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Wireless Measurement Modules for Multichannel Drivers Monitoring System

***Abstract**. A radio communication system designed to operate in multichannel drivers monitoring system is presented in the article. The presented solution provides communication in the 2.4 GHz ISM band, at speeds of up to 300 kbps in full duplex mode. System throughput is shared dynamically between the wireless measurement modules. Delays in data transmitted in packets of up to 31B do not exceed 3ms.*

***Streszczenie.** W artykule przedstawiono system komunikacji radiowej zaprojektowany do pracy w wielokanałowym systemie monitorowania kierowców. Zaprezentowane rozwiązanie zapewnia komunikację w paśmie ISM 2,4 GHz, z szybkością do 300kb/s, w trybie full duplex. Przepływność systemu dzielona jest dynamicznie pomiędzy bezprzewodowe moduły pomiarowe. Opóźnienia danych transmitowanych w pakietach o długości do 31 B nie przekraczają 3 ms. (**Bezprzewodowe moduły pomiarowe wielokanałowego systemu monitorowania kierowców**)*

Keywords: Drivers monitoring, wireless transmission, ISM.
Słowa kluczowe: Monitorowanie kierowców, transmisja bezprzewodowa, ISM.

Introduction

Most multichannel recording equipment require that the exchange of information with measurement sensors take place in real time. In case when cooperating elements are connected by cable this condition is quite easy to meet. It is more difficult in the case of wireless transmission [1,2]. The main reason for this is the fact that commonly available radio modules (Bluetooth, ZigBee, Wi-Fi) are not optimized to work in real time. In most cases they guarantee only transmission fidelity. In the driver monitoring system the key parameter for wireless measurement modules is the messages response time of the drivers for the recorder and the connection speed, if for some reason it should be lost.

In logistics there are commonly used vehicle monitoring systems recording mainly GPS positions. These systems are extended with additional modules such as fuel probes, flowmeters and CAN modules. Information from all additional modules is mostly transmitted to a device with a GPS receiver and a GSM modem. Due to simplicity of installation, it becomes increasingly popular to use Bluetooth modules for data transmission between the elements of such systems. They are perfectly suited in case of transmitting signals of fuel level or engine revolutions . This is the information transmitted usually no more than once per second, and parameters such as transmission time and the connection speed are of secondary importance.

This paper presents a general construction of a multichannel driver monitoring system [3,4,5]. The concept of the operation and the requirements that need to be met by wireless measuring modules to provide real time data processing in the system were presented. Then a dedicated measurement modules radio communications system was presented. Experimental tests that were carried out by using this system as well as obtained results were discussed.

Multichannel Drivers Monitoring System

The drivers monitoring system is composed of many hardware and software components. Some of them are closely related, and others can work independently. The most important elements of the measurement system are shown in figure 1. The primary measuring element is the Car Measurement System (CMS). Its task is to monitor the psychophysiological condition of the driver, vehicle driving parameters measurement, the situation on the road and the environmental parameters inside and outside the vehicle.

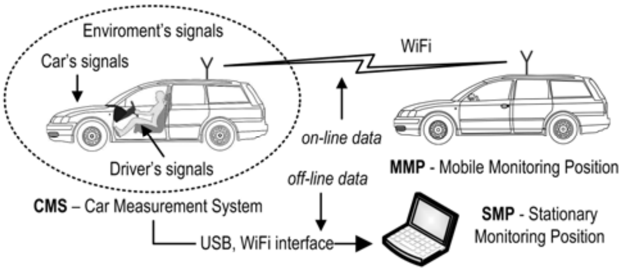

Fig.1. Driver monitoring system flow chart

Each of the measured and processed signals is stored in the non-volatile memory of the CMS system and can be later read for processing, analysis and data visualization. The reading of data can be done via USB or WiFi. Moreover, the signals in the CMS system can be sent in real time to the mobile (MMP) or stationary (SMP) monitoring position. CMS has been implemented as a distributed measurement system. Its block diagram is shown in figure 2.

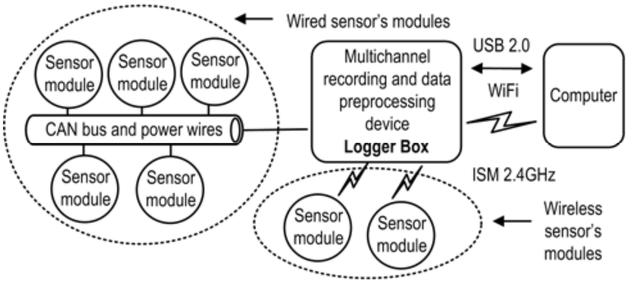

Fig.2. The sensors connections architecture of the vehicle measuring system

The type of interfaces used has been adapted to the requirements of the data speed, interference resistance and place of installation. Most measurement modules were attached to a recording device via CAN wire bus. In cases when wired connections could not be used, wireless links were used operating in the 2.4 GHz ISM band. Radio modules operate in the master-multislave configuration.

Requirements for Wireless Measurement Modules

To ensure the ability to send signals to the recording system in the real time the wireless connections should guarantee specific parameters. They have been defined on the basis of signal frequency sampling and length of messages exchanged with wireless measurement modules.

Synchronizing devices and uniform time for all the sampled signals was assured by using the mechanism of requesting each signal sample in the wireless connections. This ensures that all sampling processes take place in accordance with the clock of the Logger Box. One of the measuring modules is responsible, among other things, for sampling the ECG signal of the driver. It is recommended that the sampling frequency in this case was at least 250 Hz. This determines the response time of the message at a level no lower than 4 ms. Moreover, it is very important for the system to quickly make a radio connection in case the radio range is exceeded or interference occured.

Verifying the Ability to Use Bluetooth

To build a system for monitoring drivers common wireless communication systems were considered (e.g. Wi-Fi, ZigBee and Bluetooth). The use of Wi-Fi has been ruled out due to excessive power consumption, especially on the side of the wireless measurement modules. ZigBee, however, offers a small bandwidth. Because of this an analysis and verification of the operation of Bluetooth has been carried out using a serial port emulation profile SPP (Serial Port Profile). In order to verify the time needed to transfer data over Bluetooth the RN-42 Roving Networks module was tested. A measuring system according to the scheme shown in figure 3 is presented.

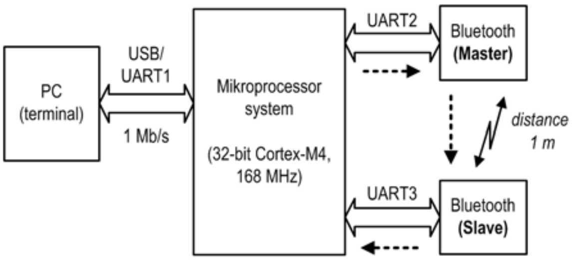

Fig.3. Bluetooth communication measurement system flow chart

Two identical Bluetooth modules were used in researches, placed at a distance of 1 m away from each other. One of them was programmed for automatic operation as a Master and the other as a Slave. The Bluetooth modules were connected to the microprocessor system via the UART interface (no. 2 and 3) supporting control signals RTS and CTS. Transmission speed between the microprocessor system and the Bluetooth module was constant at 1 Mb/s.

Measurements consisted of sending a certain number of bytes to the Master module, which in turn transmitted them wirelessly to a Slave module and then receiving transmitted bytes from the Slave module. Apart from measuring time the correctness of data was also verified. A frame of test data was sent from the Master at a selected duration from 1 to 50,000 bytes. Afterwards the data was collected by the Slave system. A time of T_p that is needed to send data was measured, determined from the moment of commencement of sending data to the Master module to the moment of receiving all data from the Slave module. For each of the analyzed test data frame length, three measurement sessions were performed, and for each of them 100 measurements were performed. After each measurement a delay of 20 ms was introduced. The time between each measurement session equaled several seconds. The average T_{pmean}, minimal T_{pmin} and maximum T_{pmax} were determined from the conducted T_p measurements. The transmission speed K was also determined of the tested connection based on the most unfavorable T_{pmax} time. Obtained test results are shown in figure 4.

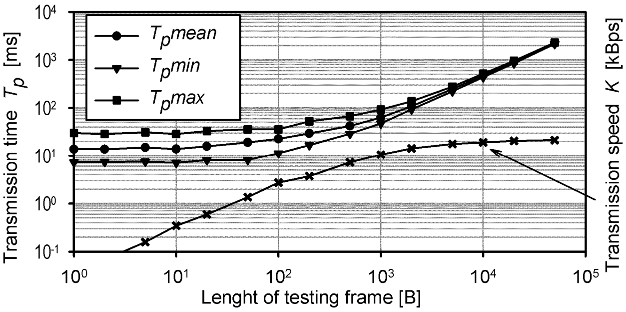

Fig.4. Bluetooth RN-42 module test results

The achieved Tp transmission times of the tested connection clearly show that the use of Bluetooth in real-time measurement systems is very limited. Assuming that data synchronization is required (for example, question-and-answer communication), then for the transmitted packages of a few bytes a signal sampling frequency could be achieved of no more than a few Hz. Moreover, most of the ready SPP profile Bluetooth modules do not support point-to-multipoint communication. For these reasons, work was undertaken to develop a new radio communication system.

Construction of the Wireless Measurement Module Designed for Real-Time Operation

Meeting the requirements of the recording system by the wireless transmission parameters required the use of directed solutions and algorithms. It was decided to design an algorithm for wireless communication beginning with the OSI model data connection layer. nRF24L01 radio systems were used as the physical layer operating in the 2.4 GHz ISM band.

Master Device – Radio Transmission Coordinator

The radio coordinator in the drivers monitoring system mediates the exchange of in-formation with all wireless measurement modules. It communicates with the cooperating devices through a wired connection with the UART systems performing hardware flow control (RST/CTS). Each wireless module is assigned a separate interface. This way the interpretation of the affiliation of exchanged data to a particular measurement module was facilitated. In addition, the cooperation of the coordinator with more than one microprocessor system is possible. This facilitates the possible distribution of support of the measurement modules between the cooperating microcontrollers in the recorder. The construction of the master device acting as the radio transmission coordinator is shown in figure 5.

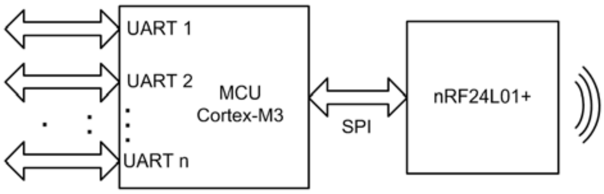

Fig.5. Master device flow chart

The main elements of the coordinator are the STM32-type microcontroller with a Cor-tex-M3 core and the Nordic Semiconductor nRF24L01+ radio interface. The operating frequency of the microcontroller is fixed at 64 MHz SPI and allows the operation of the SPI interface with the maximum supported speed of the radio system at 8 Mb/s. The radio module operates by reacting on interrupt request signal IRQ. Transmission via the UART interface is implemented by hardware and software FIFO queues supported by the DMA controller. In this way, the main thread of the program has a reduced load and the delay in data processing is minimized.

Measurement Module – Slave Device

Wireless measurement modules (BMP) in the drivers monitoring system are Personal Medical Package (OPM) and the steering wheel motion detection module. These devices sample signals, such as driver ECG, the driver's skin temperature and performed steering wheel movements and its vibrations. This information is transmitted to the recording system. Each device has a built-in nRF24L01 radio module. The transmission protocol support is implemented directly in the microcontroller controlling the operation of the measuring module. The flow chart of the wireless measurement module is shown in figure 6.

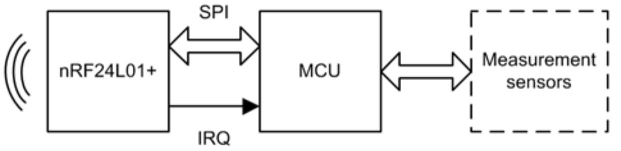

Fig.6. Wireless measurement module flow chart

As in the master device, the radio module support in the sensor takes place by responding on interrupt request signal IRQ. In the case of measurement modules events management from radio systems is much easier. Despite this, the algorithm requires that the response to this interruption was as fast as possible.

Data Transmission Algorithms

Data transmission from the point of view of the device cooperating with the coordinator takes place as if the measurement modules were connected by wire to the UART interfaces. The only difference is that the transmission protocol monitoring system should detect damaged frames, and retransmit them on its own.

The transfer of information in the radio system is done periodically between consecutive wireless measurement modules (fig. 7).

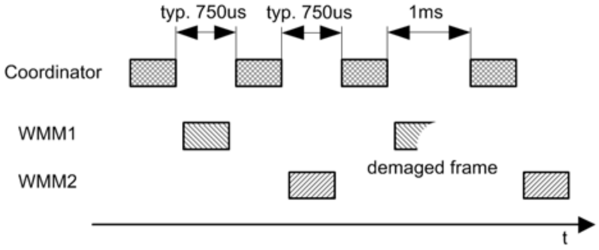

Fig.7. Exchange of messages between the coordinator and wireless measurement modules

Multiple radio access is implemented by allocating time slots for each of the slave devices (TDMA). In addition, address filters were used built into the nRF24L01 radio systems, so that the measurement modules would not have to analyze information that is not intended for them. For each message of the coordinator, the measuring module is required to immediately respond. In the data field of the radio frame the coordinator places data for the addressed measurement module and in response receives information from the module and passes it on to the appropriate UART interface.

Each time a radio frame is sent, the coordinator waits for a response time from the slave for 1 ms. If it does not receive it then the package is sent to the next addressed device. This way, in the absence of measurement modules frames are sent exactly every 1 ms and if the device answer the messages then it is typically about every 750 µs. The radio message data field has a capacity of 32 B from which only 31 B carries user data. The total bandwidth of the R_{max} radio system is presented with formula

$$R_{\max} = \frac{L_{byte} * 8}{t_{TDMA}} \qquad (1)$$

where: L_{byte} – the usable length of the data field in bytes, t_{TDMA} – the time between sent messages.

In the case of exchanging messages every 750 µs it is possible to obtain rate of 323kb/s in each direction (to and from the coordinator). The messages are exchanged continuously, even if no useful data is exchanged. The system is dedicated to a particular application, therefore no possibility of dynamic changes in the number called by the coordinator of the wireless measurement modules was foreseen. This causes a situation that, if the master device supports two measuring sensors while only one is in radio range, then unnecessary empty packages are sent to the inactive module. To prevent this, in addition to the implementation of multi-access, the coordinator also supports the message queuing mechanism.

Message queuing is activated when not all FIFO queues related with the measurement modules are at the given moment being empty or not empty. Empty queues mean that the empty packages should be consecutively addressed to slave devices. This is to verify whether they are within radio range. It can also serve to collect system information that is sent without an earlier request. All non-empty queues cause a similar system effect, with the difference that the radio packages carry useful data. None of the slave devices are prioritized by the system. When at least one of the transmission buffers is empty and the other will remain non-empty, the queuing mechanism will skip addressing the measurement module that is associated with the buffer. This way, the modules associated with non-empty queues will be targeted frequently, which temporarily accelerates the exchange of messages. This allows dynamic bandwidth allocation of the system between cooperating devices.

Experimental Studies

Verification of the system operation and the time parameters implemented by its transmission has been done by conducting experimental studies. For this purpose, a measurement station was set comprised of a coordinator and two wireless measurement modules (fig. 8).

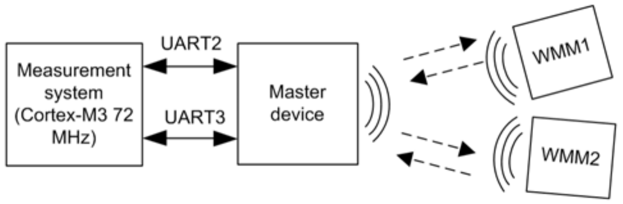

Fig.8. Scheme of the measurement system for testing the time parameters of the wireless system

Broadcasting buffers of the coordinator were supported by an additional microprocessor system. Its software executed out a research scenario prepared in advance. The results were transmitted directly to a computer through the serial port.

Experimental studies of the system have been carried out in operating conditions. Near the system was placed a turned on mobile phone and a WiFi access point. Wireless modules were located at a distance of approx. 1 m from the coordinator. It was configured in such a way that received messages were relayed without analysis to the coordinator. But these devices read the receiving buffers and recorded the broadcast buffers each time so as not to falsify the results of the experiment by skipping normally executed operations.

The microprocessor system controlling the course of the experiment periodically sent data to the coordinator using the UART interface of a predefined length of intervals of approx. 10 ms. After each sending and receiving of package data validation of received information occurred and a measurement of time T_0 was made of the time taken to returned to the measuring system. This way, the study took into account both the times of the transmission itself in the radio channel as well as the processing time of messages in the coordinator and slave devices.

System Response Time for the Message

One of the most important parameters of the created system is the time that elapses between sending a request to the measuring module and receiving a message response from it. In theory, the messages located in the data field of the communication frames can be transferred in one time slot and the response from the measuring module will reach the coordinator after a time no less than 1 ms. Unfortunately, in practice this is unlikely, because the coordinator does not synchronize in any way the moments of transmitting frames with incoming data. Therefore, there is a very high probability that even a message of a few bytes will be transmitted by a larger number of radio frames. Moreover, it may happen that there will be two or more transmissions active to the slave devices, which further delays the transmission of information via the radio system. Despite this, it is possible to analytically determine the minimum ($Tmin$) and maximum ($Tmax$) time of exchanging information with the measuring module using formulas

$$(2) \qquad T_{\min} = \lceil lp/31 \rceil * t_{TDMA}$$

$$(3) \qquad T_{\max} = \left(\lceil lp/31 \rceil + 1\right) * t_{TDMA} * n_{slave}$$

where: lp – message length, n_{slave} – number of operating slave devices, t_{TDMA} – time between sent messages.

The histogram made of 36,000 measurement response times for the message with a length of 1B and 6B is shown in figure 9.

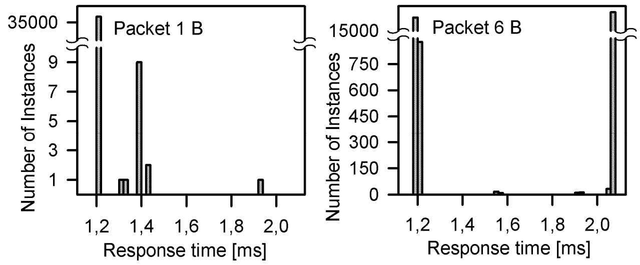

Fig.9. Histogram of response times for 1 B and 6 B length messages

These results confirm that the dispersion of recorded response times for the message is always between analytically determined values T_{min} and T_{max}. The study was conducted for messages with a length of: 15 B, 31 B, 50 B, 128 B and 256 B. The average response times for these messages are presented in table 1.

Table 1. Average response times for messages transmitted by radio

Message length [B]	1	6	15	31	50	128	256
Response time [ms]	1.20	1.62	2.16	2.57	4.05	5.46	8.45

Summation

The analysis of psychophysiological performance of drivers, environmental conditions and technical parameters of the vehicle allow to carefully look at road safety [6,7,9]. The reconstruction of all the parameters that influence the behavior of the driver requires recording a large number of signals inside and outside the vehicle [8]. This is quite a difficult task, due to the variety of signals and their measurement. Another important problem is the synchronous measurement signals from sensors, with which communication is carried out by radio.

The wireless communication system discussed in the article allows the integration of real-time data from autonomous measurement systems. Due to the presented solution the effective operation of the analytical module of the main recording system is possible based on synchronized data and generated alarms in case of detected threats on the road. The probability of correct identification of critical situations will increase due to simultaneous analysis of signals from sensors and measuring devices. Creating a detailed description will be possible of processes taking place inside and outside, multi-level dependencies between components that influence the level of static and dynamic range of risk of the occurrences of road collisions as well as accidents.

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