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A wireless data acquisition and processing system

Abstract

The paper describes an idea and realization of a system for collecting and processing data from different types of wireless distributed sensors. The system consists of wireless sensor networks. Each network consists of a server connected to the Internet and theoretically unlimited number of clients. The described server has been built with two types of microcomputers. It provides tools for data collecting and processing. A client, described in Section 5, can be implemented on any PC *(Personal Computer)* with Windows or Linux including the Raspberry PI and any other microcomputer with HDMI joint. It allows providing an interactive signboard. The data coming from a wireless measuring unit is stored in the server. Two versions of the measuring unit (Section 6) were developed. They differ in wireless modules (compared in Section 2). The first solution uses XBee-PRO 868. The second one uses CC-2530 working in ISM 2.4GHz band. The coverage comparison of both solutions is presented in Section 7. The system can be adjusted to measure any environmental value starting with temperature, humidity and ending with more advanced like the chemical composition of air. There is also included comparison with existing commercial solutions.

Keywords: metrology, wireless sensor network, microcomputers, radio transmission.

1. Introduction

Continuous development of technology allows measurement systems to expand their functionality and area of operation. There is an opportunity to replace previously used man-operated analog sensors with modern, energy saving electronic sensors. This is a way to automate a measurement of environmental parameters e.g. within laboratory rooms in a given institution. An appropriate network is necessary to handle sensors. But modern technology allows engineers to avoid making a complicated wired network to transmit data. Instead of the wired network, radio modules may be used to build a wireless network. In the presented solution, two kinds of radio modules were used: the XBee-PRO working in the ISM *(Industrial, Scientific, Medical)* band 868 MHz and the CC-2530 working in 2.4 GHz ISM band.

The described system can be used e.g. to monitor environmental parameters in laboratories of a given institution, where special requirements must be satisfied to carry out work. Replacing analog sensors like a thermometer or a hygrometer with electronic devices allows simultaneous measuring the whole monitored area. Due to using a microcomputer, acquisition and data processing is possible at any time. The Internet connection allows remote measuring and reading the measured data from anywhere. Therefore there is no restriction of the number of remote monitoring locations by using the proper application. This program allows reading and visualizing measurements from chosen locations where the presented system has been installed.

2. Radio modules

Radio modules allow transmitting data without any wires. This is the reason why measurement units can be placed anywhere. Building the wired network could be too expensive and problematic. The XBee-PRO® 868 and the CC-2530 radio modules were used in the presented work.

The first model, the XBee-PRO® 868, works in the ISM 868 radio band [2]. This interface is used to send small portions of information. It is also possible to connect together large number of modules, making various network topologies, e.g. star, grid or tree topology. The transmitted power can be adjusted within the range from 1 mW (0 dBm) to 315 mW (25 dBm). The bit-rate is limited to 24 kbps [3]. The AES (*Advanced Encryption Standard*) data encryption is used, with the key size of 128 bit. Communication with this radio module is possible through the UART (*Universal Asynchronous Receiver and Transmitter*). According to the manufacturer possible indoor range is 500 m and 40 km outdoor by using directional antennas with a high gain in the line of sight [3].

The CC-2530 is a radio module produced by Texas Instruments. In fact, this is a microcontroller with a built-in radio module. This microcontroller contains 256 KB flash and 8 KB of RAM. The ISM 2.4 GHz radio band is used to wireless transmission due to IEEE 802.15.4 standard. The possible bit-rate is less than 250 kbps [4]. Measurement units can be minimized due to the existence of this integrated radio module with a microcontroller. The CC-2530 can be also connected in various network topologies. Searching other station is possible in this module range. It gives a possibility to dynamically set a new path to the server when one node does not operate. Also transmitting data through other nodes is possible.

3. Microcomputers

The proposed solution uses microcomputers Raspberry Pi and BeagleBone Black as a server and clients. Despite the fact that they have less computing power than full sized PC computers, they are able to work with the presented system. Their low price can also be beneficial.

The Raspberry Pi is produced by the Raspberry Pi Foundation. It is available in two versions: A and B. In comparison to model A, model B contains an Ethernet port, more USB *(Universal Serial Bus*) ports and more RAM. In the described project, the model B was used.

Tab. 1. Specification of the Raspberry Pi mod. B [5]

CPU	700 MHz ARM1176JZF-S core (ARM11 family)
RAM	512 MB (shared with GPU)
Network	10/100M Ethernet (RJ45)
USB	2× USB 2.0
Additional ports	8 × GPIO

Currently it is possible to buy a newer version of this microcomputer released as the Raspberry Pi 2 model B. Comparing to the older version, this model contains two times more RAM storage, the processor quad-core ARM Cortex-A7 900 MHz and 40 GPIO ports.

The BeagleBone Black is produced by Texas Instruments. Its specifications are presented in Table 2.

Tab. 2. Specification of the BeagleBone Black [6]

CPU	1GHz AM3359 Sitara ARM Cortex-A8
RAM	512 MB
Network	On-chip 10/100 Ethernet
USB	1-port USB 2.0 Host 1-port USB 2.0 Client
Additional ports	2x 46 pin headers

The BeagleBone is a low-cost, community supported development platform for developers and hobbyists. It is equipped with 4 GB 8-bit eMMC on-board flash storage and also a microSD card reader. This platform is compatible mainly with Debian, Android and Ubuntu [7].

Both microcomputers use a memory card as a data storage. There is a noticeable difference in the speed of operating system related to the class of memory card. This concerns both models. In the Raspberry Pi, the Ethernet card is supported by a USB controller. The BeagleBone Black CPU (*Central Processing Unit*) communicates directly with the Ethernet controller which delivers a higher bit-rate. There is another important difference between the presented microcomputers - the Raspberry Pi has the VideoCore IV. It is a hardware decoder which is not available in the BeagleBone. It is the reason why FullHD video is smoothly played on the RPi, while on the BeagleBone there is noticeable strong jamming.

In the presented system both microcomputers work without any troubles. The biggest data packet is sent when a new client has been connected. The difference in the bit-rate of the Ethernet card is negligible. But when a slower memory card is used, the response time of the system strongly falls down.

4. System construction

The presented system consists of a number of distributed sensor networks. Every network contains several wireless measuring units and a microcomputer as an independent server. Figure 1 shows the scheme of the whole system.

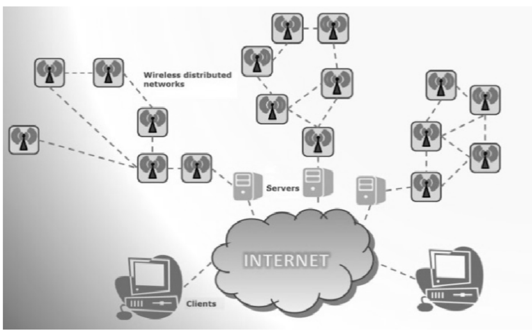

Fig. 1. Block diagram of the system

The presented system integrates independent sensor networks. Each of them is installed in a different location. The networks are composed of wireless measuring modules which need only power supply to work properly. Due to the adapted technology, various network topologies can be made statically and dynamically. In a static network, if one intermediate node does not work, any further node loses connection with the server. In a dynamic case, if an intermediate node is down, other nodes search the modules in their range and connect to them. The end point of each network is a microcomputer connected to a radio module. The dedicated server application is running on the microcomputer. This application receives data from the radio module through the UART interface. The received data are stored in the local data base. There is also a possibility of using the external data base located on more efficient servers. Another task realized by the server is data reading from the data base. It takes place when a new client connects. Then the data from the last 24 hours are read. Moreover, the server sends the received measurement data to the connected clients. It gives an opportunity of the real time monitoring of parameters from chosen locations.

5. Client application

The client application connects to the server using the TCP/IP protocol. This application is used for graphical presentation of the received measurements. A user can choose any sensor and gain the data. The measurements from the last 24 hours are presented as clear charts and in numerical format. The user can adjust the safety threshold for chosen sensors. Then the application monitors the chosen sensor. If a given value is exceeded, the specified action will be performed. For instance it may change the font color from white to red. Sending an e-mail to a specified receiver is also possible. Information of the exceeded parameter and a source of it can be included in a message.

The presented client application is a multi-platform. It can be started on various operating systems. The application is compatible with Windows and Linux operating system family.

The example of the client application is shown in Figure 2. It presents a version of a single distributed sensor network that measures temperature, humidity and atmospheric pressure.

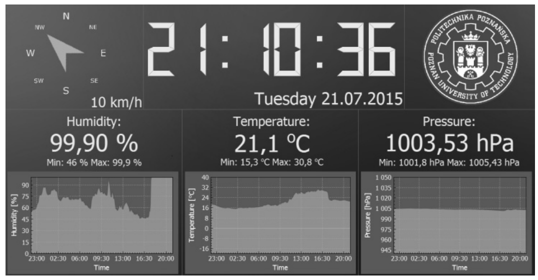

Fig. 2. Screen of the client application

6. Wireless measurement unit

The main idea of the project was to design a universal measuring system with the possibility of connecting any sensor. The devices working in a specified network measure the same or completely different parameters. A unit that measures temperature, humidity and air pressure was designed as a prototype. Two different types of measuring devices were created. The first one was based on the AVR architecture with the XBee-PRO 868 radio module. The second one was based on the microcontroller CC-2530 produced by the Texas Instruments. The CC-2530 is a microcontroller with integrated radio module.

The version with the CC-2530 is a smaller device due to using one small chip instead of two. Both versions support analog and digital sensors.

7. Coverage comparison

Tests of the signal range were conducted inside a modern reinforced concrete building. Also the spectrum of both radio modules was analyzed. The spectrum analyzer Anritsu MS2711 was used to make spectrum analyses.

The first measuring set consisted of two devices equipped with the XBee-PRO 868 radio module and ¼ wavelength whip antenna. Data were sent from the mobile device to the server. The transmission range inside the building with transmit power equal to 0dBm was measured. All packets were received successfully at the distance below 30 m. At the greater distance a significant amount of packets was lost.

The transmitted signal from the XBee-PRO 868 was measured using the spectrum analyzer. The function "HOLD MAX" was used. This function remembers the higher power level at the given frequency. Figure 3 presents the analyzed spectrum.

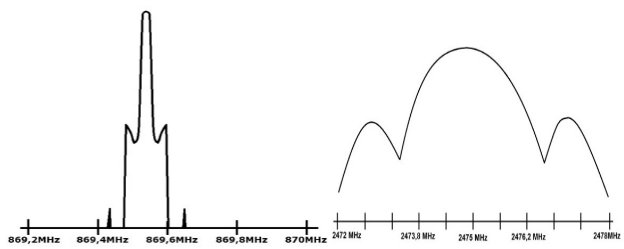

Fig. 3. Spectrum of the XBee-PRO 868 and CC2530 signal

The center frequency is 869.5 MHz. The maximum recorded power is equal to -46.9 dBm. It can be noted that the Xbee transmits power only in the transmission time. The occupied band width is approximately 100 kHz.

The second measuring set consisted of two devices equipped with the CC-2530 module working at 2.4 GHz band. A dipole antenna of 10 cm length and 2 dBi gain was plugged to the devices. The transmitted power was equal to 4.5d Bm. The distance of transmission without packet loss was approximately 32 m.

The CC-2530 module works in the ISM 2.4GHz band. The spectrum of this module was analyzed. The result is shown in Figure 3. The center frequency is exactly 2475.2 MHz. The width of the occupied band is 6 MHz. the maximum power level is equal to −12.9 dBm.

8. Comparison to existing solutions

Among available commercial solutions two recorders LB-731A [8] and THB-R [9] were compared. Both are designed to record some environmental parameters. Data coming from independent sensors is transmitted by wires using the RS-485 protocol [8, 9]. In the presented solution data is transmitted by internal protocols with wireless modules.

The number of connected sensors was compared. Both, LB-731A and THB-R, record data from no more than 16 sensors. The presented system is not restricted by this condition. The number of sensors is determined by throughput of the used radio modules. If a single sensor generates less amount of data, more sensors can be connected.

Some features are similar in each mentioned system. It is possible to read data from the desired time interval. Current parameters are shown using a special information device. Also a computer program can be used to get current values.

9. Conclusions

The proposed system integrates wireless distributed sensor networks and the Internet into a coherent data acquisition and processing system. It is possible to monitor many different parameters, e.g. environmental parameters, in different locations using only one computer program.

The number of parameters such as temperature, humidity, air pressure etc. can be monitored. It is also possible to expand the measurement unit adding sensors of wind velocity and direction, rain sensor, radiation counter and any available chemical composition of air sensor. The wireless modules allow transmitting data without any cables. Two different kinds of radio modules were used: the XBee-PRO 868 and the CC-2530.

The XBee is a high power radio module, so it can be used for further transmissions. The CC-2530 is a lower power consumption module. Various computer platforms can also be used. Due to the size and the energy requirements, microcomputers were used. The server application works on any Linux distribution, so also the Raspberry Pi with Raspbian and the BeagleBone Black with Debian can be used. The client application is a multi-platform. The same source code may be compiled in Windows and any Linux operating system. There are some differences between the used microcomputers but it does not influence the system operation. The client program can be used for advanced monitoring or as a simple information board. It is possible due to the existence of the HDMI *(High Definition Multimedia Interface)* display port in both microcomputer types.

The presented work has been funded by the Polish Ministry of Science and Higher Education within the status activity task 08/83/DSPB/4712 in 2015.

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Received: 17.04.2015 Paper reviewed Accepted: 02.06.2015

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