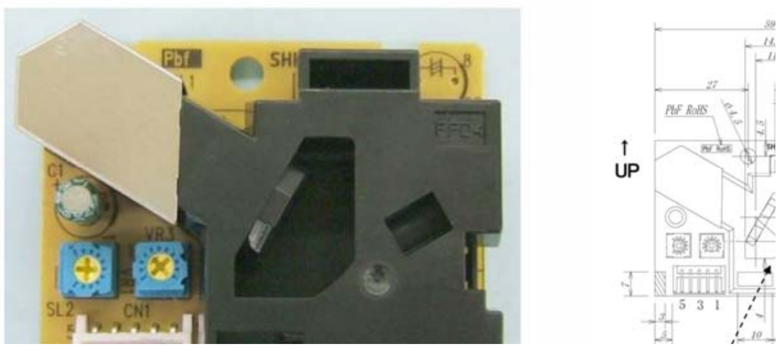

Fig. 6. Shinyei particle sensor PPD4NS

Lo Pulse Occupancy time (LPO time) is in proportion to PM concentration. The minimum detectable particle size is approx. 1μm with a detectable range of concentration of 0~28,000 pcs/liter.

We created a laboratory setup to perform the calibration of dust detectors and other environmental parameters that can be potentially measured, as depicted in Fig. 7.

By using this design we can control dust, humidity, temperature from each source and get long term readings to find out the relation between environmental parameters and also perform the calibration for each sensor. With this network we can integrate many types of sensors to make a comparison between the results obtained from them, in particular for dust, we can use an optical dust device, triboelectric device or piezoelectric device, to study the response time, accuracy and performance, to understand which one is more suitable for a specific application.

Hardware used is commercially available from Memsic Inc. and consists of IRIS sensor nodes and an USB radio base station .The IRIS node has a modular structure, comprised of a radio/processing board, a sensor board, compact plastic enclosure and 2 AA batteries.

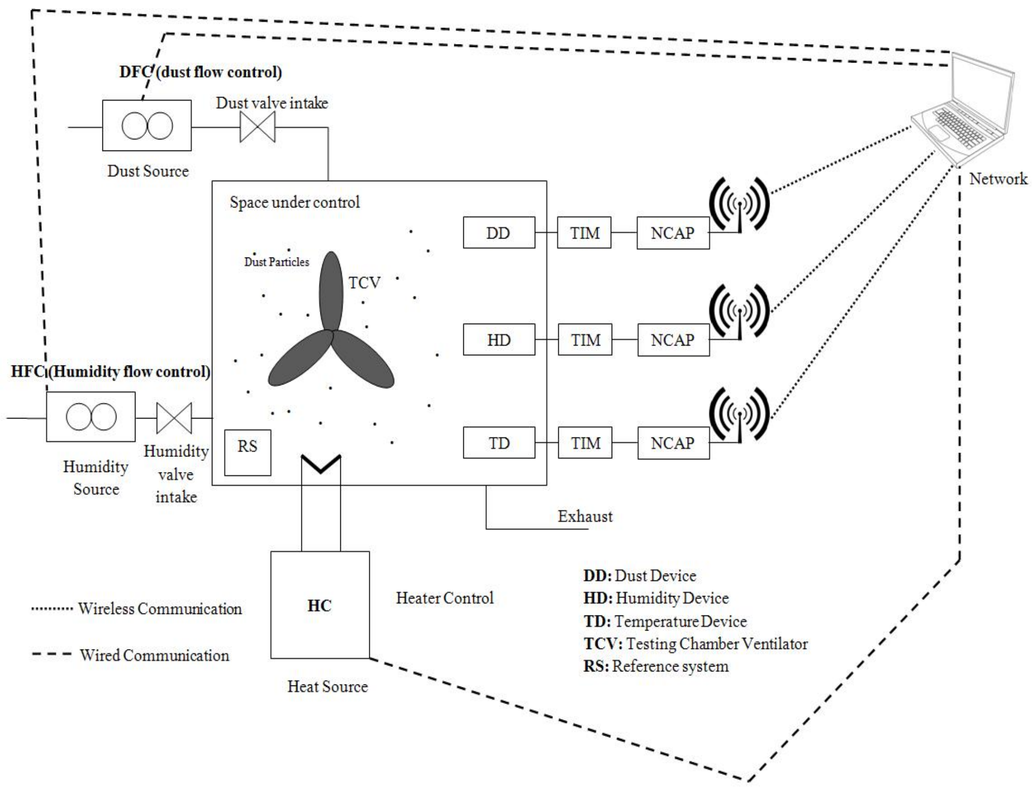

Fig.7. Calibration system diagram

The XM2110 is the main radio/processing board, which hosts an ATMega 1281 8 bit MCU and a IEEE 802.15.4 compliant RF230 radio transceiver operating in the 2.4GHz ISM band. This is the newest module in the line of the original Berkeley motes and is supported by the open-source community under TinyOS 1.x and 2.1 – an event-based, low footprint operating system for resource constrained devices.

3. Experimental Results and Evaluation

We obtained the results first for Sharp GP2Y1010AU0F. The graphic in

Fig. 8 shows the data stemming from a continuous indoor monitoring with three high particle concentration events. The events were generated using paper smoke. What can be observed it that, while the sensor becomes saturated upon incidental smoke, the width of the peaks gives an indication of the persistence of the contaminant. The steady state evolution of the dust concentration is also noticeable via an increasing baseline. The sensor signal is scaled as to conform to the analog-to-digital converter (ADC) accepted range on the sensor node, in this case 0-2.5 V. Depending on the chosen sampling rate, the output signal has to be filtered in order to suppress noise, while maintaining the valuable information regarding the investigated phenomenon. In this case the sampling rate was set at 1 sample every 30 seconds.

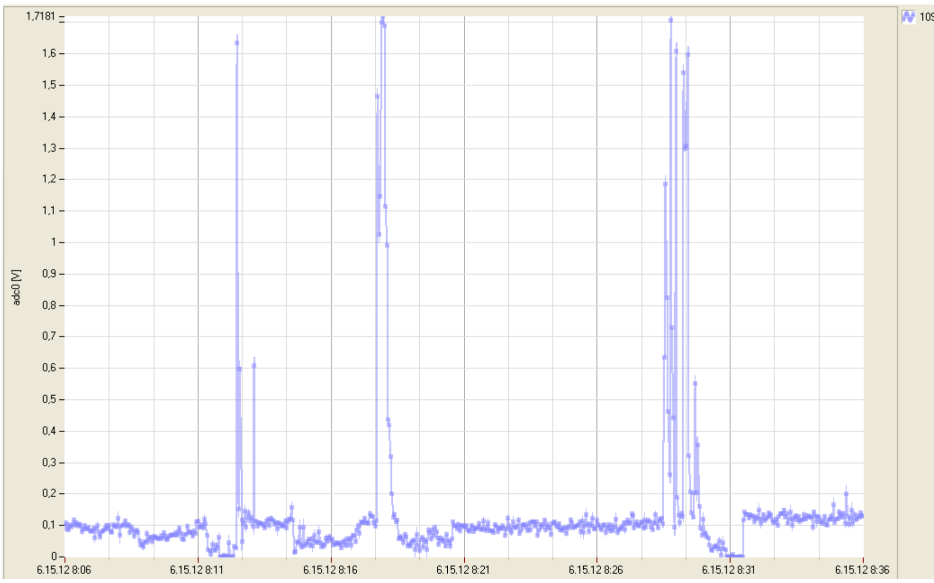

Fig. 8. Sharp GP2Y1010AU0F monitoring results

The results of the particulate monitoring via the Shinyei sensor are illustrated in Fig. 9. The monitoring was performed on a longer time scale and we can observe similar static and dynamic characteristics as compared to the previous sensor.

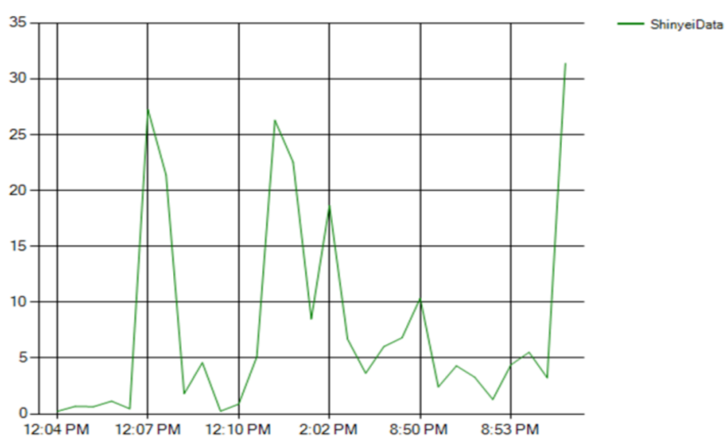

Fig. 9. Shinyei PPD4NS monitoring results

The reference system for the validation of our setup is the Dylos DC1100 laser particle counter which is a semi-professional device used by air quality specialists in commissioning air purifying equipment. The two characteristics shown in Fig. 10 include small particle quantities (blue) and large (red) over the studied period of time. Small particles are considered the ones smaller than 2.5 µm while large particles are between 2.5 and 10 µm. One can notice similar behavior compared to the one with the developed system using both the Sharp and Shinyei sensors.

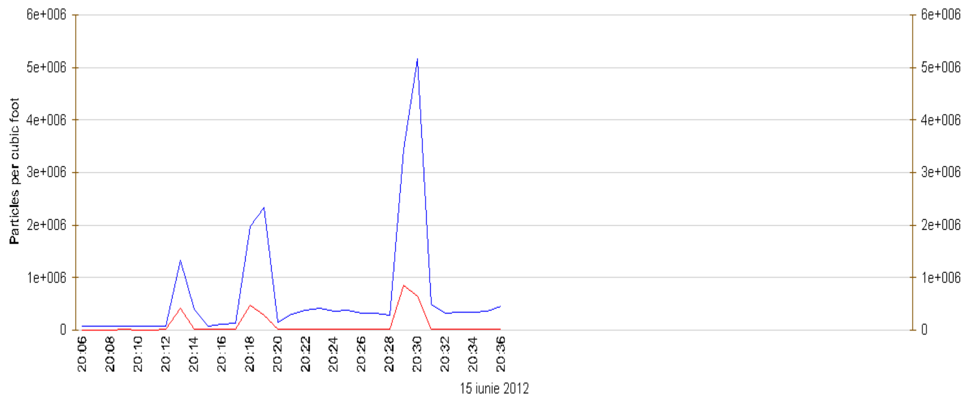

Fig. 10. Dylos DC1100 monitoring results

Table 1 presents a summary of the experimental data. It can be seen that the data is comparable, which gives an initial evaluation on the feasibility of the dust monitoring sensor network. Average, low and high values are listed, all expressed in milligrams per cubic meter. Absolute differences are very small, while, expressed in relative terms, it can be concluded that sufficient precision for non-critical monitoring scenarios has been achieved.

Table 1

Dust sensor measurements comparison

	Dylos DC1100 dust sensor results	Shinyei PPD4NS dust sensor results	Sharp P2Y1010AU0F monitoring results
Average mg/m^3	0,2118	0,201	0,253
Low mg/m^3	0,01785	0,0151	0,0192
High mg/m^3	1,8735	1,921	1,964

4. Conclusions

The main contribution of this paper lays in the proof-of-concept for creating a vital dust smart sensor compatible to use in any environment. We obtained encouraging results by comparing the practical results obtained from 2 types of optical dust sensors with the reference device Dylos DC1100.

Our approach is easily applicable to use in a WSN application such as generic environmental monitoring, energy monitoring and infrastructure and asset tracking. This approach will open the door to use this smart dust sensor in a harsh environment and also in wide areas as a pervasive WSN. The perspective application for the created nodes is to establish a connection between WSN and HMI (Human Machine Interface) software, thus allowing the system to become a part of an industrial application.

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