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WNCSbed: A WSAN Based Testbed for Networked Control Systems

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ABSTRACT

In this study, a new testbed which has a WSAN structure and is utilized for monitoring and controlling of industrial systems is designed and implemented. In order to investigate the performance of the testbed developed, a first order plus dead time process control system is tested using both of on-off with hysteresis and PID algorithms, respectively. In the light of the discussion given through the study, it can easily be deduced that, experiments related to monitoring and controlling of industrial systems can be realized by the testbed, easily, and lots of time can be saved from creating an experimental environment.

1. Introduction

In the last decade, rapid progress in embedded data processing and wireless communications has given rise to use these technologies in control engineering. In a traditional Wireless Sensor Network (WSN) system, sensing nodes (SNs) get the data measured from the vicinity and transmit it to a central processing node through wireless medium. SNs in the network are small in size and have local processing and wireless transmission abilities. Nowadays, WSNs are deployed in plenty of areas since they are flexible, have low cost and self organizing capability. They are commonly deployed in industrial, medical, military, and environmental areas for especially monitoring and tracking purposes [1]. As well as their prominent deployment options, nowadays, they can also be employed in the field of networked control systems in order for industrial systems to be controlled over wireless medium. This new approach is referred as Wireless Sensor and Actuator Network (WSAN).

There are a few standardization bodies commonly used in WSN communications. Some of them are given below in brief.

1.1. ZigBee

ZigBee is based on an IEEE 802.15 standard and is a specification for a suite of high level communication protocols used to create wireless personal area networks. Low powered devices using ZigBee protocol stack are capable of creating mesh network that allows long distance communications with low power. ZigBee can operate in 868 MHz (Europe), 915 MHz (USA and Australia) and 2.4 GHz (worldwide) ISM bands. Data rates may vary from 20 Kbps in the lower ISM bands mentioned above to 900 Kbps in the 2.4 GHz frequency band [2]. In this study, WSAN part of the testbed introduced employs ZigBee protocol suit.

1.2. WirelessHART

It is another wireless sensor networking technology based on the Highway Addressable Remote Transducer Protocol (HART). WirelessHART utilizes mesh architecture, operates in the 2.4 GHz ISM band using IEEE 802.15.4 standard radios and was defined for the requirements of process field device networks [3].

1.3. ZigBee IP

It aims at providing seamless Internet connections in order to monitor and control low-power, low-cost devices. ZigBee IP was emerged to support the forthcoming ZigBee Smart Energy version 2 standard [4].

1.4. 6LoWPAN

IPv6 over Low power Wireless Personal Area Networks is the name of a working group in the Internet area of the IETF and suggests that low-power devices with limited processing capabilities should be able to connect to the Internet. Encapsulation and header compression mechanisms defined through this standard allow IPv6 packets to be sent to and received from over IEEE 802.15.4 based networks [5].

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The goal of this study is to design and implement a WSAN based testbed, called WNCSbed (testbed for Wireless Networked Control Systems), in order for industrial systems to be controlled over wireless medium. The study also includes experiments related to control of a first order plus dead time system (process control trainer) using both of on–off with hysteresis and PID methods, so that the performance of the testbed can be validated. In the case studies, the proposed system, initially, gets the reference value, i.e. desired temperature value, from the user as an input by a user interface running on the PC. This value is then forwarded to the MDA 320 data acquisition board (DAQ) by means of XServe software and MIB520 access point, respectively, over the wireless medium using ZigBee protocol stack. After it gets the reference temperature, MDA 320 delivers this information to the microcontroller using I^2C interface. Reference temperature and the temperature measured from the process control trainer are then incorporated into the control algorithms, i.e. on–off with hysteresis and PID, running on the microcontroller in order to generate an output controlling signal that puts the system into desired state. The contributions of this study can be summarized as follows:

- A new testbed, i.e. WNCSbed, has been designed and implemented using WSANs in order to monitor and control industrial systems through wireless medium.
- WNCSbed can be employed in any application related to the monitoring and controlling of industrial systems, provided that the user interface and control algorithm are modified according to the application requirements.
- Experiments on monitoring and controlling of industrial systems can easily be realized by means of the testbed developed, which implies that lots of time can be saved from creating an experimental environment.
- In order to manage system control functions, MD320 DAQ has been integrated with a microcontroller through I^2C interface.

The remainder of the paper is organized as follows. In the next section, a brief literature search is given related to the study. Section 3 presents general information about the WSANs. Overall properties and the components of the testbed developed are presented in Section 4. Design stages of the testbed together with related algorithms are described comprehensively in Section 5. Section 5 also includes example WSAN experiments each using individual control algorithms. The paper is concluded with the last section providing summary about the study with final remarks.

2. Related works

Although the WSAN concept is relatively new, plenty of related studies can be found in the literature. Some of them are summarized in this section. In [1], authors present WSN concept and the factors that affect WSN design. It is a survey study on WSN. Authors of [6] design a smart sensing system in order to monitor scientific data from the active volcano, Mt. St. Helens. In the study, MDA320 DAQ is employed for only monitoring purpose, however, we used it for both monitoring and controlling of industrial systems in our study. A testbed that allows for realizing experiments in heterogeneous WSN is designed in [7]. By the testbed developed, users are able to customize their applications for specific SNs and experiments locally with remote hardware resource. Article [8] presents a model based predictive control over WSAN. The validation of the approach is also realized using a testbed in the study. In article [9], an autonomous light control system based on the feedback from light sensors carried by users is proposed. The control system developed concentrates on providing users' preferences and energy efficiency. Whole and local lighting devices are considered in the study. The design is tested by using simulations and experiments. The proposed system in [10] monitors water quality in restricted marine environments. Contrast to our study, MDA320 DAQ is employed for only monitoring purposes. The authors in [11] design and implement a WSAN system for robotics in indoor environments. They investigate the localization accuracy and the navigation accuracy metrics experimentally in the study. In article [12], an interface system is developed for WSN monitoring and controlling purposes. The authors of article [13] develop and deploy WSN for Precision Agriculture and examine the impacts of WSN technology in agricultural environment. In contrast to our study, MDA320 DAQ is deployed here just to provide monitoring functions. A new simulation model of WirelessHART written in OMNET++ is developed and comparative performance evaluation is presented in [14]. In [15], behavior of the fire in a specific area and the reaction time of WSAN to the fire are simulated using Ptolemy environment. Article [16] introduces a testbed for designing and experimenting with WSAN based Ambient Intelligence applications, whose goal is energy saving. In [17], authors investigate the design of WSAN systems for control applications with desired QoS guarantee. They present a generic application level design methodology that is independent of computation and communication platforms.

Article [18] introduces the current status of a WSAN testbed SANDbed which is still in development state (to the best knowledge of us, there is no publication related to the completed version of this study). When the study is completed, following goals are intended to be achieved: i) Side effect free monitoring, which implies obtaining sensed data as precise as possible. ii) Easy deployment and management of WSAN experiments through a web based user interface. iii) In order to optimize energy efficiency and accordingly prolong the network lifetime, providing distributed energy measurement. Our study differs from [18] in terms of following aspects: i) WNCSbed, is a completed testbed with all hardware and software components. ii) Other contributions of our study are summarized in the paragraph just before the last paragraph of the Introduction section.

3. Wireless Sensor and Actuator Network architecture

Although the WSNs have been widely used for especially monitoring and tracking purposes, together with the last technological developments, they are recently deployed in industrial control applications as well. This new trend, as stated before, is named as WSAN. A WSAN system has the capabilities of monitoring, data processing, and decision making. These network infrastructures are deployed in such applications as battlefield monitoring, determination of chemical and biological attacks, home and industrial automation, environmental monitoring and tracking, and etc.

For example; in case of a fire, when it is in initial stages, sensors may determine the fire place and a controller may get the valves opened to extinguish it. Similarly, as in our case studies, temperature of the process control trainer is sensed and compared to the desired value so that a controlling signal can be generated. In WSAN, sensing and actuating actions are handled by SNs and actuator nodes (ANs), respectively.

As can be seen from the Fig. 1a, commonly, a wireless SN is composed of four major components, i.e.; a sensing unit, a processing unit, a power unit and a wireless transceiver unit [19]. The sensing unit is in charge of converting measured physical quantities like humidity, pressure, temperature, and etc. into a voltage signal and of transforming this signal to the digital form for further operations. The processing unit manages all of the functions of SN including communication protocols in order to carry out specific tasks. SN is attached to the network by transceiver unit. Finally, required energy is supplied to all of the units by the power unit. Additional components such as power generator, location finding system and mobilizer can also be incorporated into an SN according to requirements of application implemented.