Sensors and Actuators B 224 (2016) 266–274

Contents lists available at ScienceDirect

Sensors and Actuators B: Chemical

journal homepage: www.elsevier.com/locate/snb

A wireless sensing system for monitoring the workplace environment of an industrial installation

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ARTICLE INFO

Article history:
Received 16 March 2015
Received in revised form 31 July 2015
Accepted 14 October 2015
Available online 19 October 2015

Keywords:
Chemocapacitors
Sensor array
Mote
Wireless sensing system
Industrial application

ABSTRACT

The realization of a wireless sensing system and its sensing performance evaluation, under laboratory conditions, for the monitoring of specific volatile organic compounds (VOCs) present in printed flexing packaging industries is demonstrated. Prior to the utilization of the wireless mote, we present the microfabrication of appropriate sensor array based on chemocapacitors and its integration with appropriate low power consumption read-out electronics meeting the requirements of the application. The sensing unit is an array of interdigitated chemocapacitors (IDCs). The wireless sensing system is tested upon exposure to VOCs, humidity and gaseous mixtures simulating the real industrial environment and the raw data are transmitted via a wireless network and monitored to a front-end software. Results showed that the sensing system is characterized by very good sensing performance with high repeatability and long-term stability. Further data processing with principal component analysis (PCA) highlights the sensing system's ability to discriminate between gaseous environments with different composition/concentration. Thus the particular wireless sensing system is suitable for remote real-time unattended industrial environment monitoring.

1. Introduction

Wireless sensing systems and wireless sensor networks (WSNs) have emerged as a consequence of engineering smaller sized sensing devices characterized by low cost fabrication and low power operation, which enable many applications in diverse fields. Currently, they are very promising in several fields such as environmental science, agriculture, medicine, military surveillance and home health care or assisted living [1–10]. The WSNs are usually composed of a few sinks which in turn communicate with several sensors nodes also referred as motes. These motes can operate in a wide range of environments and provide advantages in cost, size, power, flexibility and distributed intelligence compared to conventional wired sensing solutions. Motes can change place and configuration, be added or removed while the continuous operation of the network remains attainable. Moreover, due to the inherent characteristics of the WSN, a mote can indirectly contact the network coordinator via multiple hops with several sophisticated stream environment scenarios [11].

The key components of an intelligent and smart WSN are usually several motes consisting of three units: sensing, processing and communication [12]. The sensors are analytical devices where a sensing material is applied onto a suitable physical transducer to convert a change in a property of a sensing material into a readable form of energy [13]. The energy-transduction principles that are usually employed for chemical sensing involve radiant, electrical, mechanical and thermal types of energy. The analog signals produced by the sensors are converted to digital signals and are afterwards guided to the processing unit [14]. At this step, the signal obtained from the transducer is processed to provide useful information about the concentration of species in the sample of interest.

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http://dx.doi.org/10.1016/j.snb.2015.10.043
0925-4005/

The motes, with their embedded CPUs, RF communication module and sensor units, gather information from the surrounding environment and communicate with each other via a gateway unit to send the measured data to a base station for further processing [15]. These gateway units can also communicate with other computers via Internet, building Internet of Things (IoT) [16–18].

The monitoring, evaluation and control of the air quality within facilities workspace, with the use of WSN appears to be a promising trend in industrial applications. Thus, on-site measurements in real time, rather than collecting samples for off-line laboratory analysis, are of great importance. In this direction the miniaturization of detection systems is one of the major trends.

Toward this objective, a mote is developed operating in Zigbee communication protocol. In this study a hybrid sensor array composed by 8 interdigitated chemocapacitors (IDCs) with the appropriate read-out electronics is used as the analytical device. The design/fabrication of the interdigitated electrodes (IDEs) layout is optimized in terms of sensing performance and is in accordance with the selection of the polymeric materials that will coat the sensing area and the read-out electronics specifications. Then this system is connected with a wireless node that is guided and coordinated by a gateway unit. Evaluation of the wireless sensing system is performed under laboratory conditions upon exposure to gaseous environments, simulating the workspace of a specific printed flexing packaging industry. Effective safety precaution measures, relating both to the flammability of the solvents [45% of the lower explosion limit (LEL)] as well as to the upper limit of safe exposure of the employees (time weighted average, TWA) require the continuous monitoring of the gaseous environment composition in the working areas. In particular, in flexographic or rotogravure printing technologies ethyl acetate is used as the main ink-solvent. Thus for the case of interest, focusing mainly on ethyl acetate vapor, the corresponding values are 9000 ppm and 400 ppm for 45% LEL and TWA respectively [19]. The system is also tested in sensitivity/selectivity to ethanol vapor, since it is reported that at industries established at countries with warm climates (e.g. Southern Europe) in order to sustain the fluidity of the ink solutions, ethyl acetate is often mixed for certain inks with low molecular weight alcohols.

2. Realization of the sensing system

An overview of a WSN for real time application is illustrated in Fig. 1. Each mote comprises a wireless node connected with the sensing unit developed. The motes communicate with a gateway unit that collects the various data and further transmits them to a computer for monitoring and further processing with appropriate software.

In this study, we investigate the realization and the evaluation of the sensing performance of a wireless sensing system, as the core unit of such a network. Details about the sensing unit which consists of the sensor array and the read out electronics are presented below.

2.1. Fabrication of the sensor array

The sensor array should be appropriately designed for the targeted application. The use of chemocapacitor type sensors has been chosen due to previous reported promising results of their sensing performance (e.g. selectivity/sensitivity, reproducibility) for complex gaseous environments in conjunction with low power consumption [20–24]. The dielectric layer of the chemocapacitors, which acts as the sensing material, is a polymeric layer with appropriate sorption properties for certain analytes. The configuration of planar IDEs addresses the need of feasible fabrication and appropriate personalization through the application of suitable polymeric material via drop casting or inkjet printing [25–27].

Two interpenetrating comb metallic electrodes with well-defined geometry are fabricated on Si wafers with a thick layer of SiO_2 on top. The thickness of the SiO_2 layer should fulfill the basic requirement that it should be higher than half the spatial

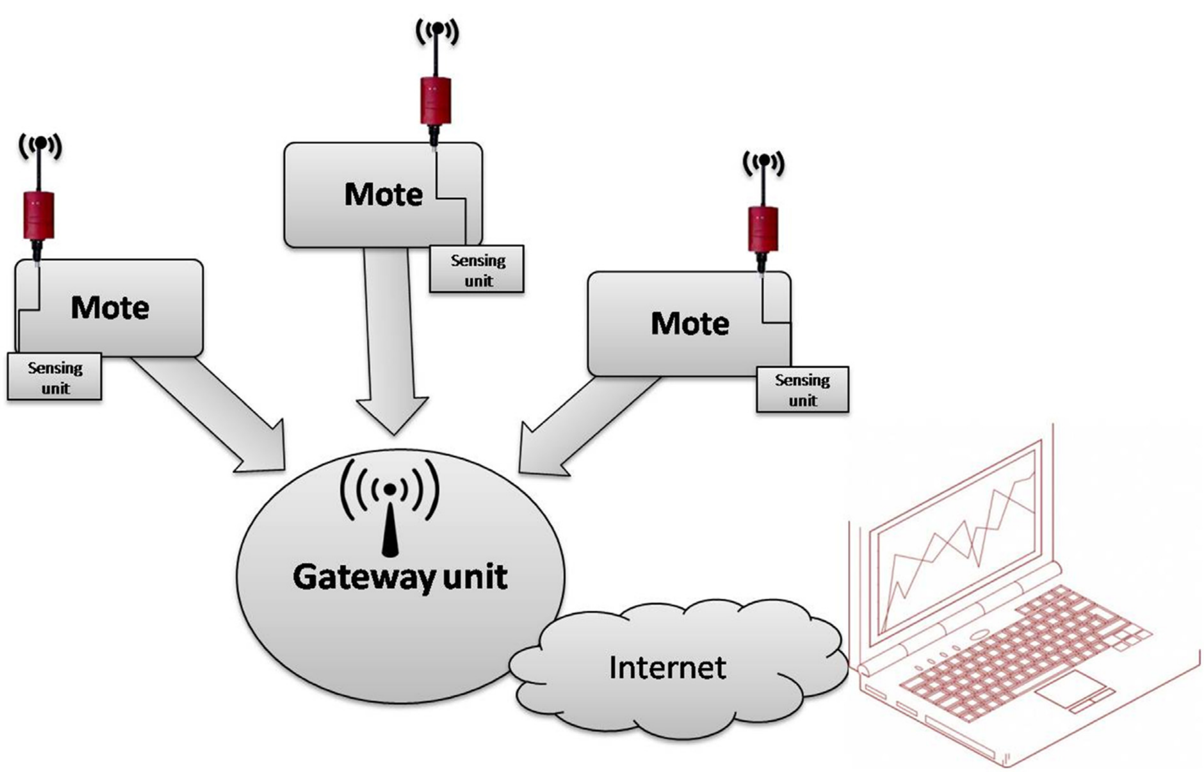

Fig. 1. Overview of a wireless sensor network (WSN) for real time applications.