WIRELESS SENSORS SYSTEM FOR ROWER MONITORING

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Abstract: the aim of this work was to develop a telemetry system for monitoring in real time of sportsman paddling a canoe. The developed system is intended to facilitate the coach in individualizing and optimizing the workouts of elite athletes. The proposed system comprises two sets of sensors measuring mechanical parameters of the boat (speed, acceleration, force to the paddle) and physiological parameters of the sportsman in order to asses his functional status. The prototype of telemetry system for monitoring of mechanical and physiological data of sportsman and canoe during rowing is designed and developed.

Introduction

The impact of technology on sport is increasing very fast. New materials such as carbon fibre have allowed lighter and stronger boats; electronics is used to provide feedback on the sportsman performance. The individualization of the workouts for the optimization of the rowing performance is substantiated in the coaching theory [1]. The interesting results are presented in study [2]. Authors concluded that the rowing economy has obviously expressed values of the most economic and the least economic stroke rate for small boats. However, this investigation was based on mathematical modeling. In order to improve training and coaching performance there is a need for technology that could monitor and provide objective feedback on mechanical as well as on physiological parameters [3], [4].

The rowing sports literature analysis suggests that most of commercial monitoring systems in sports use indoor training simulators (ergometers) [5] and some of them could be used in the boat on the water [6]. However, the information they provide is not adequate to real time monitoring of the training. Most of these systems are not intended to provide the information to the coach remotely in real time, they mostly log the data in the devise memory during training. The shortage of current technology – the high cost of commercial sports data logging systems, combined with lack of acquisition of physiological parameters and wired technology leave room for improvement. The aim of this study was to design a solution that addressed the inadequacies of current systems and satisfied the requirements for detailed real time data analysis and wirelessness.

Materials and Methods

A. System requirements

Special attention was paid to these system requirements: a) the size and energy consumption of the sensors must be as small as possible, b) the system must be wireless, c) the system must be able to store the data locally and transmit in real time to coach computer, d) the transmission range not less 300m, f) the coach should be able to start and stop the system remotely.

B. System Architecture

The component diagram of the proposed system is presented in Fig. 1. It consists of rower and coach components. Rower components include 5 sensors for monitoring of mechanical and physiological parameters, master unit for aggregation of data and standard personal digital assistant (PDA). The sensors together with master unit form the 2,4GHz wireless, proprietary star topology sensor network. The aggregated data from the master flow to the gateway – PDA computer with WLAN capability. The PDA is used for local storage of data and for wireless delivery of data in real time to remote laptop (coach laptop) with integrated WLAN card.

C. Monitored parameters and transducers

The following mechanical parameters are monitored: a) acceleration of the stern of the boat in X and Z axes- $a_x(t)$, $a_z(t)$, b) acceleration of the bow of the boat in Y and Z axes- $a_{y,z}(t)$, $a_z(t)$ c) force to the paddle- F(t), d) speed of the boat v(t).

In order to go faster, it is important to ride the canoe without bobbing on waves. Thus, it must be measured the synchronization of movements at both ends of the boat along the vertical axis (Z axis). These type of movements are measured by ADXL202 MEMS type accelerometers, Analog Devices Inc.

It is important to measure the change of the speed of the boat during time period of each stroke. The common speed sensors are based on the magnet spinning in the impeller outside the hull of the boat. This induces the additional resistance of the boat to the water. Our solution for speed measurement is based on the electromagnetic induction principle of flow measurement. The disadvantage of the method is that it needs two holes in the floor of the boat.

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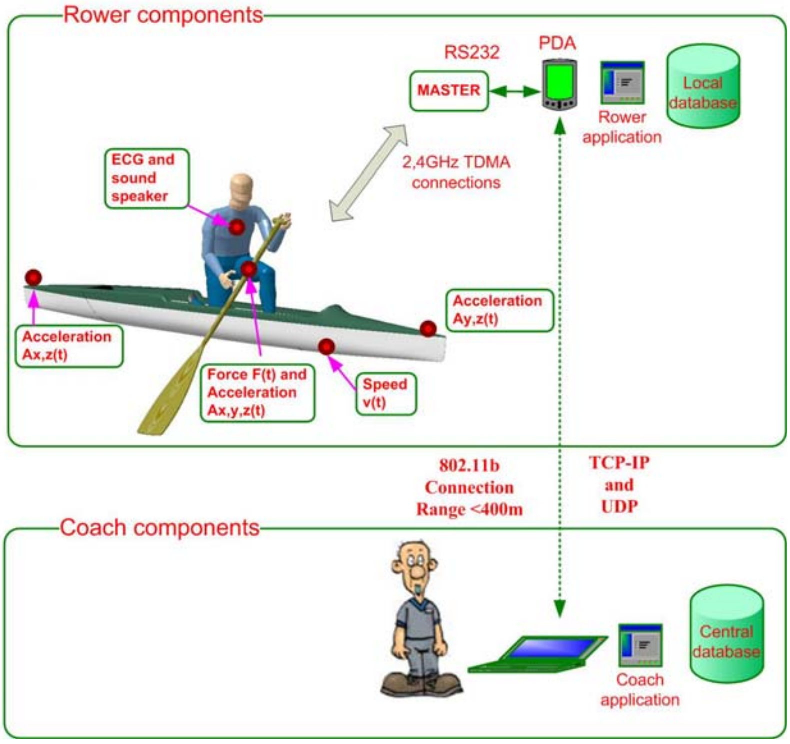

Figure 1: The component diagram of the rower real time monitoring system

The time course of the force applied to the paddle should be as rectangular as possible, in addition, the “duty cycle” of this curve should be as big as possible. The applied force is measured by measuring the bend of the paddle shaft as the force is exerted on it. The primary sensors were strain gauges. The sampling rate was set to 100Hz for each channel of mechanical parameters. The same force measurement sensor also comprises the measurement of acceleration in three axes. These parameters are used to measure the angle of paddle insertion into the water. This angle must be as close to 90 degrees to the surface of the water as possible.

The electrocardiogram (ECG) is used for evaluation of functional state of the rower during training. The functional state evaluation methodology was developed in the Institute of Cardiology, Kaunas Medicine University [3]. The standard 12 leads ECG is used in this methodology. However, 12 leads configuration is not convenient for rower and, in addition, it generates excessive amount of artifacts when rower is in motion. The solution to this issue was decision to use EASI type configuration of ECG leads [7]. The 3 EASI leads (5 electrodes) of this configuration are less sensitive to the noise. The needed standard 12 leads for sportsman functional state evaluation are recalculated from EASI by using 3- to- 12 transformation matrix [8]. The sampling rate was set to 300Hz for each of 3 channels of ECG. In addition, because this sensor is placed in the closest position to the ears of the sportsman, the sound speaker is adopted here. This sound speaker is used to generate rhythmic short clicks of sound, which can be used to control the stroke rate. The rhythm can be changed remotely by the couch.

D. Hardware and wireless communication

The sensors size, low energy consumption and wireless data transmission requirements were fulfilled by using low cost system on chip- nRF24E1 (Nordic Semiconductor ASA) [9]. This chip features: 9 inputs ADC, 8051 MCU and 2,4GHz transceiver, single 1,9-3,6V supply, low 10,5mA transmission and 19mA reception currents. It requires only several external passive elements. The data transmission range about 30m is able to meet short-range communication requirements within the boat.

The useful feature of this chip is capability to send the acquired data in ShockBurst^{TM} mode, see Fig. 2:

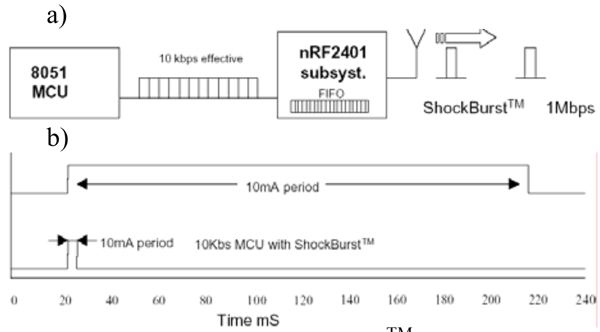

Figure 2: Energy saving ShockBurst^{TM} technology: a) data acquisition with data rate of 10kbps and transmission with data rate of 1Mbps on the air, a) continuous mode current consumption versus ShockBurst^{TM} current consumption

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Because of much higher data rate on the air than flowing to the transmitter subsystem, the transmitter is ON for much shorter time, thus consuming less energy.

The acquired mechanical and physiological parameters are sent to the master unit (data aggregation unit). The short range link between sensor nodes and master is bidirectional. This feature provides opportunity for the coach to control sensor network: to start needed sensors and to stop that are not needed. The transmition of data and control commands among master unit and sensor nodes is implemented using the proprietary Time Division Multiple Access (TDMA) protocol.

The aggregated data stream is relayed by master unit to PDA computer via USB interface. PDA computer serves two requirements: local storage of the data and provision of long range transmission of data stream to the coach computer using wireless LAN (WLAN 802.11b) technology. This kind of wireless link is convenient to use as it is already integrated in modern PDA and laptop computers. The declared communication range for WLAN devices reaches 500m in open environment and satisfies our requirements. The TCP-IP protocol is used for transmission of control commands from the coach computer and for acknowledgements from the sensors system. The UDP protocol is used for real time transmission of data as less protocol overhead is sent than in the case of TCP-IP.

E. Software

The system software includes several applications: firmware in sensors (Assembly language), software in PDA computer (C# language) and software in laptop (coach) computer (LabView, National Instruments Inc.). All digital signal processing: digital filtering, transformation of EASI leads to 12 lead is concentrated in the laptop computer of the coach.

Results

The developed wireless acceleration sensor is shown in Fig.3. The generic part of the sensor contains only 2 chips: nRF2E1 and SPI memory EEPROM 25320 for storage of the firmware code when off power. The average power consumption is about 20mA in transmit / receive modes.

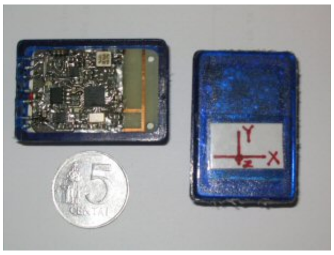


Figure 3: The acceleration sensor nodes (3rd iteration)

Fig.4a,b show force transducer and sensor mounted on the paddle. The calibration of force sensor is not implemented, yet.

a) b)

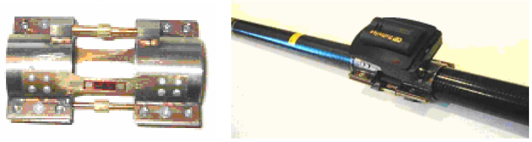
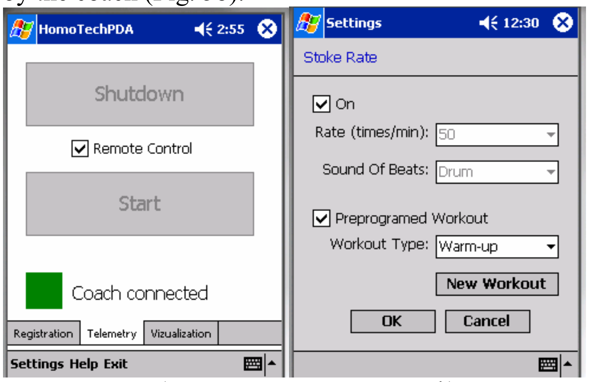


Figure 4: The force sensor: a) strain gauges based force transducer, b) the sensor mounted on the paddle

The developed software application (Fig. 5a, b) in PDA performs several tasks: a) Scans and configures the sensor network, b) Stores locally the acquired data, c) Relays the acquired data to the couch computer. In addition, it helps the rower to maintain the predefined stroke rate. This rate can be defined locally or remotely by the coach (Fig. 5b).



a) b)

Figure 5: Screen shoots of PDA application

The trends of the measured mechanical and physiological parameters (force, acceleration, speed and ECG) are shown in Figure 6.

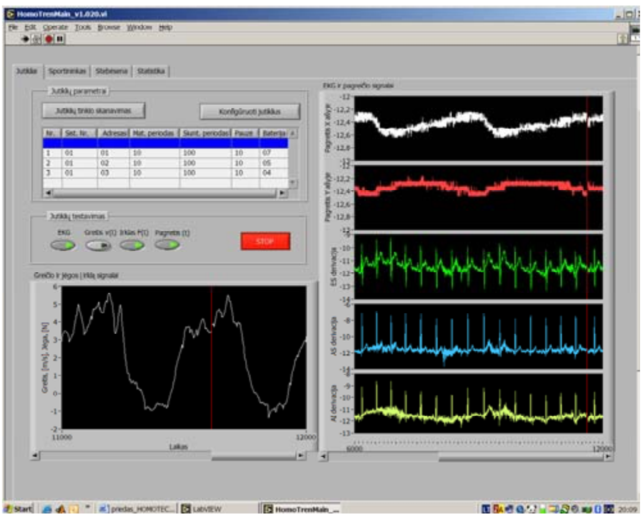


Figure 6: Monitoring of the force to the paddle, boat acceleration, boat speed and ECG in real time

The ECG recording results show strong motion artifacts present during rowing. One possibility of artifact removal could be application of the adaptive filter by

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taking advantage of multichannel recordings of coherent signals: the force and the signals from accelerometers. These signals could feed the reference channels of adaptive filter for noise reduction in ECG.

Discussion and conclusions

The prototype of wireless sensor network for monitoring of mechanical and physiological data of the sportsman and canoe during workout is designed and implemented. The proposed system makes use of several types of sensors (acceleration, force, speed, ECG) for signal fusion and extraction of useful parameters and characteristics. A few useful parameters were identified which characterize the canoe paddling process: synchronization of movement of the bow and stern in vertical axis, shape of the force curve, duty cycle of force curve, angle of exertion of the paddle into the water, stroke rate and others. One of innovations in the proposed system is assessment of the physical status of the sportsman by analyzing the transmitted ECG in real time. The estimated heart rate of the sportsman shows the effectiveness of the paddling process.

The testing of wireless LAN range in real environment (on water) showed the satisfactory data transmission range of about 350 m (measured using GPS device). However, longer range is desirable because distance in real competitions is 500m. The solution to this issue could be higher quality WLAN antennas.

In conclusion, the preliminary results of testing the developed hardware and software are promising and show that telemetry system could be used for monitoring of ECG and motion parameters when sportsman is in action. However, investigation is needed to asses the operability of the system for monitoring of indoor sports, where more 2,4 GHz devises are working in close proximity (e.g. office WLANs) and where environment is more noisy.

Acknowledgment

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