

# Measuring Vibration Parameters with ZigBee Sensor Network in Aspects of Driver Safety

**Abstract.** The paper presents the model for measuring the vibration parameter of the cushion-rigid human seat and for presenting the resulting data on the remote graphical display. Some programming examples of graphics display controller are presented. To transfer the data the model uses a wireless, RF communication in Tx/Rx duplex mode and ZigBee transceivers. The ZigBee coordinator module is connected to 32-bit Cortex microcontroller for ability to process the results and to present them graphically. ZigBee technology can be used as an alternative one to other vibration research techniques.

**Streszczenie.** W artykule zaprezentowano metodę badań szkodliwych dla człowieka drgań generowanych przez pojazd. Kierowca pojazdu wyposażony został w czujniki, tworzące sieć sensoryczną. Akwizycja danych przeprowadzana jest w oparciu o technologię ZigBee. Urządzenia RFD (Reduced Function Devices) wykorzystują dane otrzymywane z 3-osiowych akcelerometrów, które następnie przetwarzane są przez 32-bitowy mikrokontroler Cortex M3. Uzyskane z RFD dane mogą być prezentowane na graficznym wyświetlaczu (280x128). (Wykorzystanie transmisji ZigBee do analizy drgań generowanych przez pojazd)

**Keywords:** Microcontroller Cortex, ZigBee, 3-axis accelerometer, WBV.

**Słowa kluczowe:** Mikrokontroler Cortex, ZigBee, 3-osiowy akcelerometr, WBV.

## Introduction

The whole body vibrations (WBV) are very important for healthy reasons. This kind of vibrations is described by Griffin in [5]. WBV and segmental vibrations occur when the human body is in contact with vibrating surfaces: a driving seat, a back seat and a floor. Mechanical vibrations can be harmonic, random or transient and are characterized by a vector quantity and thus consist of both intensity or magnitude and directions measured in three different points (feet, seat, and back). Especially dangerous are vibrations which have frequency similar to natural frequency of human body parts and organs, because then we obtain a phenomenon of resonance frequency shown in Table 1.

Tab.1 Resonance frequency of body parts

Part of body	Resonance frequency [Hz]
Head	17-25
Chest	10-50
Heart	4-6
Stomach	2-4
Spine	10-12
Pelvis	5-9

## Side effects of WBV

Local vibration occurs when one or more limbs are in contact with the vibration surface. Local vibration like WBV also can cause vibration through the body. Seated person exposed to the whole body vibration is also often simultaneously exposed to local vibration of the head from the headrest, and of the hands from the steering wheel and the feet from the floor. Vibrations may also enter the body as a result of contact with the backrest of a seat. The whole body vibration is capable of producing a wide variety of different effects. It can generate a range of subjective sensations, which can be quantified in many different ways. Both simple and complex activities can be disturbed by vibrations affecting the various components of a performed task, beginning from the input of the information to the body (vision), and ending on the output of the information from the body (hand control). Physiological parameters may be disturbed by vibrations with either transitory effects or permanent changes.

Vibration also causes a range of physical movements of parts of the body, which may be quantified by objective methods and expressed by mathematical equations or simulated with anthropodynamic dummies. Figure 2 outlines physiological, activity, biodynamic and subjective categories of human responses to the WBV.

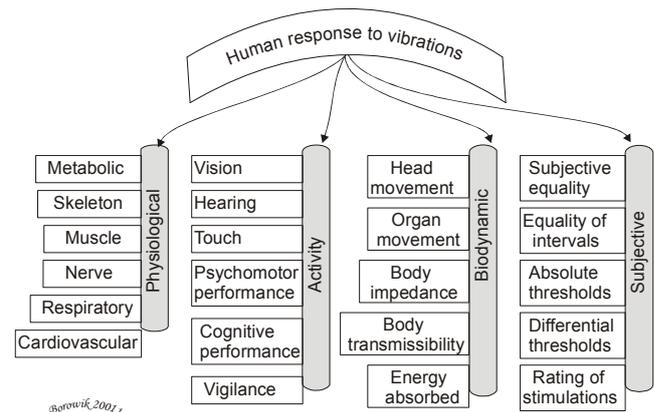


Fig.1. Physiological, activity, biodynamic and subjective categories of human responses to WBV

By analyzing vibration magnitude in time domain we obtain a statistical comparison value. This can be related to human tolerance or comfort, but this evaluation method does not reflect the importance of time exposure. A cumulative measure that considers this - is Vibration Dose Value (VDV) expressed by equation (1).

$$(1) \quad VDV = \left[ \int_{t=0}^{t=T} a_w^4(t) dt \right]^{1/4}$$

where:  $a_w(t)$  = frequency-weighted acceleration time history  
 $T$  = period of time over which vibration occurs.

An objective method to evaluate dynamic seat comfort and to compare one seat to another – consists of calculating so-called Seat Effective Amplitude Transmissibility (in short SEAT):

$$(2) \quad SEAT = \left( \frac{VDV_{Seat}}{VDV_{Floor}} \right) \times 100$$

A SEAT% value equal to 100% indicates that the vehicle seat produces no improvement in vibration comfort. SEAT% value below 100% indicates a vibration comfort improvement. SEAT% value larger than 100% indicates that vehicle seat deteriorates the vibration comfort.

### General description of the proposed model

The block diagram in fig.2 outlines the investigated model. In the ZigBee network we have end device and coordinator (consisting all together of 5 nodes).

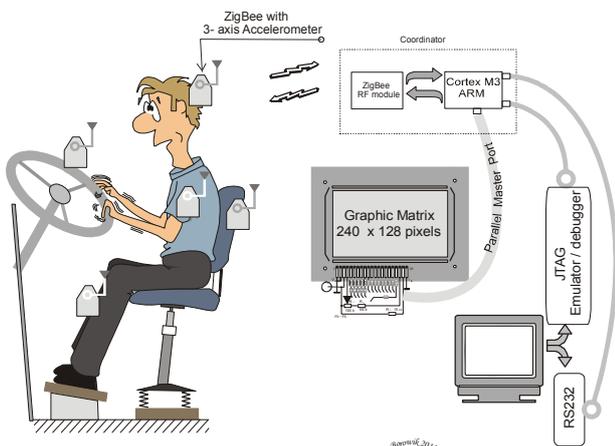


Fig. 2. The model for monitoring vibration of dynamic object

The end device contains analog 3-axis accelerometer together with ZigBee RF module, mounted on the body of the driver and the seat. The used module has its own A/D converter. Voltage values from the sensor are proportional to the acceleration level of the dynamic object. These values are sent through the ZigBee radio to the remote coordinator module.

The coordinator module contains a ZigBee RF transceiver for wireless communication and an intelligent PIC microcontroller responsible for processing received data and for presenting results graphically. The microcontroller through a parallel master port controls the graphical LCD display. The microcontroller is connected to the PC through the RS232 protocol (a COM port on the PC). For the purpose of programming the flash memory of the microcontroller and the JTAG debugger (via USB) are used.

### Data acquisition and data transfer by means of the ZigBee solution

ZigBee with its inherent firmware provides a wireless personal area networking (PAN) of data from a sensor to a PIC microcontroller. The base of the Zigbee hybrid module is Xbee ZNet 2,5 ser. 2.

Zigbee networks are called personal area networks. Each such a network contains a 16-bit identifier called a PAN ID. The PAN ID is selected by the coordinator when the work of a PAN is initiated. Routers and end devices become a part of a PAN and they inherit the coordinator's PAN ID when they join a PAN. All devices in a ZigBee network when they join a PAN, they receive a 16-bit network address. The 16-bit address of the coordinator is always 0.

The 802.15.4 protocol upon which the ZigBee protocol is built specifies two address types:

- 16-bit network addresses
- 64-bit addresses

A 16-bit network address is assigned to a node when the node joins the network. Each node in the network contains a unique 64-bit address. Every 64-bit node's address in a network uniquely identifies the given node and is permanent. ZigBee transmissions are always addressed to a 16-bit address of the destination device.

The Xbee ZNet 2.5 modules can be identified by their unique 64-bit addresses or by a user-configurable ASCII strings. The ASCII string identifier is configured using the NI command. To transmit data using device addressing, only the destination address must be configured. The destination address can be specified using either the destination device's 64-bit address or its string obtained after applying the NI command (NI - string). Device addressing in the AT firmware is configured using the DL, DH, or DN commands. To send a packet to an RF module using its 64-bit address (Transparent Mode) it is necessary to set the DH (Destination Address High) and DL (Destination Address Low) parameters of the source node to match the 64-bit Address (SH (Serial Number High) and SL (Serial Number Low) parameters) of the destination node. The NI-string can alternatively be used to address a remote module. Sending a packet to an RF module using its NI-string (Transparent Mode) issues the DN (Destination Node) command using the NI (Node Identifier)-string of the destination node as the parameter. (Xbee ZNet 2.5 modules support analog inputs and digital IO).

Analog samples are returned as 10-bit values. The analog reading is scaled such that 0x0000 represents 0V, and 0x3FF = 1.2V. (The analog inputs of the module cannot read values greater than 1.2V). Analog samples are returned in order starting with AIN0 and finishing with AIN3, and the supplied voltage. Only enabled analog input channels return data. To convert the A/D reading to mV, there is a need to calculate it in the following way:

$$AD(mV) = (ADIO \text{ reading} / 0x3FF) * 1200mV$$

To sample the current value of all enabled A/D and digital input lines - the IS command can be used.

The IS command can be sent to a device locally, or to a remote device using the API remote command frame. When the IS command is sent, the receiving device samples all enabled analog input channels and returns an IO sample. If IS is sent locally, the IO sample is sent out using the UART. If the IS command was received as a remote command, the IO sample is sent over-the-air to the device that sent the IS command. The following table 2 shows an example of the fields in an IS response.

Table 2. Sample AT responses

Example	Sample AT Response
0x01	1 sample set
0x03	Analog Inputs: A/D 0,1
0x03D0	Analog Input ADIO 0 = 0x3D0
0x0124	Analog Input ADIO 1 = 0x120

### Connecting ZigBee module to accelerometer

Schematic diagram in fig.2 shows the connection of the ADXL 330 3-axis analog accelerometer to the Xbee module. On this schematic diagram three output lines of the accelerometer: X-out, Y-out and Z-out are connected to three analog input pins of the Xbee module, i.e. to pin 17, 18 and to pin 19. It is however our future consideration, because only vibration along X axis has been investigated.

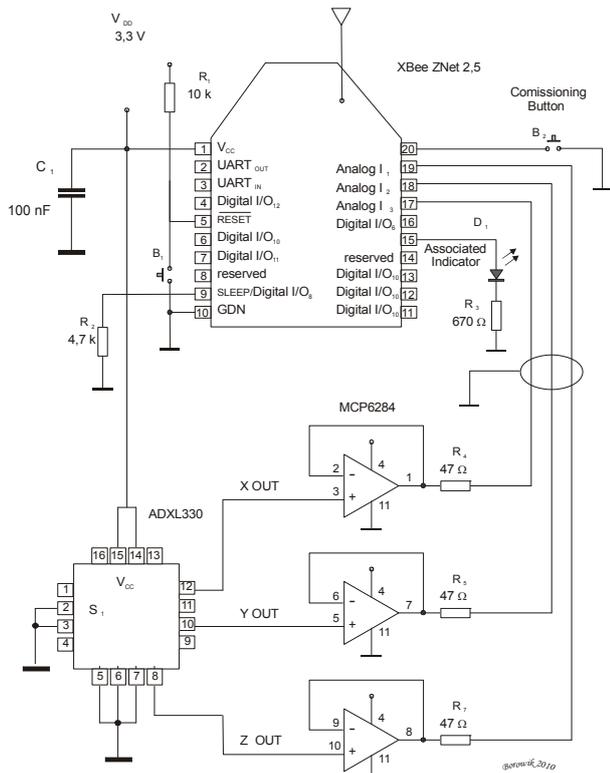


Fig.3. Schematic diagram of the 3-axis accelerometer with X-Bee transceiver

Output lines from the 3-axis accelerometer are connected to the Xbee module through the op amp MCP6284 with the shielded wire. The associated LED diode D1 is connected to the Xbee pin 15 and it indicates the device's network status. Once the module successfully joins

the network, the associated diode blinks 2 times per second. Pressing button B1 can restart the device. A commissioning B2 push button is connected to the Xbee pin 20 and it serves as node's identification. Voltage of 3.3 V is supplied from a Voltage regulator.

### Conclusions

The paper presents the example of measuring and monitoring a vibration model. The schematic diagrams included in the paper show a practical solution for particular connections. A user can monitor a vibration level of the WBV on a remote graphic display. The amplitude threshold of accelerations can be set up in the software, so in the case of excessive vibrations the special scenario can be switched-on. By monitoring, analyzing, processing and graphical displaying vibration parameters of the presented here model may help to avoid the threat of human health damage.

### REFERENCES

- [1] Borowik B., Kurytnik I., P. Microcontrolery PIC w zastosowaniach *PAK-Pomiary, Automatyka, Kontrola*, Warszawa, 2009.
- [2] Borowik B., *Interfacing PIC Microcontrollers to Peripheral Devices*, Springer, 2011.
- [3] Kurytnik I., Karpinski M., *Bezprzewodowa transmisja informacji, PAK Pomiary Automatyka Kontrola*, Warszawa, 2008.
- [4] Borowik B., et al., *Meandry języka /C++*, PWN, Warszawa, 2006.
- [5] Griffin M.J., *Handbook of human vibration*, London, 1996.

### Authors:

*dr inż.* Bohdan Borowik, *prof. dr hab. inż.* Igor Piotr Kurytnik  
<sup>1</sup>University of Bielsko\_Biala, Electrical and Automation Dept.,  
 2 Willow street, 43-309 Bielsko-Biala, Poland  
 E-mail: [bborowik@ath.bielsko.pl](mailto:bborowik@ath.bielsko.pl), [ikurytnik@ath.bielsko.pl](mailto:ikurytnik@ath.bielsko.pl)