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Evaluation of a low cost wireless chemical sensor network for environmental monitoring

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Abstract

We present work on the development and testing of a low-cost wireless chemical sensor network (WCSN) for monitoring irritant/toxic gases in the environment. The WCSN used in this work takes advantage of recent advances in low power wireless communication platforms and uses colorimetric sensors to detect the presence of certain target gases. This sensor network adopts a star configuration and performs one way RF communications from individual sensor nodes to the base-station. Each node in the network is composed of a multiple sensor platform that measures light intensity, temperature and motion. The light sensor was used as the chemical sensing platform in such a way that the node is housed in a specially constructed sealed container that has a colorimetric chemical sensing film coated PMMA window aperture directly above the light sensor. The light intensity reaching the light sensor is modulated by changes in the colour of the sensing film and such changes indicate the presence of chemical plumes.

Keywords

low, cost, wireless, chemical, evaluation, sensor, monitoring, network, environmental

Disciplines

Life Sciences | Physical Sciences and Mathematics | Social and Behavioral Sciences

Evaluation of a low cost Wireless Chemical Sensor Network for Environmental Monitoring

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Abstract— **We present work on the development and testing of a low-cost wireless chemical sensor network (WCSN) for monitoring irritant/toxic gases in the environment. The WCSN used in this work takes advantage of recent advances in low power wireless communication platforms and uses colorimetric sensors to detect the presence of certain target gases. This sensor network adopts a star configuration and performs one way RF communications from individual sensor nodes to the base-station. Each node in the network is composed of a multiple sensor platform that measures light intensity, temperature and motion. The light sensor was used as the chemical sensing platform in such a way that the node is housed in a specially constructed sealed container that has a colorimetric chemical sensing film coated PMMA window aperture directly above the light sensor. The light intensity reaching the light sensor is modulated by changes in the colour of the sensing film and such changes indicate the presence of chemical plumes.**

I. INTRODUCTION

The majority of the research effort into wireless sensor networks have been on the hard ware and software configurations and the modeling of the network performance, there has not been a great deal of work into the application of these sensor networks, especially when chemical sensing is concerned.. At present, research into chemical sensors and wireless sensor networks are still essentially discrete fields despite the requirement in merging these two disciplines for applications such as environmental monitoring. The main obstacles for realizing such wireless sensor network are the high unit cost and until recently, high power requirement of the hardware (wireless communication platform) and the cost and reliability of the (chemical) sensors. To deploy sensors in large numbers (even in hundreds) the unit cost of individual device must be affordable, which can only be achieved by stripping the device components to a minimum, and preferably, employ sensors that perform very basic functions to reduce unit cost and power consumption. The sensor should be on board of the wireless communication platform instead of having a discrete sensor driven by a separate circuit that relays the sensor data to the wireless platform.

Wireless sensor networks are composed of sensor nodes which are the smallest component of a sensor network that has integrated sensing and communication capabilities (and sometimes referred to as motes). The sensor node has basic networking capabilities through wireless communications with other nodes, as well as some data storage capacity and a microcontroller that performs basic processing operations. Typically a sensor node comes with several on-board transducers, for temperature, light level, motion and so on. They will often have a sensor board that usually slots onto the controller board and which allows for the interface of other sensors provided the signal is presented in the appropriate form for the controller.

Examples of the application of WSN in the real world include:

Tree micro-climate monitoring
In this case, network of 33 Mica2Dot motes was deployed in a 70m tall redwood tree to monitor the surrounding microclimate over a period of 44 days 17 [2]. The sensor nodes monitored temperature, relative humidity and photosynthetically active radiation, with the choice of phenomena measured guided by the biological research priorities, e.g. data on temperature and relative humidity can be fed into transpiration models for redwood forests. The sensor node was based on a Mica2Dot that had sensors that for temperature, relative humidity, solar radiation (direct and ambient) and barometric pressure on-board. The whole sensor node was encased in a specially designed housing to protect the components from physical damage during the deployment. To keep the WSN running for as long as possible without having to change batteries, the sensor nodes were activated for only 4 seconds to take measurements and data was transmitted at 5 minute intervals for a period of 44 days.

Vineyard Monitoring

The vineyard deployment involved a sensor network comprising 64 Mica2 motes which were employed to monitor temperature over a hectare section of a vineyard for 30 days [3]. The motes were deployed in a grid and configured as a multi-hop network with a maximum depth of 8 nodes. The sensor nodes were static (being placed one metre off the ground) and the routing of messages across the network was determined before the network was deployed. Two pathways for upstreaming data were chosen. The network was composed of 16 backbone nodes and associated with each backbone node were 3 sensor nodes. The backbone nodes could send packets up to 25 metres while the sensor nodes sent packets up to 15 metres. Data were recorded every five minutes and during the deployment two arctic fronts moved across the vineyard. The vineyard deployment allowed the collection of dense information on the temperature of a vineyard over an extended period of time. They discovered that the regions of highest temperature changed from day-to-day throughout the vineyard. This type of information is important as it can identify regions within the vineyard that will be more susceptible to mildew attack, and can therefore be used to determine a targeted and optimised spraying regime to minimise product loss, and hence maximise yield.

Large-scale deployments of chemical sensors in sensor networks can only happen when the sensor nodes are essentially self-sustaining in terms of all consumables (energy, reagents etc.) for many years. One example of self-sustaining chemical sensor is the autonomous phosphate system [4] developed by the Adaptive Sensors Group [5]. This system takes water samples and when a phosphate-containing sample is mixed with an acidic reagent containing ammonium molybdate and ammonium metavanadate, the intensity of the resulting yellow colour indicates the amount of phosphate in the original sample. These types of systems are still relatively large-scale and mimic procedures that are carried out in laboratories; albeit they can be deployed for months at a time. Yet the phosphate system is significantly larger than the typical wireless sensor node (e.g. www.xbow.com) which limits how they can be combined with sensor nodes to form low power, low-cost chemical sensor networks.

One way to achieve small, low-cost chemical sensor networks is to build upon sensors which are either found on existing sensors platforms or which can be easily added, e.g. LEDs or photodiodes. These light sensors can be used in conjunction with smart surfaces that change colour in response to the presence of a chemical. The readings of the light sensors can tell us something about the local environment, e.g. the presence of chemical event. This short paper demonstrates a low power and low cost wireless chemical sensing network based on modifying a low power RF communication sensing platform (Teco µParts [1]) with a colorimetric membrane that reacts to the presence of a gas/vapour.

II. EQUIPMENT

The wireless sensor network was composed of Teco µParts [1] (Fig. 1) which were tested in an environmental chamber (Fig. 2). The Teco µPart is an ultra small wireless communication embedded computing system (20x17x7mm) with a light sensor, a temperature sensor, an acceleration sensor. The Teco µPart features an embedded 8-bit Processor (4 MHz) with 1.4 kByte internal Flash, 64 byte internal SRAM and 128 Byte internal EEPROM (a schematic is shown in Figure 1). The wireless communications are carried out by an 868 MHz RF transmitter (FSK). The RF communications with the sensor platform is one-way, i.e. with only data being sent from the sensor platform to the base-station. The sensor platform can be programmed via a light sensor (Taos TSL13) on board the µPart. This sensor is a mid-sensitive analog light sensor with a linear output voltage of 24 mV/(µW/cm²) at l = 640 nm. TSL13T covers a total spectrum between 320 nm and 1050 nm. The sampling rates of the sensors on board the µPart have to be set before the sensor platform is deployed. The rates can be set from 288 milliseconds to ~78 minutes. The µPart is used in conjunction with a USB-powered base-station which receives transmissions from the sensor nodes.

By default the µPart can only detect light, motion and temperature. Using a specific chemical responsive film a change in the light level can be used to indicate the presence of a gas. A housing was developed for the µPart which has a PPMA window that covers the light sensor of the µPart (see Fig 1). The PPMA Perspex window can be coated with a specific chemical responsive film for detecting toxic gases. This film will change colour in response to the presence of a gas.
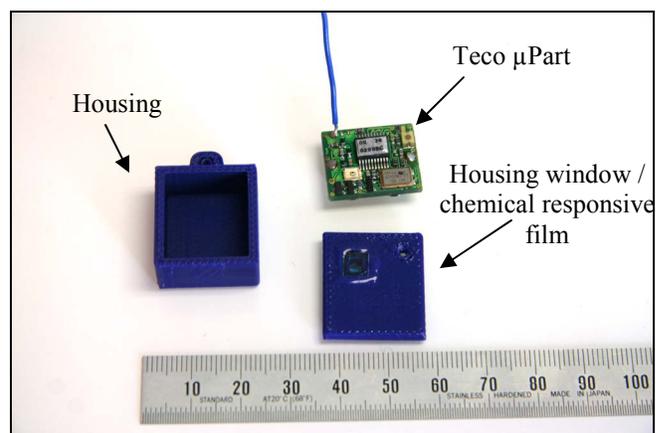

Figure 1. The teco µPart and the housing. The Teco µPart is a relatively small device which has onboard light, temperature and motion sensors. Sensor readings are sent to a base-station via RF.

The environmental chamber has been developed for testing of small scale (1–6 nodes) WCSNs (see Figure2) in a safe manner. The chamber enables testing of physical sensors, and a range of chemical sensors developed in our labs under semi-realistic conditions and includes a small 12v PC fan to disperse plumes. (A much larger chamber has also been developed but was not used in this experiment, see [6]). Gas is injected into the sealed chamber via a valve in the lid of the chamber.
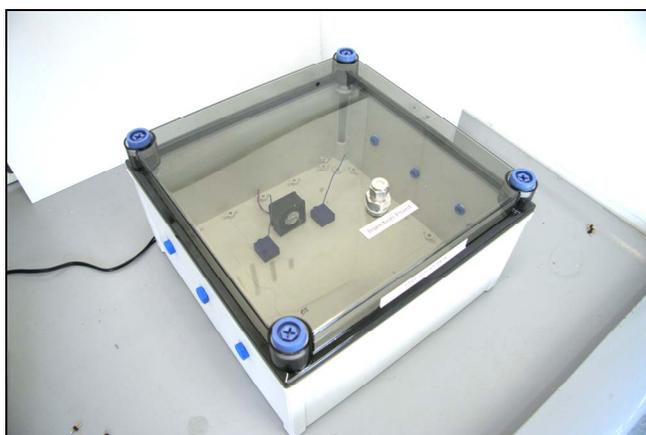

Figure 2.   The environmental chamber with two sensor nodes (1, 2). Gas samples are injected into the chamber which is sealed. A fan in the box is used to aid the dispersal of the gas.

The wireless chemical sensor network was configured into a star network (the Teco µPart only allows for 1-way communication) with a base-station connected to a PC gathering all the readings (Fig. 3).
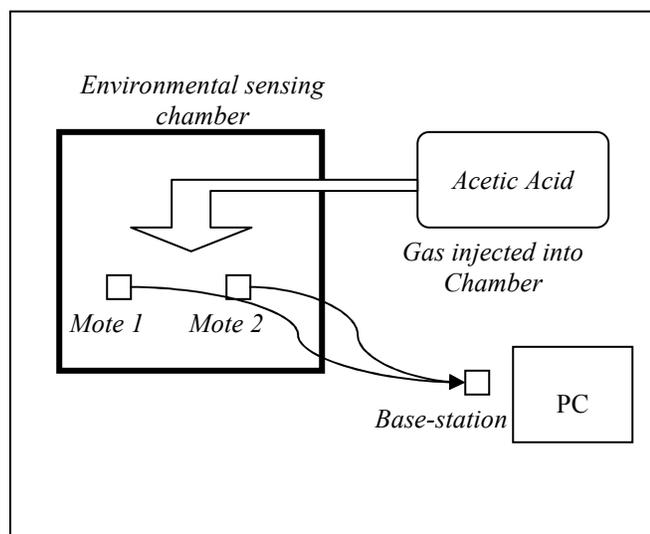

Figure 3.   Diagram of experimental setup. The chamber was situated 6.5 metres from the base-station in a fume cupboard. As acetic acid was injected into the chamber light and temperature readings from the motes were collected.

III.   EXPERIMENT

The system presented in this work uses Teco µParts as the sensor node and special home made opaque housings with a window above the light sensor was built to contain these motes (see Fig. 1). The window was coated with a specific chemical responsive film for detecting toxic gases. This specific chemical responsive film prepared by dissolving the pH indicator bromophenol blue (BPB) into a solution of ethyl cellulose in ethanol. In order to prepare an acidic responsive sensing polymer, it was necessary to stabilise the BPB in the blue base form. This was achieved by adding the salt tetrahexylammonium bromide (THABr), which acts as a solid state pH buffer, to the polymer formulation. The colorimetric sensing polymer was applied to the window in of the holder (Fig. 1).

During lab-based trials an environmental chamber (Fig. 2) was used to control the exposure of chemical plumes to the sensor nodes (and for health and safety purposes). The chamber was situated 6.5 metres from the base-station. The sampling rate and the transmission rate were set to one data set per 5 seconds. A number of trials have been carried out with the chamber which involved the release of acetic acid to test the efficacy of the system. In each trial Plumes of acetic acid were injected into the chamber. The results of a typical trial are shown in Fig.4. In Fig. 4 can be seen the response of two sensor nodes during a trial when 6ppm acetic acid was introduced into the environmental chamber. When the gas is released the color change in the sensing polymer results in a drop in the light readings of both sensors indicating the presence of the gas. The system has been demonstrated to detect a chemical event.

IV.   CONLCUSIONS

We have presented work on the development and testing of a low-cost wireless chemical sensor network (WCSN) for monitoring irritant/toxic gases in the environment. The Teco µPart which is a small wireless communication embedded computing system with a light sensor, a temperature sensor, and an acceleration sensor was used as the sensing platform. The light sensor was used in conjunction with a colorimetric chemical sensing film to detect the presence of a gas. The light intensity reaching the light sensor is modulated by changes in the colour of the sensing film and such changes indicate the presence of chemical plumes. These sensors nodes should run for 3 months on a coin cell battery at the current sampling rate.

During trials a bespoke environmental sensing chamber was filled with acetic gas. Changes in the light readings of the wireless sensors placed in the environmental sensing chamber indicate that the WSN had detected a chemical event. This demonstrates the efficacy of using light sensors on sensors node in combination with a smart material, especially where the light sensors are already on a low-cost, low-power platform.

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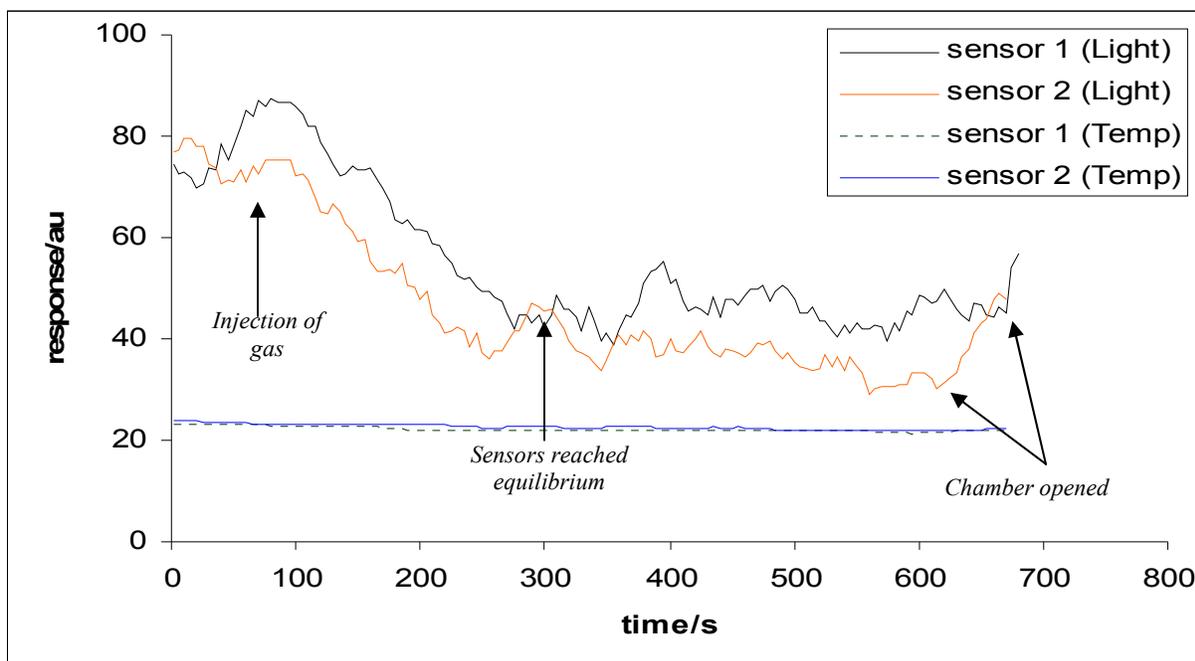
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Figure 4. Wireless Chemical Event Detection. The responses of two motes or sensor nodes (sensor 1 & 2) during a trial when acetic acid is injected into the environmental chamber. When the gas was released the color change in the sensing film resulted in a drop in the light readings of both sensors indicating the presence of the gas. The temperature readings from both sensors are also displayed. The time lapse in the responses between the two sensing nodes was due to the different positioning of the motes within the environmental chamber