Available online at www.sciencedirect.com
ScienceDirect
ISA Transactions 47 (2008) 247–255
www.elsevier.com/locate/isatrans

Development of an integrated wireless sensor network micro-environmental monitoring system

Xiangui Cao[a], Jiming Chen[a,*], Yan Zhang[b], Youxian Sun[a]

[a] State Key Lab. of Industrial Control Technology, Institute of Industrial Process Control, Zhejiang University, 310027 Hangzhou, PR China
[b] Simula Research Laboratory, Norway

Received 30 April 2007; received in revised form 5 January 2008; accepted 4 February 2008
Available online 19 March 2008

Abstract

Wireless Sensor Network (WSN) is increasingly popular in the field of micro-environmental monitoring due to its promising capability. However, most systems using WSN for environmental monitoring reported in the literature are developed for specific applications without functions for exploiting user's data processing methods. In this paper, a new system is designed in detail to perform micro-environmental monitoring taking the advantages of the WSN. The application-oriented hardware working style is designed, and the system platform for data acquisition, validation, processing and visualization is systematically presented. Several strategies are proposed to guarantee the system capability in terms of extracting useful information, visualizing events to their authentic time are also described. Moreover, a web-based surveillance subsystem is presented for remote control and monitoring. In addition, the system is extensible for engineers to carry their own data analysis algorithms. Experimental results are to show the path reliability and real-time characteristics, and to display the feasibility and applicability of the developed system into practical deployment.

Keywords: Wireless sensor networks; Micro-environmental monitoring; Data processing; Visualization; Internet access

1. Introduction

Recently, Wireless Sensor Networks (WSN) is attracting intensive research efforts due to easy deployment and a large variety of application scenarios. It can be widely applied in habit monitoring, environmental observation, structural detection, physiological tele-monitoring and even drug administration, etc. such as in [17,18,12]. To enable high performance of a WSN, there exist a number of challenges in research as well as in practice. Sensor is normally powered by a battery and has very limited power. Hence, one of the most important issues is about the hardware and protocol design on how to save the limited energy in a sensor node and sensor network as well. This will consequently prolong the network's lifetime. The other problems include enhancing the network's stability and robustness and enabling self-organization and self-healing capability. These requirements necessitate efficient routing protocol as well as the network sensor node hardware design.

Besides the issues above, sensory data processing becomes substantially increasing in a large-scale sensor networks. For instance, in a large-scale sensor network for environmental monitoring, long monitoring time or high frequency of data acquisition is required. In such a situation, the sensor networks will be flooded with very large amount of measured data [15,21]. The situation becomes even worse if the data are multimedia, e.g. monitored video. The data processing function will be intensive and consumes much energy. To alleviate this problem, advanced methods are needed in data transmission and processing. One approach is data compression in the sense that only the measured data within certain bounds will be transmitted to the Base Station (BS) for afterwards processing [25,26]. However, in this way, useful information of the sensor networks may be lost. An alternative is called distributed processing, which allows sensor nodes or distributed low-cost stations to analyze local sensory data and only deliver the results to the BS. In many cases, centric data management

* Corresponding author. Tel.: +86 571 87953762, fax: +86 571 87951879.
E-mail address: jmchen@ieee.org (J. Chen).

0019-0578/$ - see front matter © 2008, ISA. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.isatra.2008.02.001

and processing are required [21]. A third method is to improve the data processing efficiency of the data processing center. Several software platforms, e.g. Matlab [16], are excellent in handling large amount of data with high efficiency.

As indicated, WSN has a variety of applications in practice, especially micro-environment. A micro-environment is the environment of a small area such as an office and an area of crops. Taking the tea garden for example, the growth of tea is highly sensitive to its micro-environment, including illumination, temperature and humidity. Its quality and productivity can be significantly reduced by unexpected cold weather and insect pest. To prevent the tea from external harm, several traditional solutions are usually employed: (1) the first depends on the large-scaled weather forecast or insects forecast, which could not provide accurate information of a small tea garden; (2) the second is based on regular harm checking-up or field data sampling by manual apparatus. This method is accurate though, it cannot be a real-time monitoring system and any unusual event between two checking-ups cannot be detected; (3) newly developed tools based on manual information gathering are capable of data analysis and environmental modeling and predictions making. Nevertheless, lacking of ubiquitous monitoring and low automatization are their inherent limitations.

In the literature, there are many researches carried out by using WSN in micro-environmental, particularly agricultural, monitoring in practice. In 2002, researchers deployed 32 motes on the Great Duck Island to monitor Petrel's nesting behavior [11]. The self-constructed WSN continually measures environmental data including temperature, humidity, barometric pressure and light level in and around Petrel's nesting burrows without disturbing the nesting birds. In [2], a WSN designed for the long-term study of rare and endangered species of plants is presented. The WSN monitors those plants and their environment through temperature, humidity, rainfall, wind and solar radiation sensors. According to [4], researchers have built up a WSN for soil moisture observation which can react with the environment according to the amount of rain falls. The Lofar_Agro project measures the micro-climate in potato crops, and the information gathered about circumstances within each individual field will be used to advise on how to combat phytophtora within a crop [13]. In 2004, a research group of Accenture Lab. deployed a WSN monitoring system for a large vineyard. Sensory data about environmental humidity, wind, water, and soil and air temperature were collected by the BS and then forwarded to a network server, by which multiple clients could query the environmental information [1].

At the same time, there are several specific systems and platforms dealing with WSN's observation and data visualization. Mote–View, developed by Crossbow [7], is an end-user interface that provide tools for real-time charting, data logging and mote configuration. TinyDB [22] is a query-oriented platform for extracting WSN information. It provides a simple, SQL-like interface by which users are able to specify the data queried. However, the low extensibility of these tools limits their applications in scientific researches. SpyGlass [3] is another WSN visualizer, which was developed with Java and the visualization part was implemented by Java2D framework. The jWebDust [5] is a generic and modular application environment based on Java, facilitating a wide range of WSN implementations. Users can query and monitor the execution of the WSN simultaneously as long as they could access the Internet. The TAG approach could provide end-users with efficient query expression and execution, which is derived for general mote-based wireless sensor networks [14]. A practicable structural monitoring WSN called Wisden is developed in [24] which emphasizes on reliable data transportation and time-stamping techniques.

In this paper, we propose a generally applicable real-time system based on WSN. In terms of "real-time", we mean that the events taking place in a remote environment can be promptly observed, monitored, visualized and recorded to their authentic time. The main technical challenges and features are as follows: (1) the sensor network shall be generally applicable in micro-environmental monitoring with open interface for data acquisition and processing; (2) the WSN can be monitored and controlled remotely via Web-interface. In particular, our system is primarily designed to be a practical applicable and automatized running system that can be applied to general micro-environmental monitoring such as tea garden micro-climate monitoring. It was also designed as an experimental platform to facilitate the data acquisition and fundamental visualization procedures. A user-friendly interface is embedded into the system to facilitate easy programming and data analysis. In addition, it can handle a large amount of data by integrating software platform, e.g. Matlab. To date, among the data processing platforms, Matlab has been mostly used in WSN researches due to its high ability in mathematical calculation and results visualization. However, the existing applications that use Matlab in WSN are mainly in the area of data analysis, calculation, algorithm evaluation [6] and simulation. For example, the Prowler project, running under Matlab, provides a generic and network's multi-layer simulation environment based on Berkeley MICA mote [19]. These applications are always post-processing simulation systems that usually perform off-line. Based on our design, Matlab could perform on-line and real-time.

Besides, our paper emphasizes the realistic system design, analysis, implementation and test of a practical wireless sensor networks from the deployed environment-side components to the user-side interface development. The practice-oriented methodology in the paper is able to provide good reference and guideline for practical sensor networks design. In addition, we also have the following specific technical contributions: (1) a practically feasible system architecture which also enables Internet access to WSN data is proposed; (2) a significant realistic issue on data acquisition, data validation and useful information extraction, data visualization in consideration of event time authenticity, and web-based monitoring are discussed; (3) illustrative numerical results are presented to indicate the system feasibility and efficiency; (4) suggestions to apply this system to large-scaled WSNs are provided based on field experiments.