Embedded Systems in Distributed Measuring Network

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Abstract

In the paper there are analyzed two important problems concerning monitoring systems: intelligent sensors and effective transmission. First part of the paper includes, for example, the description of new solutions for specialised pressure and temperature sensors. These sensors utilize the features of monolithic silicon. The measuring parameters of these sensors (i.e. measure range, sensitivity and repetitiveness) are very high. In the second part of the paper there are developed several kinds of sensors’ network. The main interest is focused on the wireless network. The protocols implemented in these networks utilize usually only three layers defined within the OSI standard. There is developed the transmission standard (ZigBee) for sensors’ network.

1. Introduction

Monitoring systems are usually used for evaluation of environmental quality. There are three main problems that ought to be solved in monitoring systems, concerning sensors, transmission and visualisation tools. First problem focuses on functionality and quality of sensors applicable for environment’s quality monitoring. Effective solution of this problem can be found using embedded systems within the sensors. Nowadays intelligent sensors have brought new approach to the computer engineering. Moreover, the embedded systems mean new direction in computer technology and are developed intensively. Wide applications of embedded systems are connected with increasing market of microcontrollers from one side and its decreasing price from the other. In many cases there are new physical phenomena applied in construction of the sensors. These phenomena have usually been known earlier but their implementation in sensors’ construction has been impossible without computer tools, thus they are named “smart” sensors or intelligent sensors.

Very important second problem is connected with data transmission from measuring points to central computer. The choice of proper transmission medium must take into account special restrictions and individual possibilities of the environment. Traditional wire transmission is usually impossible, for many reasons. Nowadays, there are given new possibilities with wireless communication. Necessity of communication with different types of networks focused to prepare the new communication standard dedicated for these types of networks. Taking into account security and quality of data transmission, there are specialised microcomputer systems applied for communication tasks. The embedded systems realise the operation and transmission functions. The main operation functions realised by embedded system are the following: linearisation of non-linear characteristics, signal standardisation, measurement verification and sensor testing. The transmission functions are connected with service of communication protocols. Many of these solutions are supported by the embedded systems with specialised communication software utilising the new international standard dedicated for wireless sensor network. In many solutions there is used the specialized standard for environmental quality monitoring. Large measuring network is organized in special configuration utilizing the measuring nodes knowing as MASTER or SLAVE node. Very important in these types of network is minimum energy utilization, thus the measuring node is usually activated for the very short time necessary just for the measure work. Rest of time is the “sleep” state.

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2. Monitoring systems

It is necessary to express the importance of monitoring systems in environmental protection (Urbaniak, 2001). Work within the field of environmental protection ought to be directed using the effects of monitoring systems. The methodology of monitoring system design considers:

- monitoring of magnitudes (important respect to chosen point of view),
- technical aspects of effective measurement of chosen magnitudes,
- communication medium and respective protocols.

All important magnitudes’ monitoring is impossible. Thus, there are shown few most important ones based on which the overall evaluation of environmental quality is realized. This step of monitoring system design is developed in cooperation with technologists and computer scientists.

Technical aspects of measuring involve the sensor’s construction (physical sensor and microelectronic systems for signal conditioning) and functional software implementation. For these functions the embedded systems’ approach is usually utilized.

Data acquisition, collected from the sensor’s network, is possible thanks to simple and secure transmission between sensors and central monitoring station. Usually, the best solution is to use some kind of wireless network. Another important aspect of sensor’s construction is to ensure the minimum energy consumption for very long time.

3. Smart sensors

3.1. Pressure sensors

Nowadays, it is easy to find some solutions of sensors utilizing nanotechnologies. As an example, here are presented chosen sensors of physical magnitudes pressure and temperature.

Pressure sensors have numerous applications: measurement of pressure in pipelines, altimeters, atmospheric pressure also many medical applications. These sensors are very often used in special solutions for level and flow measures. New pressure sensors’ solutions utilize the features of monolithic silicon crystal. Respectively, they are named: semiconductor sensor, monolithic sensor or simply – the silicon one. Inside constructions of semiconductor sensors for measurement of absolute pressure and differential pressure are given on Figure 1 and 2, respectively (Baibich, 1988).

![Figure 1: Semiconductor sensor for measurement of absolute pressure (Baibich, 1988)](image-url)
In case of differential sensor, the pressure moves both sides of membrane thus its diffraction is the function of pressures’ difference. In case of absolute measure the bottom cell is closed. Semiconductor sensor takes up the low surface (ca 2mm*2mm). The main part of the sensor is membrane which is obtained in the chemical process of deep silicon etching. The measure range is determined by membrane thickness (usually from 5 to 200μm). The working range of these sensors is between hundred’s Pa to MPa. On the upper surface of the membrane there are four piezoelectric sensors which create the Wheatstons’ bridge. The placement of piezo-resistors allows effective increase sensor’s sensitivity. Silicon sensors characterize high level of measurement repetitiveness together with their low cost because of numerous production series and high level of their automatization, too. Unfortunately, these sensors need the temperature compensation.

![Diagram of Semiconductor Sensor](image)

Figure 2: Semiconductor sensor for measurement of differential pressure (Baibich, 1988)

Electrical output signals from the sensors are not sufficient for control systems. Usually, there must be applied the additional circuit for converting output signal to standard control signal. These two inconveniences: temperature compensation and signal conditioning are solved by converter connected with sensors.

### 3.1 Temperature sensors

Traditionally, the temperature measurement was realized using thermo-couple sensors or thermoresistors. Since the last year, the silicon temperature sensors have been used more and more intensively. These sensors are equipped with the A/D converter and linearization circuit (Figure 3) (Binasch/ Grunberg/ Saurenback, 1989; Philips, 2004).

### 4. Sensor network

The effective communication between sensors and concentrators require to satisfy standards concerning output signals from the sensors and also standards for transmission. The traditional standard for analog current (4 – 20 mA) is very often used for transmission and control up to 3000 m. The distributed network of sensors demands new standards for signal transmission. They are implemented as local networks usually called: Fieldbus and they allow to connect intelligent measuring nodes. Because these networks are dedicated to industrial applications thus the Fieldbus must be the Real-Time (RT) networks.
with increased immunity against the noise. Intensively developing standards of local network result in the radical drop in costs of the network’s elements. Thus many solutions utilize the modules (intelligent sensors and integral network controllers) of embedded microcontrollers with dedicated software.

4.1 Local network (Fieldbus)

Local network based on HART®\(^3\) protocol is the natural extension of industrial analog standard 4-20 mA and ensures the digital communication between intelligent network elements. This protocol has many industrial applications especially within the chemical industry (Bowden, 1998; Kriesel/Madelung, 1994).

Another simple network AS-i\(^4\) is configured as a serial bus (AMI 1998). The main goal considered with this standard was to reduce the assembly elements (cabling, assembly boxes and slats). This standard is very effective in the binary sensors and actuators. The AS-i protocol was defined as a European Standard - EN50295.

To the most popular network standard can be ranked the CAN\(^5\). This network were prepared for cars but it is now used in many other applications. The network has the multi-master buses, means that the particular nodes can appeal for bus access in the same time. The CAN standard was authorized as ISO standard for high and low speed transmission, separately. Accessible documentation, security of data transmission, low-cost of transmission elements, integral CAN network controllers – all these features resulted in popularity of applications within this standard.

There are many accepted network standards both for universal and specialized (dedicated) applications (eg. EIB – dedicated for Intelligent Building Systems). An example of the first digital industrial interface was Modbus standard. The expansion of controllers caused the growing number of input/output.

An alternative solution was to use the controllers with low number of input/output but more controllers working in the network. The protocol utilized in this standard involves three layers of OSI computer network model: physical layer, data layer and application layer.

In case of large network the solution is to used INTERNET/INTRANET network.

\(^3\) HART® - Highway Addressable Remote Transducer
\(^4\) AS-i – Actuator Sensor Interface
\(^5\) CAN – Controller Area Network
4.2 Wireless Sensor Networks (WSN)

Development of different networks for data transmission focused in main interest towards the wireless communication. The important step in this research and application was to develop two standards: IEEE 802.15.4 and ZigBee. The ZigBee protocol defines the physical layer (PHY) and the sub-layer called Medium Access Control Layer (MAC) (Kubiak, 2005; ZigBee, 2005; IEEE, 2003). The main features of IEEE 802.15.4 standard are the following:

- high security thanks to answer signification,
- mechanism for integration and confidential transmission,
- transmission with spectrum diffusing,
- connection based on priorities,
- frequency changeability for interference effect removal.

The ZigBee protocol expands the possibilities of IEEE 802.15.4 taking into account the network structure realisation, security of transmission and communication with application layer. This protocol is treated as a standard for many applications, such as sensor network, monitoring systems, diagnostic systems, Automatic Meter Reading and Heating, Ventilation and Air Conditioning systems. The important parameters of ZigBee protocol are the following (Sinem, 2004):

- very low power consumption,
- only two working states: active or sleep,
- low cost of elements and exploitation,
- possibility of high density of network nodes,
- simple protocol and implementation,
- secure of data transfer,
- un falling transmission.

For optimization of node costs there are two solutions defined for the IEEE standard:

- full-function device – FFD
- reduced function device – RFD.

In the RFD network topology is limited to star topology, possibility connection only with network coordinator, very simple realisation.

In the PHY layer three frequency bands are assumed with 27 canals numbered from 0 to 26. In Europe there are two bands opened – 868 MHz (with 1 canal) and 2.4 GHz (with 16 canals) (Figure 4).

For industrial application the more efficient band is 2.4 MHz because of more canals, higher transmission speed and more effective modulation. In this solution the phase modulation (DSSS – Direct Sequence Spread Spectrum) was applied (Roshan/Leary, 2004). The modulation process for 2.4 MHz band is described in (IEEE, 2003). For many-bytes data fields, first youngest byte is transmitted. Each byte is divided in four-bit symbols. The youngest symbol is transmitted as a first one. In the next step each component has 32-elements representation. More precisely, instead of one sequence of components there are two sequences moved at $\pi/2$ to each other. The components of even number are called in-phase components and of odd number quadrature ones.
Wireless Personal Area Networks can be applied in two basic topology: star and peer to peer one. In the network data’s source and goal have direct contact (so called one-hop network). The special node – coordinator PAN as a device FFD type – is necessary in this network. For star topology nodes can communicate with coordinator only but for peer to peer one each node can communicate with another node using its radio range. It is possible to communicate with nodes placed in longer distance using multi-hop mechanism. The chosen nodes will be used as transmission nodes in this way. This solution needs the tracing algorithms.

4.3 Nodes

The telemetric network is configured with measuring nodes where each node serves one or more measuring points. The measuring point can be sensor, converter or measuring device. The data exchange is realised respect to the chosen protocol. There will be described an example of node configuration based on Modbus network. The microcontroller utilized in Modbus module is supported by relatively large RAM memory that is necessary because of tables’ organisation for autonomic node’s work (measurement with given cycle). The microcontroller architecture with reprogramming Flash memory and possibility of ISP programming is a very important tool for modules’ easy debugging and servicing. The microcontrollers’ peripherals are the interface circuits that modify signals from internal USART circuits to Modbus standards and to sensors’ interfaces. The galvanic separation was realised in the case of individual supply of measuring device. The module was ensured with temperature sensor and LED’s for diagnostic functions. Microprocessors used in nodes have different configurations based on the nodes’ functions. They are ensured with large memories (RAM, Flash, EEPROM) and can be programmed using ISP and JTAG buses. Additionally, there are CA and DC multi-channel converters and different interfaces embedded. The tendency is observed to low supply voltage (2.7 – 3.6 V) and to follow simple instruction (usually in one clock cycle). The microcontrollers’ producers developed new models of microcontrollers with specialised hardware elements supporting ZigBee implementation and compatible with IEEE 802.15.4 standard.

The special interest in WSN applications is placed on the energy consumption. In new solutions an user can influence peripherals activity. The processors can be in a “sleeping” state or in an active one. In specialised processors exist few states with lower energy consumption. The energy consumption can be decreasing by choice of dedicated working algorithm. A node usually is in the “sleeping” state but it “wa-
5. **Final remarks**

The modern measuring systems applicable in various environments utilize the embedded systems in a large scale. Main feature of these solutions is the high level of integration concerning microprocessors with matter systems. There are the solutions named MEMS – Micro Electro Mechanical System or iMEMS – integrated Micro Electro Mechanical System where the construction is based on the monolithic silicon structures. These solutions are developed both as measuring devices and actuator ones (micro-actuators).

The communication process is very important problem that can be solved by the Wireless Sensors Networks. Fortunately, there exist standards dedicated especially for these networks and giving the high security of data transmission and other very good technical parameters.

**Bibliography**

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