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MULTIPARAMETRIC MEASUREMENT SYSTEM

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Abstract: The article presents a multiparametric system for the measurement of selected physical variables required to control the exoskeleton developed at the Biomechanics Lab of the Military Institute of Aviation Medicine. The control of this type of devices is a very complex problem. It requires precise measurements being taken from kinematic segments of both the human wearing the exoskeleton and the exoskeleton itself. The key issues affecting the quality of exoskeleton control include the selection of the optimum number of sensors and optimum locations for sensors, as well as the interpretation of physical quantities measured by these sensors.

Keywords: exoskeleton, IMU, MEMS, accelerometer, magnetometer, gyroscope

Table: 1 • **Figures:** 7 • **References:** 14 • **Full-text PDF:** http://www.pjamp.com • **Copyright** © 2015 Polish Aviation Medicine Society, ul. Krasińskiego 54/56, 01-755 Warsaw, license WIML • **Indexation:** Index Copernicus, Polish Ministry of Science and Higher Education

INTRODUCTION

The efficiency of soldier in battlefield is determined by their combat training (acquired knowledge, skills, and experience), battle gear at their disposal as well as their current psychophysical status, including the magnitude of fatigue. Gear and equipment being carried are one of the basic factors that add to the soldiers' fatigue. Basic gear and equipment consists of combat suit, tactical vest weighing ca. 23 kg, machine gun weighing ca. 5 kg, helmet, ammo clips (mass may vary), bag holding the gas mask weighing ca. 1 kg, pistol gun with a holster weighing ca. 2.5 kg and a hydration kit weighing ca. 3 kg. When the mission demands that soldiers be employed as porters, the battledress and equipment combined with a backpack weighing ca. 30 kg can get up to 65 kg per soldier at that time [10].

Studies aimed at the development of devices facilitating the transportation of individual gear and equipment have been conducted since mid-20th century. Similar solutions are also developed for broadly understood rehabilitation and physical therapy uses [3,4,8].

All these solutions amount to a group of exoskeletons with different designs and making use of different types of motors (servomotors) that support the work of the human musculoskeletal system [1].

In case of military solutions, exoskeletons should provide support for the basic motor tasks. High level of compatibility between the mechanical design of the exoskeleton and the soldier's body is very important in this regard. Exoskeleton should also be moved and controlled by natural movements performed by the soldier [2].

The Military Institute of Aviation Medicine is a partner in the research project titled "Exoskeleton compatible with the ISW TYTAN gear transportation system", pursued under the contract with the National Centre for Research and Development. The scope of design activities includes the selected aspects of the biomechanics of human motor system specific for the types of tasks undertaken by soldiers in the battlefield.

Having analyzed the requirements and available technologies, the researchers agreed upon the basic principles of the design and function of the exoskeleton. According to one of these principles, exoskeleton should be a self-propelled robot with moves synchronized with and parallel to those of the soldier so as to maintain constant position relative to the soldier's body and follow the soldier's movements.

The design of the exoskeleton should not alter the soldier's silhouette. It should allow for the widest possible scope of adjustment to individual dimensions of all soldiers. When started up, the propulsion and control should not require soldier's attention. The exoskeleton should not disturb the function of the general combat systems while enhancing the functionality of their transportation systems. In practice, this amounts to facilitating the transport of soldier's gear and equipment by ensuring maximum relief of lower limbs and the spine.

Implementation of these assumptions requires finding solutions to numerous problems related to the mechanical structure of the exoskeleton, propulsion systems, energy sources and control systems. In line with the assumptions, the control systems should function in an autonomous manner, without active participation of the soldier. Therefore, information required for the control of the exoskeleton must be obtained from a system of sensors incorporated in the design. The sensors should provide information on forces exerted on selected construction elements, changes in the locations of propelled kinematic segments and changes in three-dimensional positions of selected constructional elements of the exoskeleton.

Advances in electronics facilitated the development of systems that describe the kinematics of the human body (in this case, the system Xsens MVN developed by Xsens Technologies B.V.). Such a system [11] was used in the pursuit of this research project to develop a virtual model and describe the dynamics of selected motor tasks performed by soldiers carrying load corresponding to the weigh of gear and equipment with the total weight of ca. 55 kg (Fig. 1.).

The system makes use of converters based on the MEMS (micro electro-mechanical system) technology. Systems of this type were planned for inclusion within the structure of the exoskeleton. Distribution of sensors containing the MEMS converters will derive from the measurement needs that would take into consideration the mechanical design of the exoskeleton. The number of these sensors will be possibly minimized due to optimization of the control system carried out so as to reduce the quantity of data being processed within the exoskeleton control system and to maximization of the accuracy of the measurements of changes within the dynamic state of the human/exoskeleton system. Functional examinations of exoskeleton making use of additional sensors being placed on soldiers' bodies were provided for

a)

b)

Fig. 1. Employment of Xsens MVN system to capture soldier motion data:
a) sensors' placement,
b) soldier with a comparable equipment load.
Source: author's own material.

at the initial stages of the study. A multiparametric MEMS-based measurement system was designed while an appropriate test station was developed at the Biomechanics Lab of the Military Institute of Aviation Medicine.

OBJECTIVE

The objective of this study was to develop and produce multiparametric measurement systems facilitating examination of selected kinematic segments during controlled exoskeleton movements.

MATERIAL AND METHOD

The multiparametric measurement system is a solution consisting of two primary modules, namely the converter module and the Bluetooth module (Fig. 2.).

The sensing module is an electronic system consisting of the following integrated circuits:

- IMU (Inertial Measurement Unit) for the measurement of acceleration, angular velocity, and magnetic field; each of these quantities is measured in a system of three perpendicular axes [9];
- barometric pressure sensor;
- temperature and humidity sensor;
- dsPIC (Programmable Intelligent Computer) controller for acquisition and distribution of data [6], featuring a universal asynchronous receiver and transmitter (UART) interface responsible for communication;
- communication interface facilitating wired transmission of signals using the RS485 standard.

The Bluetooth module is an electronic system (type P120205) with an interface for wireless radiofrequency data transmission.

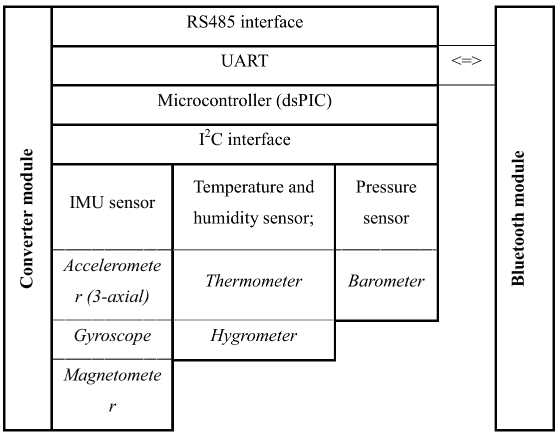

Fig. 2. The design of a multiparametric measurement system.

CONVERTER MODULE

The main objective of the designed multiparametric measurement system consists in conversion of selected physical quantities into electric signals for real-time transmission (within the acceptable delay limits). The system is a universal solution that may be used in research studies involving transmission of measurement data: either wireless or, following disconnection of the Bluetooth module, via the RS485 interface. The design of the exoskeleton provides for the wired transmission of data. In case of resignation of the environmental parameters (pressure, temperature, humidity), the measurement system may comprise solely of the IMU device (for the measurement of acceleration, angular velocities, and magnetic field). The MPU9150 system used within the IMU comprises a digital motion processor that facilitates processing of the measurement data for further transmission in the form of quarternions [5]. The use of the MPU9150 in the final exoskeleton design may significantly reduce the burden associated with online computations within the central controlling processor.

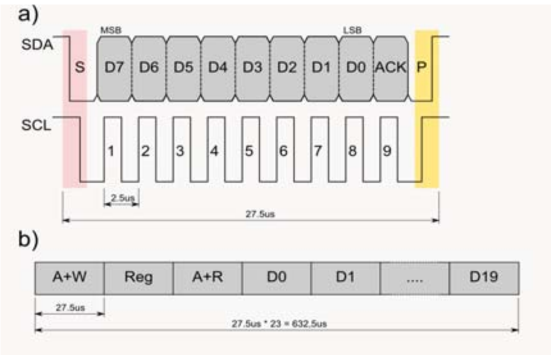

Fig. 3. I²C data frame a) time waveforms of the received signal line and the clock signal with marked time required to send 1 byte of data; b) transmission of 1 sample consisting of 10 measured signals with time marking.

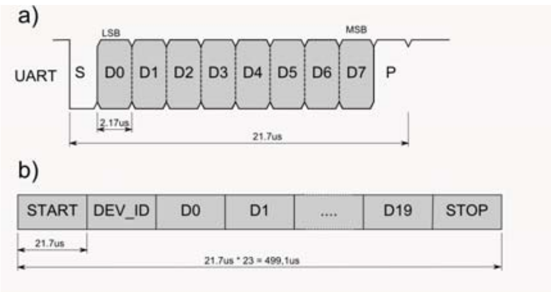

Fig. 4. A graph presenting temporal relationships of data transmission a) UART-BT signal line waveform marked time required to send 1 byte of data; b) transmission of 1 sample consisting of a frame identification data byte and 10 measured signals with time marking.

Multiparametric measurement system may be powered from sources with the voltage of range 3.8÷5 V. Current consumption is not larger than 100 mA. The system, powered from 3AA (LR6) cells, is capable of running for many hours. When the Bluetooth module is disconnected the power consumption is lower by ca. 80÷90% which markedly extends the operating time of the system.

Time required for the acquisition of data from the converter and for its transmission into the control system is the critical element in the design and development of measurement systems used to measure a large number of signals at relatively high sampling frequency and resolution. Both the data acquisition bus and the data transmission bus are of the serial type. Owing to the fact that the processor is fitted with implemented serial interfaces, the use of the multiparametric measurement system is simple and effective.

Maximum data transmission rates offered by the peripheral devices were adopted so that the time-related criteria are met. Data transfer sampling rate of 400 kHz was adopted for the I2C bus while 460.8 kBps transfer speed was adopted for the UART-BT interface [7].

Fig. 3. presents the size of the data frame and the time required for its transmission. It is shorter than the time between individual samplings and amounts to slightly more than 630 µs.

Fig. 4. presents a full data frame transmitted by the UART-BT module with the marking of the time between the samples. As seen in this figure, the minimum time required for all data to be sent is about 500 µs.

At the frequency of 1 kHz, the time between individual samples is 1000 µs. The total time of the acquisition of data from the transducer and the transmission via the BT module is 630 µs+500 µs=1130 µs. This time should be extended by the time required e.g. for the programmed change in the data format, etc. It is therefore longer than the time between the sequential triggering pulses and thus the task cannot be accomplished in the serial data processing mode. The assumed task consisting in the readout and transmission of a predefined amount of data may be achieved only by means of parallel acquisition of data from individual sensors and simultaneous transmission of the previously acquired sample to the communication interface.

In the proposed solution, the data are sent in packets consisting of a data frame start identification byte, several hundred data samples, and data frame end identification byte. This method reduces the number of bytes required for identification of data and minimizes the number of bytes required for identification of data frames. This solution if supported by the MPU9150 system featuring a 1024-byte FIFO (first in, first out) data buffer allowing for the data being transferred in packets (e.g. after the buffer is half-full).

However, when planning to measure a smaller number of parameters at lower sampling frequencies, the buffer should be used mindfully as it may take as much as 0.5 s to fill half of the buffer's capacity with data at the sampling frequency of 100 Hz. When the waiting times are as long as 0.5 s, the transmission should not be referred to as real-time transmission.

Software managing the configuration of measurement sensors and acquisition of data was designed to handle the multiparametric measurement system. After the software startup, the computer uses the Bluetooth interface for connection with the measurement system(s) so that the measurements may be started and stopped and the data may be transmitted and saved. Fig. 5. presents an example screen of the computer running the software. The software runs on the Microsoft Windows operating system.

Fig. 6. presents the temporal changes of accelerations recorded along three axes as the result of the changes in the positions of sensors within the space of the measurement system.

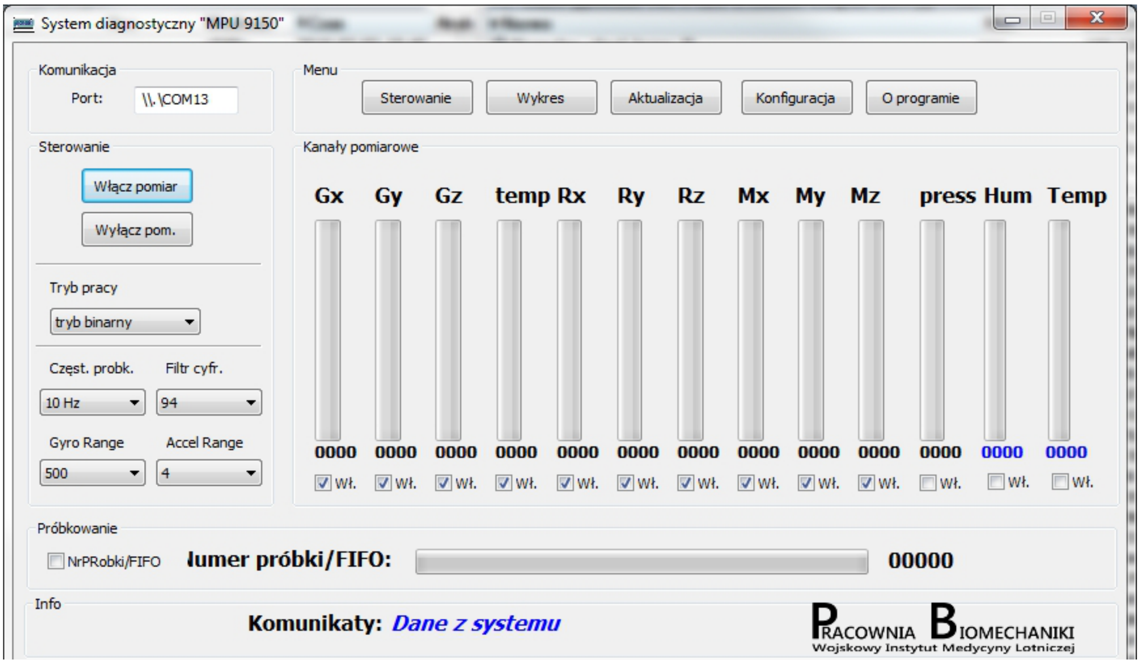

Fig. 5. Interface of the software for the control and acquisition of data from the multiparametric measurement system.

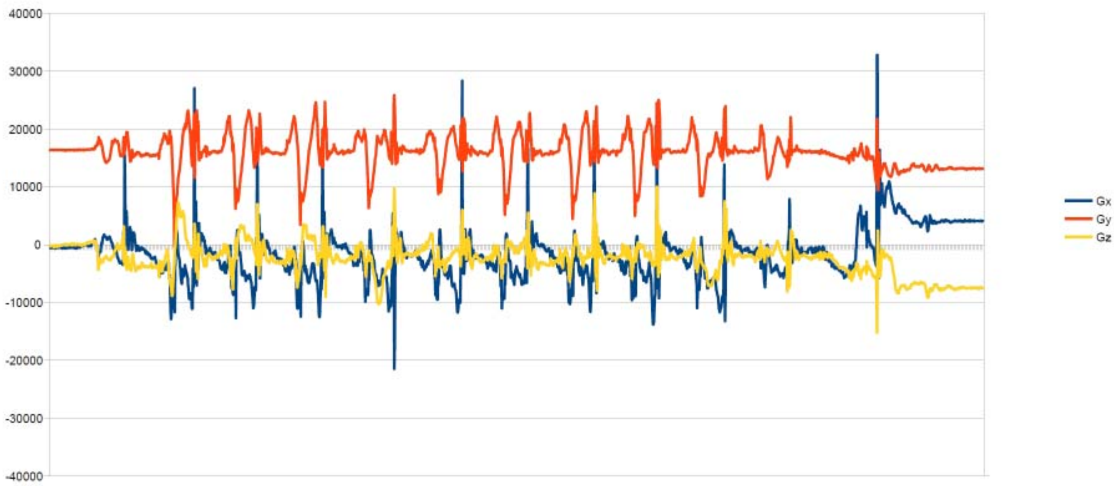

Fig. 6. A test record of accelerations along 3 axes.

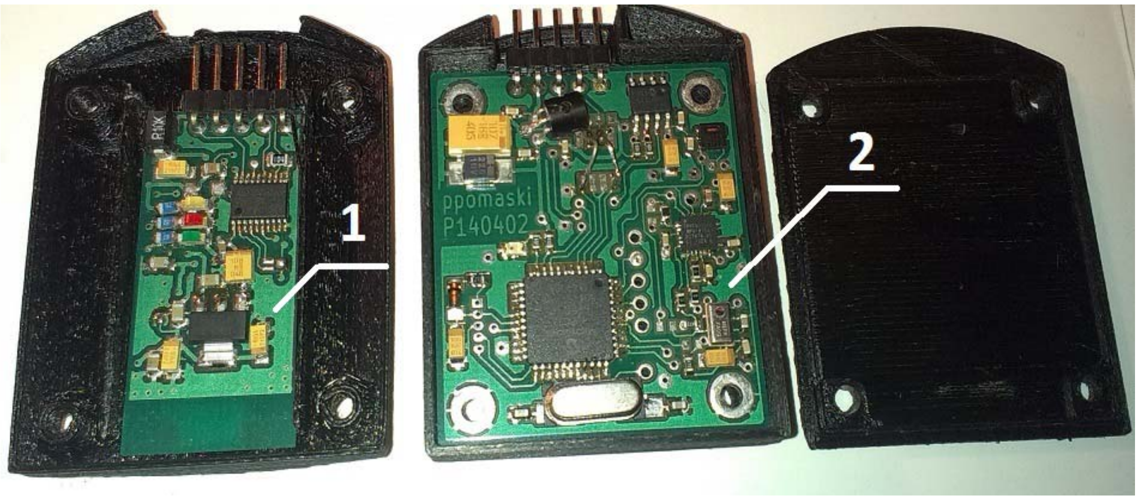

Fig. 7. Multiparametric Measurement System 1) Bluetooth module; 2) Converter module.

Tab. 1 . Technical specifications of the measurement system.

Parameter	Value
Nominal power supply voltage	3.3V or 5V
Gyroscope	4 ranges: ±250, ±500, ±1000, ±2000 deg/sec
Accelerometer	4 ranges: ±2, ±4, ±8, ±16 g
Magnetometer	±1200μT
Gyroscope, accelerometer, and magnetometer sensors	3-axial
AC converters, gyroscope and accelerometer	16-bit
AC converter, magnetometer	13-bit
Signal sampling frequency	≤ 1000Hz
Absolute pressure	50 - 115 kPa
AC converter, barometer	10-bit
Humidity	0 - 100%
Temperature	-40 - 125 st C
AC converter, thermometer	14-bit
AC converter, hygrometer	12-bit
Communication interface	RS485 half-duplex or UART 3.3V or Bluetooth - module P120205.
External synchronization input	square pulses, 50% max. 1 kHz, TTL 3V

Appropriately configured multiparametric measurement systems will eventually be installed within the constructional elements of the exoskeleton. Experimental studies were carried out using multiparametric measurement systems consisting of two modules (Fig. 2.) placed within a dedicated plastic case (Fig. 7., view 1) manufactured using a 3D printer.

TECHNICAL SPECIFICATIONS

Presented above are technical specifications of the multiparametric measurement system (Tab.1.)

AUTHORS' DECLARATION:

Study Design: Paweł Pomaski, Mirosław Dereń, Marcin Piotrowski; **Data Collection:** Paweł Pomaski, Mirosław Dereń, Marcin Piotrowski; **Statistical Analysis**: Paweł Pomaski, Mirosław Dereń, Marcin Piotrowski; **Manuscript Preparation:** Paweł Pomaski, Mirosław Dereń, Marcin Piotrowski; **Funds Collection:** Paweł Pomaski, Mirosław Dereń, Marcin Piotrowski. The Authors declare that there is no conflict of interest.

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