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# APPLICATION OF WIRELESS STANDARDS IN DYNAMIC PARAMETERS MONITORING SYSTEM FOR VEHICLES AND INDUSTRIAL MACHINES

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***Abstract:*** *This paper presents the design of a wireless sensing system based on ZigBee networks and GSM communication standards for measurement and monitoring of dynamic parameters of industrial machines and vehicles. ZigBee standard is particularly suitable for developing a wide network of intelligent sensors. Combined with GSM technology such system can be implemented in various places without depending on power or communication with computer for data transfer and processing. The underlying benefit of combining the two technologies is remote control of multiple systems and their flexible management. In this paper we report a new concept of a multi-point, multi-sensor intelligent system for monitoring and analysis of certain parameters in industrial machines and vehicles. For this particular application data acquisition and measurement modules are designed. Experimental results and functional evaluation of system is reported as well. Various crucial for the industrial machines parameters are measured and analyzed – vibrations, temperature, charging voltage, speed, position tracking etc. The designed wireless sensing system for measurement and monitoring of various dynamic parameters in industrial machines or vehicles is suitable for simultaneous monitoring of desired parameters in particular points and places. The ZigBee standard provides reliable radio communication channel and different network topologies which assure system flexibility and reliable communication link.*

***Key words:*** *wireless standards, intelligent sensors, measurement system, ZigBee network, industrial measurement.*

## 1. INTRODUCTION

In recent years the wireless ZigBee standard is receiving an increasing popularity on the market. It is offering remote control, expandability, security and flexibility. This standard is particularly suitable for developing a network of intelligent sensors [1–3]. Its main advantages can be formulated as follows:

- low energy consumption;
- relatively easy implementation;
- long battery life;
- low cost device installation and maintenance;
- large network capacity;
- unlimited number of devices;
- global deployment.

Wireless sensing and control is especially useful in cases when the monitored objects are situated in remote and hardly accessible places. Examples of such objects are electrical drive systems that make the basics of manufacturing processes, robotics, building automation, etc. Main parameters controlled in such objects in general are: current, voltage, torque, position, temperature, energy consumption and vibrations. The typical signals for transferring can be divided into two groups: analog signals – mainly from current, voltage, temperature and speed sensors [4, 5]; pulse signals – from incremental speed, position and distance sensors [6]. Application of appropriate devices for wireless data transfer allows development of remotely controlled drive systems with good performance.

Various types of networks are studied [7] to choose the most adequate protocol for remote control of an induction motor drive. Comparison of positive and negative aspects and their cost was done. After comparative analysis [8] the ZigBee standard is chosen because it offers a number of solutions appropriate for control and measure device reading. The basic instructions for wireless control of the considered two-coordinate driving system are as follows: motors selection; motion directions determination; setting the movement sequence; setting the displacement distances; operation mode selection; sending task execution feedback. Applications of wireless control for manipulation systems and robots are described in [9 and 10]. The considered way of remote communication is based on ZigBee protocol that allows simple implementation with low power consumption. Examples for effective applications of wireless sensor networks are described in [11–13]. There has been increased interest in the ZigBee standard, in particular for building automation and industrial controls [14]. An industrial real-time measurement and monitoring system

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based on ZigBee standard is presented in [15]. The measurement items include length filtering, ground vibration sensing, weight grading, electricity sensing, energy monitoring, temperature monitoring, and carbon dioxide concentration.

Combined the ZigBee standard with GSM technology wireless sensing systems can be implemented at any place or environment. The underlying benefit of combining the two technologies is remote multi-parameter measurements of various industrial systems or machines. Such wireless communication systems could be implemented for a variety of applications. In industry they can be utilized for measurement of particular dynamic parameters in manufacturing processes and system monitoring where strict requirements are demanded. These remote systems are also suitable for monitoring of some environment parameters such as: air pollution, humidity, pressure, etc. [16].

This paper presents the design of a wireless communication system for sensing and measurement in mechanical industry. The ZigBee network of intelligent measurement modules is combined with a coordinator device for network management and data acquisition which also includes a GSM modem. This configuration expands the low-range ZigBee network and provides an opportunity to develop a widespread network of intelligent sensors. The wireless ZigBee standard provides a high reliability and interference immunity against any narrow-band interferences. The measurement devices could be installed to almost any place due to its compact size. An additional advantage is the flexibility and opportunity for utilizing of these devices in a variety of practical applications.

The paper includes description of the multi-point wireless sensing system, block diagrams and operation algorithms of the designed measurement and data acquisition devices. Implemented data processing techniques are also reported. Experimental and measurement results are introduced including vibration and acceleration analysis of an electrical induction motor, temperature monitoring, vehicle position tracking, speed analysis and battery charging voltage measurement.

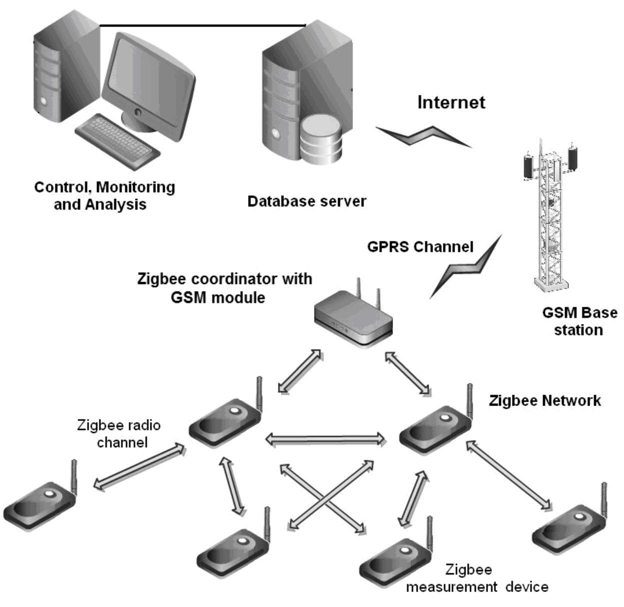


**Fig. 1.** Structure of the wireless measurement system.

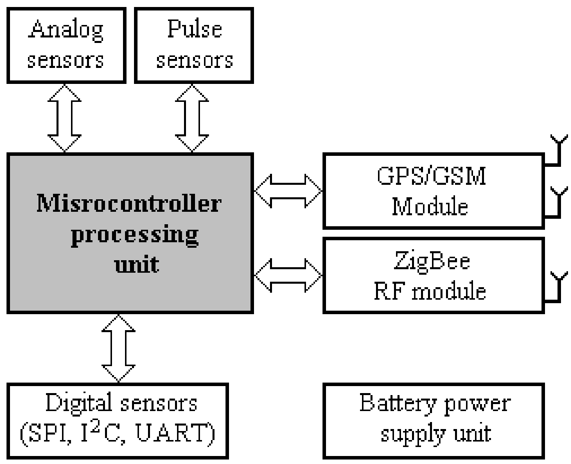


**Fig. 2.** Block diagram of Zigbee coordinator device.

## 2. SYSTEM STRUCTURE AND FUNCTIONALITY

Structure of the wireless sensing system for measurement and monitoring is presented in Fig. 1. It consists of ZigBee network, which is realized by measurement devices with integrated sensors and radio transceivers. This standard supports various network topologies such as star and mesh. It provides security and flexibility of data transmission. The mesh structure is particularly suitable for developing an intelligent network of sensors. In this configuration packets are retransmitted over the network of measurement devices and in case of interferences or losses of any node different path is utilized. It makes this network self-healing and reliable [1, 2].

The crucial part of the system is the coordinator device. It consists of ZigBee transceiver and GSM module. And this device configures and manages the ZigBee network – radio parameters, network settings, addressing and packet retransmission. It also acquires all data from measurement devices, configures a GPRS data channel via the GSM modem and retransmits all acquired measurement data over the GSM network to Database server. The measurement information from all ZigBee networks is stored there and is available for analysis, processing and monitoring of every available parameter.

Therefore by having measurement data from various points and parameters, substantial dynamic characteristics of monitored industrial machine can be determined and analyzed. Certain parts of the monitored system could be investigated for problems, deflections or production flaws.

## 3. COORDINATOR DEVICE DESIGN

A block diagram of Zigbee coordinator device is shown in Fig. 2. It consists of a microcontroller unit, ZigBee module – XBee-Pro by Digi Electronics and GSM/GPS module - GE863-GPS manufactured by Telit. The major task of the microcontroller is to manage the ZigBee network – radio channel configuration, device association and sensing data acquisition. Communication with data-base server is realized with GPRS data channel and it is configured with a specific AT commands. If the monitored industrial machine or system is in motion a

GPS receiver is configured to track the position and speed – for example trains or specialized measurement vehicles.

To measure certain general parameters of the system additional sensors could be connected to the coordinator module such as environment parameters – temperature, humidity, air pressure, or if system is moving - direction, speed, axial speed and etc. All collected data from other Zigbee measurement devices is arranged into a packet which via GSM modem is transmitted to the database server. The communication between the microcontroller and RF modules (Zigbee and GSM/GPS modems) is realized by utilizing serial UART interfaces.

## 4. ZIGBEE MEASUREMENT DEVICE

The primary task assigned to the Zigbee measurement device is after association to an existing Zigbee network to perform measurements of certain parameters with the implemented sensors.

Main difference between Coordinator and Measurement devices is that to the latter a GSM module is not connected and only performs data acquisition from sensors, performs signal processing – noise filtering, compensation and calibration of signals [17]. Because of the low power consumption of Zigbee module and microcontroller unit, the measurement device is powered by a rechargeable battery and with a single charging could perform long-term measurements [18]. A block diagram of Zigbee measurement device is presented on Fig. 3.

Various analog sensors can be implemented in the measurement device – temperature, pressure, humidity, strain, voltage and current. And sensors with pulse-width modulation such as orientation, position, angular speed, could also be utilized in the monitoring scheme. Most agile and informative of all sensing device for industrial machine analysis is 3-axis accelerometer. It gives much information for the forces that influence on the machine during normal operation and it can also provide valuable data for early diagnose of machine failures.

## 5. OPERATION ALGORITHM DESCRIPTION

The developed algorithm of the coordinator device in the wireless sensing system for measurement and monitoring is presented in Fig. 4. It consists of the following operation steps. At start-up the microcontroller performs initial ZigBee module and GSM modem configuration. Then the device configures the GSM modem and connects via GPRS to the Database Server. It is followed by ZigBee network set-up and device association.

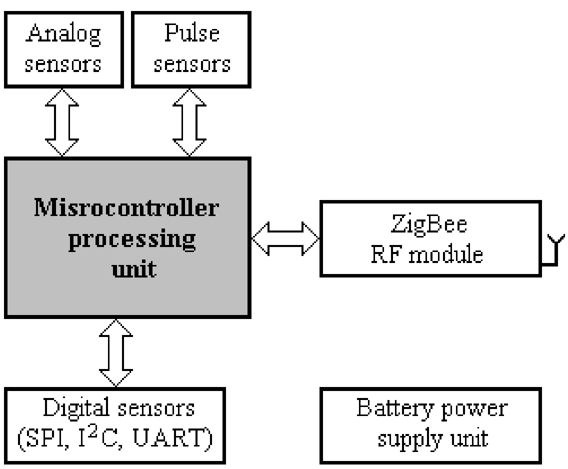


**Fig. 3.** Block diagram of the Zigbee measurement device.

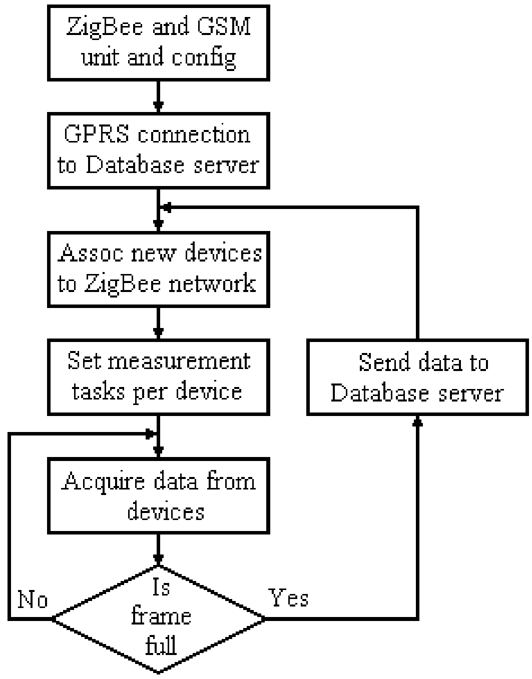


**Fig. 4.** Operation algorithm of the Coordinator device.

When the ZigBee network is formed and measurement tasks are sent to every sensing device the coordinator module starts collecting packets with data. Every packet is checked for errors and is added to a bigger frame of information. When the necessary amount of data is acquired and the frame is full it is transmitted to the Database Server where data is collected [19].

The structure of a packet received from ZigBee network contains one byte of packet identification sequence, two bytes of device address and measured data from the respective sensors. The next two bytes contain the network identification number – PANID. It is followed by the frame data which is the payload of the frame and includes M packets received from the measurement devices over ZigBee network. The frame finishes with a checksum of the transmitted data. It is calculated by the following equation:

$$\text{Checksum} = \text{0xFF} - \text{SUM(FrameData)}\,, \qquad (1)$$

where SUM(Frame data) is performed as all bytes from the data frame are added keeping only the lowest 8bits of the result. Then this sum is subtracted from 0xFF which is resulting in the 8-bit checksum. Data frame is the part of the packet excluding the packet identifier byte and the two bytes of the packet length [3].

## 6. DATA PROCESSING TECHNIQUES AND MEASUREMENT RESULTS

A measurement tests were conducted by investigating various sensing parameters – vibrations (acceleration), battery charging voltage, temperature and etc. Several

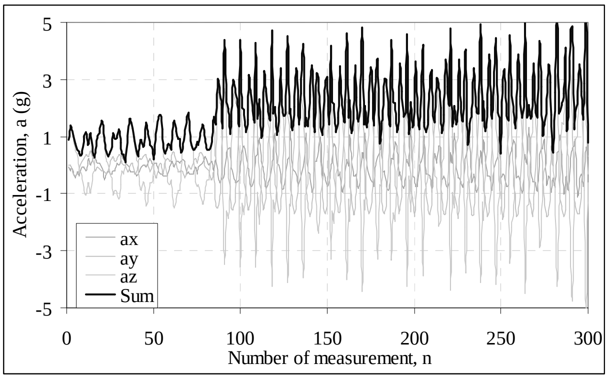


**Fig. 5.** Measured acceleration on all 3-axis and calculated amplitude of acceleration vector.

other parameters were calculated from these values – speed and distance derived from acceleration data, resonance frequency and etc. Along with the conducted measurements a various data processing techniques for filtering and data analysis are introduced [20].

Analysis of vibrations in electrical induction motor is performed by measuring the accelerations on 3-axis. Combined graphic of all 3-axis and the amplitude of resulting acceleration vector is presented in Fig. 5. The amplitude of acceleration vector is calculated with formula (2):

$$a_{\Sigma} = \sqrt{(a_x)^2 + (a_y)^2 + (a_z)^2}\ . \tag{2}$$

Spectral analysis of one of the measured axis ($a_y$ – Fig. 6) is shown in Fig. 7. Its main resonance frequency is $f = 110\,\text{Hz}$, other second and third order resonance frequencies also are observed on the presented graphic. The constant offset component at $f = 0\,\text{Hz}$ is caused by not perfect alignment of the axis to the ground. To calculate the spectral characteristics fast Fourier transformation is performed.

The velocity of measured vibrations from accelerometer senor is calculated using Eq. (3) for uniform linear acceleration and its relation with velocity.

$$v(n) = a(n)\frac{nt}{f_s} + v(n-1)\ . \tag{3}$$

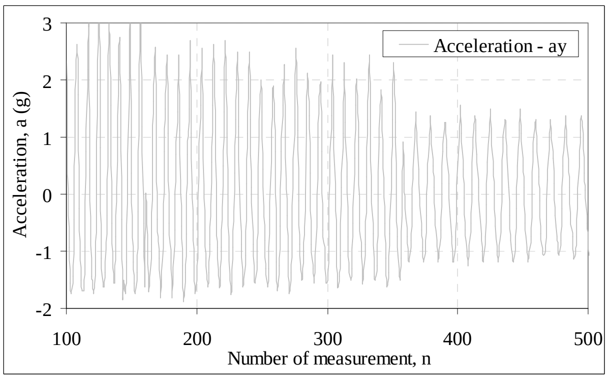


**Fig. 6.** Measured acceleration on *y* axis: $a_y$.

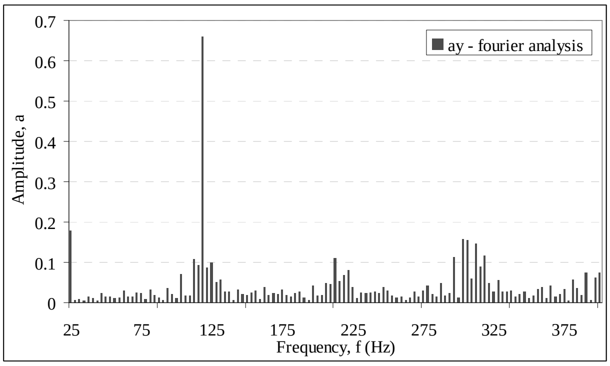


**Fig. 7.** Fourier analysis of $a_y$ axis from accelerometer data.

Thus calculated velocity includes constant drift component due to initial vExamples for effective applications of wireless sensor networks which are described in alue change and accumulates in long-term measurements. Therefore these values present approximate estimation of velocity and its influence on investigated system. In Fig. 8 are presented results from measured accelerations and calculated velocity on y-axis.

Another system test and measurements were conducted by analyzing vehicle in motion behavior. Various parameters were monitored – vibrations, GPS position and course tracking and velocity. With Zigbee measurement devices placed on various crucial positions – suspension, motor, chassis and etc., certain dynamic parameter of vehicle can be monitored and analyzed. Combined analysis of all there parameters give substantial information for early diagnosis of forthcoming failures or problems with the vehicle.

Chassis vibrations while vehicle was in motion over a test track are presented in Fig. 9 and Fig. 10. Both *x* and *y* axes give information for forces during acceleration and stopping but also for side forces and accelerations in turns. In Fig. 10 are presented detected vibrations in the moving vehicle caused by going through an obstacle or a bump on the road. By analysis of the acquired data can be diagnosed any flaws or problems in vehicle's suspension or assessed the driver operation.

Tests with GPS positioning and tracking vehicles movement is presented on Fig. 11. It includes the map and recorded route of the vehicle during a test drive over a previously arranged route. Graphic of calculated speed along the covered distance is presented on Fig. 12.

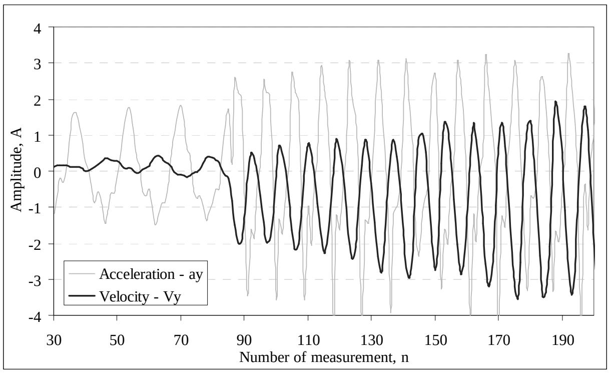


**Fig. 8.** Measured acceleration on *y* axis and calculated velocity.

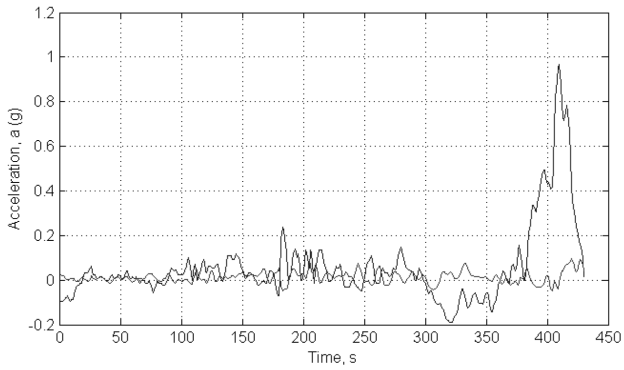


**Fig. 9.** Vibrations measured on *X* and *Y* axes of tested in-motion vehicle over a particular route.

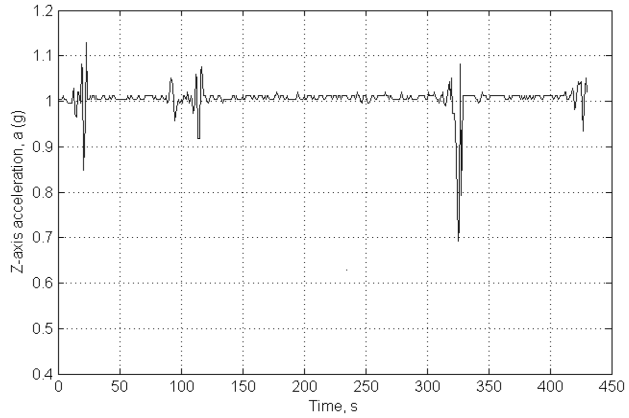


**Fig. 10.** Vibrations measured on *Z* axis of tested in-motion vehicle over a particular route.

Together with measured accelerations and vibration data can be utilized in complex analysis of vehicle in-motion behavior. Graphic of motion direction along the covered distance is presented in azimuth values on Fig. 13. The next equation presents a cross-correlation [21] between the two measured sensor data – $x[n]$ and $y[n]$ and the resulting coefficient $R_{XY}$ corresponds to the level of likelihood between these two signals.

$$R_{XY} = \sum_{\tau=-N}^{N} x[n] * y[n-\tau]. \quad (4)$$

One particular application is analysis of vibrations in industrial machine and if a particular signal is detected in several sensing positions the source can easily be detected and afterwards subtracted from signal analysis in order to focus measurements and analysis on other signal particular spot. If such event occurs there will be a correlation between data from all sensors and local vibrations on separate sensors will not affect the results.

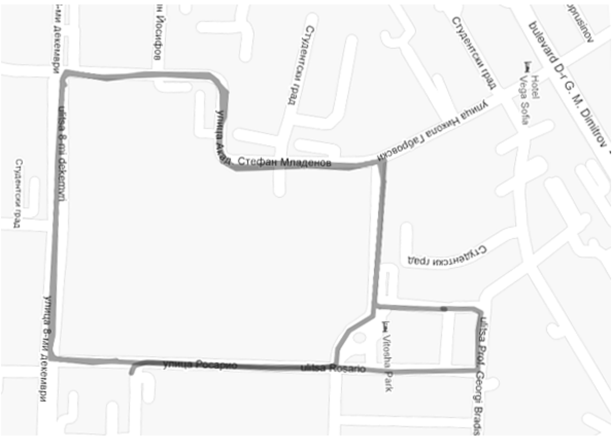

**Fig. 11.** Tacking vehicle movement with GPS positioning.

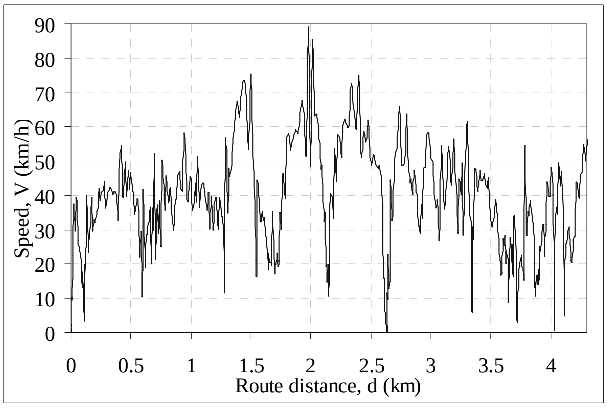


**Fig. 12.** Recorded speed of test vehicle in reference to the covered distance.

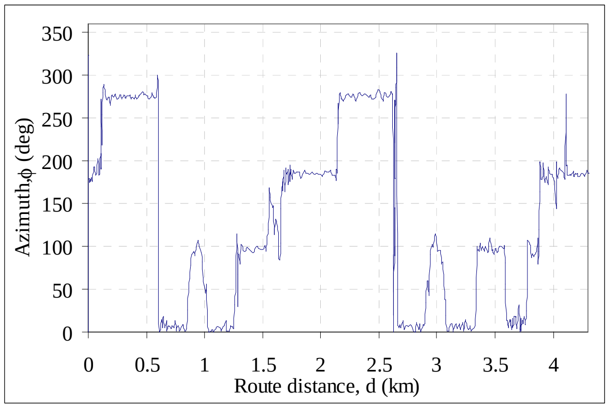


**Fig. 13.** Recorded motion direction in azimuth values of test vehicle in reference to the covered distance.

To demonstrate the ability to measure temperature at certain place of investigated machine Fig. 14 is introduced. It presents temperature variation of a battery charger during operation. In first stage of the graphic sensor is placed on the module and the measured temperature rises to the charger's initial state. When a battery was connected to it, monitored temperature rises quickly to a certain saturated stable values. When sensor is disconnected from monitored unit temperature drops quick-

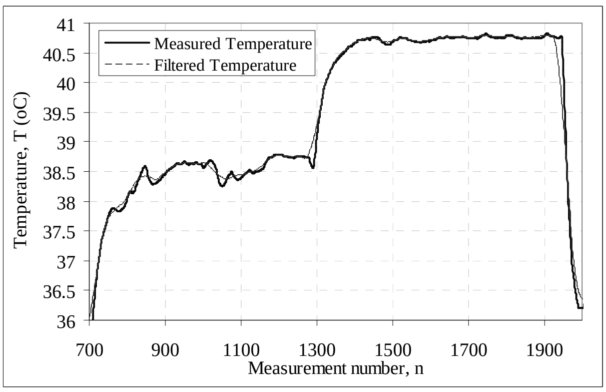


**Fig. 14.** Temperature monitoring of a working induction motor.

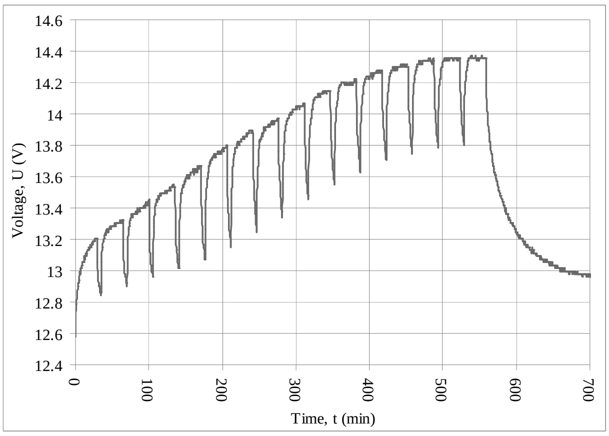


**Fig. 15.** Voltage monitoring of battery charge - discharge cycle.

ly. Measurement accuracy of this particular set-up is $\Delta t$ = 0.1°C. To remove some of the high-frequency noise, a low-pass averaging filter is introduced (2), where mean value of last i-measurements is calculated [21].

$$S(n) = \frac{1}{N}\sum_{i=1}^{N} S[n-i]\,. \qquad (5)$$

Voltage monitoring of full battery charge-discharge cycle is presented on Fig. 15. In this particular measurement voltage is gradually increased as both charging voltage and actual battery level is monitored. The observed minimums on the graphic present interruptions in charging for several minutes in order to measure actual battery voltage level. After battery is fully charged to a certain voltage the quick discharging is introduced and monitored on the presented graphic.

## 7. CONCLUSIONS

This configuration expands the low-range ZigBee network and provides an opportunity to develop a wide-spread network of intelligent sensors. Its structure is very suitable for measurement and analysis of complex dynamic characteristics of industrial machines, sophisticated systems or even environment parameters of particular area.

The designed wireless sensing system for measurement and monitoring of various dynamic parameters in industrial machines or vehicles is flexible and reliable. The ZigBee standard provides reliable radio communication channel, different network topologies. And combined with well developed GSM's network coverage and accessibility ensures secured data transmission to the database server.

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