Acta Technica 63 No. 3C/2017, 95–106

Control system of fitness equipment for physiological index monitoring with Bluetooth

Yunan Jin[1]

Abstract. A treadmill system communicating with Bluetooth was built to study control system of fitness equipment based on monitoring physiology parameters. First, physiology parameters and movement data collected and recorded for a long time were analyzed. To collect heart rate data, Bluetooth 4.0 of few relative interference and heart rate chest belt and normal hand-holding heart rate sensor was used. Then, practical suggestions was made for physical condition, exercise effect and fitness scheme according to analytic results. For one-time exercise, parameters of exercise effect and physical reserves evaluation were given according to body builder's dynamic physiological parameter and movement data. Thus, body builder knows better about his physical condition and exercise effect, which helps improving exercise effect and avoiding over-exercise and hypomobility.

Key words. Bluetooth 4.0, physiological index, fitness equipment, heart rate monitoring, control system.

1. Introduction

Muscle and bone can be strengthened by running. With the improvement of material life, more emphasizes were put on physical conditions. Thus, monitoring and recording basic physiological parameter and its change were significant to medical science when diagnosing, treatment and nursing clinically. Basic physiological parameter includes blood pressure, pulse and body temperature [1], which was the first to be abnormal when people being ill or injured [2]. In conclusion, monitoring basic physiological parameter was crucial to improve people's quality of life. Therefore, health monitoring technology was used to collect various physiological parameters in order to evaluate users' movement conditions when workout on a treadmill.

[1]Hangzhou Vocational and Technical College, Hangzhou, 310018, China; E-mail: yunanjinhangzhou@126.com

2. Literature review

At first, treadmill was of single function- running. With the development of science and technology, there were many additional functions for treadmill such as speed display, slope adjustment and heart rate monitoring [3]. Besides, treadmill was developing from heart rate monitoring to heart rate control [4] and some electronic treadmills were already with heat rate control function. However, there were also some transitional fitness systems which formulated personal fitness program according to height, weight and age. And those transitional fitness systems were unscientific because it did not take individual differences and dynamic change of physiological parameters into full consideration.

Thus, below fitness system was designed: collecting and recording physiological parameter (heart rate) and movement data (speed, distance, slope and time) in a long period. Parameter definitions and corresponding formula for health keeping, weight control, aerobic exercise and sports training according to single movement were put forwarded in order to evaluate exercise effect. Besides, a filtering algorithm that put forwarded according to wire and wireless heart rate data acquired a relatively ideal effect, which applied interpolation operation at first and then weight compares mean value.

3. Research method

3.1. Overall structure

Hardware was made up of treadmill hardware, upper computer main board, cardiotachometer, frequency converter, display, keyboard and mobile terminal. The structure is shown in Fig. 1.

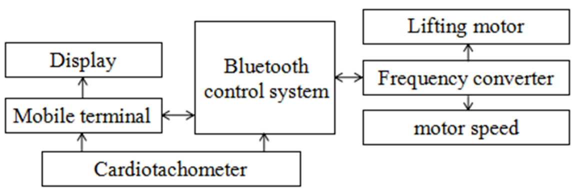

Fig. 1. Diagram of overall structure

Treadmill hardware was mainly made up of motor, belt and metal framework. And the core device motor was mainly used to adjust speed and slope. Bluetooth 4.0 was used to communicate with mobile terminal wirelessly. Upper computer was the bridge between mobile terminal and frequency converter, which was used to transmit status of frequency converter to mobile terminal and transmit order of mobile terminal to frequency converter. And frequency converter was mainly used to control speed and slope of the treadmill. Cardiotachometer was the feedback signal of physical condition, which was directly related to exercise intensity, energy consumption, respiratory degree and physical condition. When buying electronic fitness equipment, people regarded performance of heart rate measurement system as one of the important reference standards. Hand-held heart rate sensor and wireless heart rate chest belt were popular in modern industry. Bluetooth 4.0 with low power dissipation protocol was used to achieve above functions such as control and display.

3.2. Model selection of heart rate sensor

Principle of heart rate sensor to collect heart rate [5]: heart was like a power supply, through which blood circulates around body to maintain normal activity. Complex weak currency was produced by cardiac muscle during heart beat, and the currency was transmitted to different tissues. Because distances between heart and different tissues was varied and tissue in different body part was different, electric potential varies in different body parts. Weak electrocardiosignal can be collected by two different electrodes that randomly put on the human body surface.

Hand-held heart rate sensor, wireless heart rate chest belt and Bluetooth 4.0 with low power dissipation were popular in modern fitness industry. Hand-held heart rate sensor compatible with Bluetooth 4.0 chest belt were chosen instead of common wireless heart rate chest belt with relatively loud noise.

3.3. Filtering processing for heat rate data

Filtering processing was needed again because there were noises for most signals outputted by heart rate module (wireless heart rate and wire heart rate). Heart rate data was collected by electrocardiogram (ECG) which contained physiological information that reflecting performance of cardiac system [6]. Standard electrocardiogram (ECG) is shown in Fig. 2.

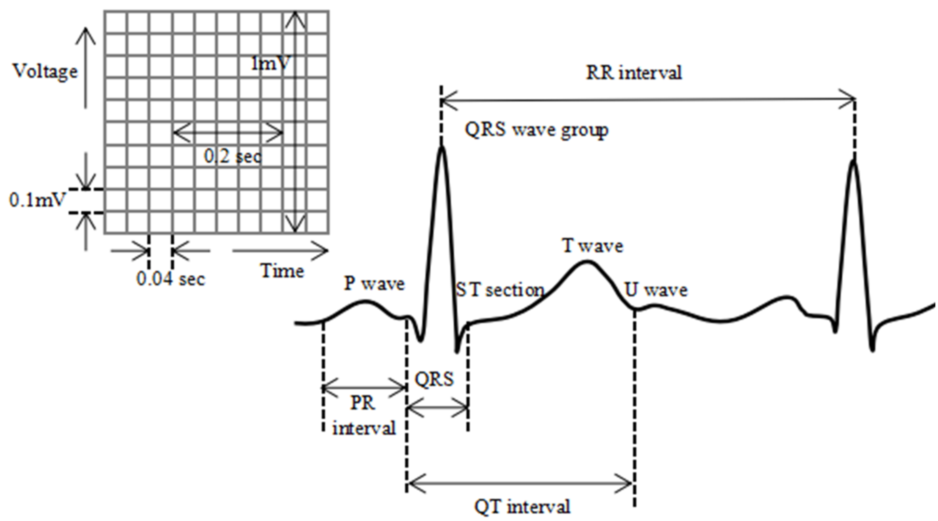

Fig. 2. Standard electrocardiogram

Most of the frequency spectrums of weak electrocardiosignal collected from human body was varied from 0.05 to 100 Hz and amplitude rage was around 10 uV-4 mV. Feature of electrocardiosignal was demonstrated by waves with bandwidth of 0∼8±3 Hz, 0∼11±2 Hz and 0∼55±19 Hz. Besides, electrocardiosignal was vulnerable to external factors, such as power line interference, electrical interference, base line drift and electromagnetic interference.

Flow for signal acquisition is shown in Fig. 3.

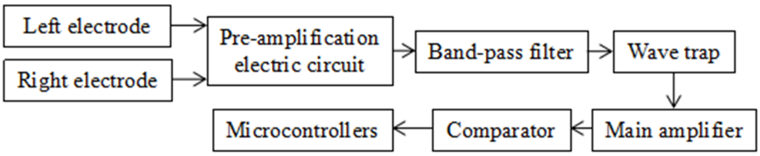

Fig. 3. Signal acquisition flow

Electrocardio energy normally worked at 17 Hz, whose frequency was around 0.05∼100 Hz and range was 5 mV. Besides, frequency of 0.5∼30 Hz was regarded as useful monitoring frequency. Butterworth band-pass filter of forth order that consisted of general operational amplifier LM324 whose bandwidth was 15 Hz and frequency was 17 Hz was used to test. After filtering, around 0.5 V electrocardiosignal can be obtained by reverse phase proportional amplification in 100 amplification times which was made up of LM324. Band elimination with relatively narrow bandwidth was named wave trap circuit. Generally, double T band-block filter circuit featuring low cost and well performance was used, which was mainly used to elimination signal at a certain frequency band and power line interference of 50 Hz.

Existing filtering algorithm for heart rate was made up of median filtering, mean filtering and slicing filtering. For mean filtering, filtering effect was well with stable data while in vigorous exercise with unstable data, filtering effect was poor. Under circumstance of poor contact and interference, filtering effect of mean filtering was better than that of median filtering though there were certain of fluctuation. Slicing filtering can effectively overcome impulse interference caused by chance factor. However, it could not restrain seasonal interference and poor smoothness [7].

Besides, another two filtering algorithm was put forwarded, interpolation operation method and method of weight comparing mean value.

1. Interpolation operation. If interval time between two pulses was close enough, median value can be eliminated. Normal heart rate of 45∼180 times/min was used in experiment and the corresponding time interval was 1.33∼0.33 ms. If time interval was longer than 1.33 ms, a pulse should be added. If time interval was shorter that 0.33 ms, comparing the two time interval next to it and found out which one was shorter. Then the time interval should be included into the shorter one. With this method, it can avoid missing pulse and collecting noise of the wrong pulse.

2. Method of weight comparing mean value. Principle of this method was comparing to the neighboring points. Weights were given according to the difference value between those neighboring points and the mean value. Then, mean value was calculated. Given filtering window was 9 and the collected original data was $a_1, a_2, \cdots, a_9$ ranged according to time sequence. Value of a_5 was to be solved.

First, mean value $\bar{a}$ should be calculated. Then, absolute differences between those neighboring points and average value were calculated: $K_n = |a_n - \bar{a}|$. If K_n was large, it meant difference between this point and the other 8 points was large. Thus, weight of this point should be lowered. Given weight of this point was $1/K_n$, and formulation of normalization constant was identified as $1/\alpha = \sum_{n=1}^{9} 1/K_n$. Thus, the value of this point was $\alpha' = \alpha \cdot \sum_{n=1}^{9} (\alpha_n K_n)$. Calculating the mean value with this method results in effective elimination of the influence of noise to mean value. It can be seen from Fig. 4 that weight comparing mean value can effectively eliminate noise and achieve accurate value.

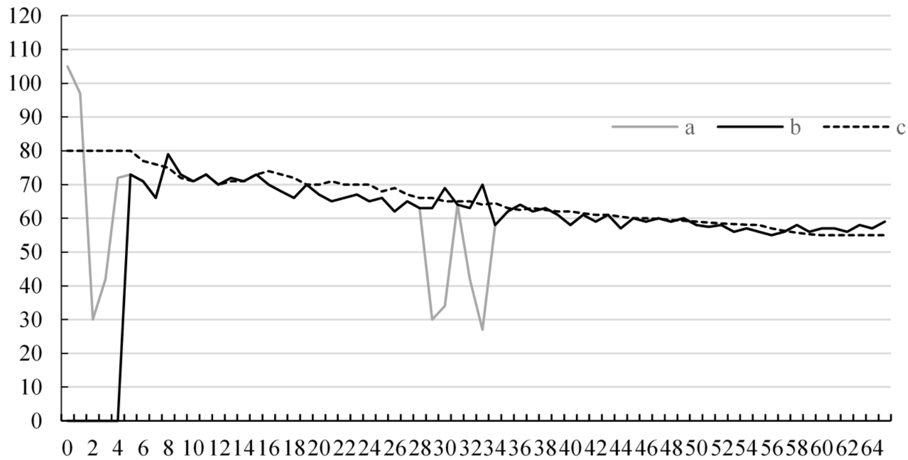

Fig. 4. Filtering effective diagram of weight comparing mean value (a was original data, b was data obtained after margin calculation, c was data obtained after mean value filtering)

3.4. Software design

CC2540 chip from Texas Instruments Company was used in lower computer studied (see Fig. 5).

Comparing to Bluetooth 3.0 version, Bluetooth 4.0 with low power dissipation protocol was featured low cost, low latency of 3 millisecond and AES-128 encription [8]. Bluetooth 4.0 can be widely applied to fields such as pedometer and heart rate monitor. There would be a heavy demand for Bluetooth 4.0 in the next 5 years. However, single mode was incompatible to classic Bluetooth device. There are two wireless technologies for Bluetooth standard 4.0, basic rate (BR, also called BR/EDR, enhanced data rate) and Bluetooth lower power dissipation (BLE). Equipment that supports both BR and BLE was called double module device. BLE protocol stack was shown in Fig. 6.

Lower computer should be able to connect to upper computer to transfer orders from upper computer to frequency converter and collect state of frequency converter.

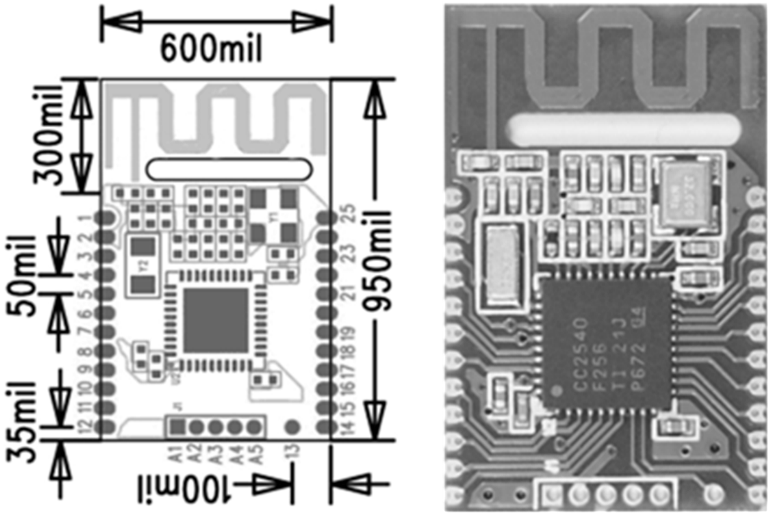

Fig. 5. CC2540 chip

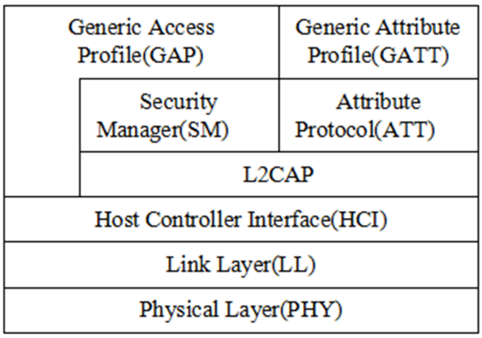

Fig. 6. Structure chart of BLE protocol stack

Thus data of computation speed, slope, and distance were transferred to the upper layer computer. Besides, lower computer can collect wire heart rate and transfer those data after in Fig. 7.

The protocol should include speed, slope, heart rate, fan, safety switch and send or accept. Protocol establishment is shown in Table 1.

3.5. Hardware design

CC2540 chip was adopted in wireless communication technology of lower computer and interface of module was shown as following:

Power interface: providing 5V direct-current supply to module.

Serial interface: for communicating with frequency converter. Serial interface was mainly used to lifting and drop treadmill and transfer state of treadmill to CC2540 chip.

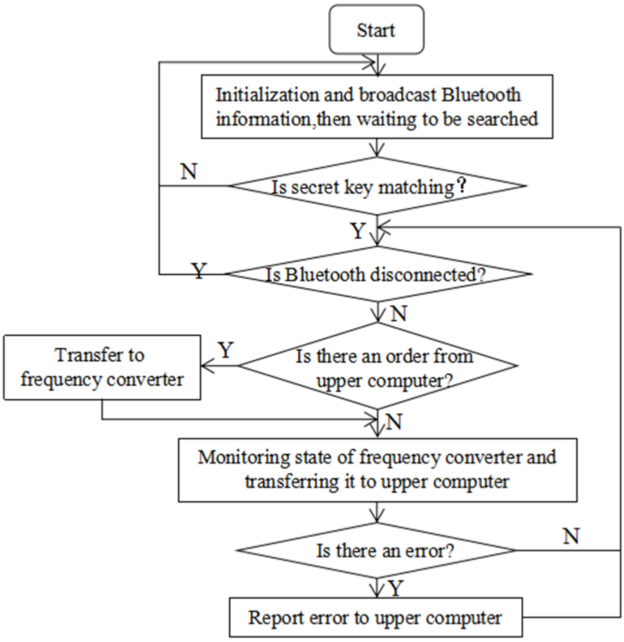

Fig. 7. Design flow chart of lower computer

Table 1. Protocol establishment

Bytes	Orders	iPad → Lower computer	Lower computer → iPad
0	Message header	FF	FF
1	Command number	00	11
2	Data 1	High speed	High speed
3	Data 2	Low speed	Low speed
4	Data 3	High slope	High slope
5	Data 4	Low slope	Low slope
6	Data 5	Heart rate: value of Bluetooth chest belt received by iPad	Heart rate: hand-held heart rate
7	Data 6	Fan(0∼255)	Fan(Retain)
8	Data 7	Safety switch(00 Open)	Safety switch(01 Close)
9	Data 8	0(Retain)	0(Retain)
10	Checksum	Checksum	Checksum
11	Data 10	00	00

Wire heart rate interface: collecting heart rate signal through wire heart rate module and transferring it to CC2540 chip after process.

Safety switch interface: monitoring state of safety switch. When safety switch was opened, safety switch would transfer this information to master chip. This interface was adopted to transfer the stop information to frequency converter and upper computer (iPhone and iPad) when user stopped it urgently.

Bluetooth wireless interface: mainly used to transfer data to upper computer (iPhone and iPad) wirelessly.

3.6. Experimental design

This experiment was designed based on IOS system and Xcode development environment and its specific design was shown as following.

1. Convert speed and slope to distance and calorie Distance increased = Speed * Time, and Total distance: $S = \int \mathrm{d}S$, whose code was

   float mDistIntervalKm = 0;// Distance increased

   mDistIntervalKm=((double)[self GetSpeed])*(mIntervalMS/60. 0/60. 0/1000. 0);

   m_Distance+=mDistIntervalKm;// Calculate distance

   Calorie increased:

   Calorie= Speed × Weight/(1.3×(38-Slope)×150×0.45)×Time.

   Among which, speed unit was km/h, weight unit was kg (defaulted as 60 kg) and slope was integer within 0–20. Total calorie: $Q = \int \mathrm{d}Q$ and the corresponding code was:

   float m_Energy;// Total calorie M_Energy+=

   =DistIntervalKm*3.6*1000.0*60/ (1.3*(38-selfGetSlope)*150*0.45)*0.3;

2. Evaluation for effect of single exercise: American College of Sports Medicine (AcsM) put forward that it was obtained by using this equation: limiting value of heart rate in each minute = 220−actual age. If heart rate was higher that this value, it was deemed to be harmful and may be dangerous. This value was regarded as one of the most important indicator for exercise program. Target heart rate can be simplified according to Cassette formula as follows:

   The maximum heart rate 50——60,% Keep fit.

   The maximum heart rate 60——70,% Weight control.

   The maximum heart rate 70——80 % Aerobic exercise.

   The maximum heart rate 80——100 % Sport training.

   It was known that the effect of single exercise can be evaluated by detecting heart rate proportion in every section. When one was under the same exercise intensity, the larger the heart rate, the poorer the physical reservation. When different people were under the same exercise intensity, the larger proportion of actual heart rate to the maximum heart rate means the poorer physical reservation.

Thus, a variable reflecting physical reservation L was given

$$L = 1 - \frac{1}{P_{\max}} \int P \, \mathrm{d}t \, .$$

When under the same amount of exercise, value L can reflect people's physical reservation.

Open software on the iPad, the main operation interface would show 6 buttons, such as accelerate, decelerate, increase the slope, decrease the slope, start, and stop. Besides, it also displayed value of speed, slope, distance, time, calorie, and heart rate. What's more, two icons were displayed, speed table and slope table. Bluetooth connection interface was made up of two buttons, one progress bar, two switches and a table, which was used to search and connect to treadmill. Data analysis interface was made up of function buttons such as velocity curve, heart rate curve, distance, time, calorie, and evaluations and an icon, which was used to display those recorded historical data. Interface design would not be described.

4. Result and analysis

Control variate method was adopted. Four experimenters were requested to jogging 20 min (male: 6 km/h, female: 5 km/h) at 5:00 p.m. every day. Change of heart rate curve was analyzed and physical reservation and exercise effect were evaluated. Those were required for one month.

Data and analysis results on 14th August, 2016 were selected, which was shown as below.

Experimenter A: male, 25 years old in good health, sometimes outdoor exercise.
Experimenter B: male, 44 years old in good health, hardly outdoor exercise.
Experimenter C: female, 22 years old in good health, hardly outdoor exercise.
Experimenter D: female, 41 years old in good health, sometimes outdoor exercise.

Table 2. Experimental data

Experimenter	Physical reservation parameters	Keep fit	Weight control	Aerobic exercise	Sports training
A	0.28	4.7 %	24.9 %	66.2 %	0.8 %
B	0.22	5.5 %	0.5 %	31.7 %	57.2 %
C	0.32	3.4 %	34.6 %	59.8 %	0.0 %
D	0.27	3.2 %	28.7 %	53.5 %	12.3 %

It can be known form Table 2 that different experimenters were different in physical reservation. Experimenter B was in poor physical reservation because of no regular exercise and relatively older that the other experimenters. Experimenters A and C was in good physical reservation because of young. Experimenter D who was relatively elder than the other experimenters was in middle level of physical reservation because of regular exercise.

Besides, it can also evaluate their exercise effects by comparing it to the expected ones. Physical reservation of experimenter A in August, 2016 is shown in Fig. 8.

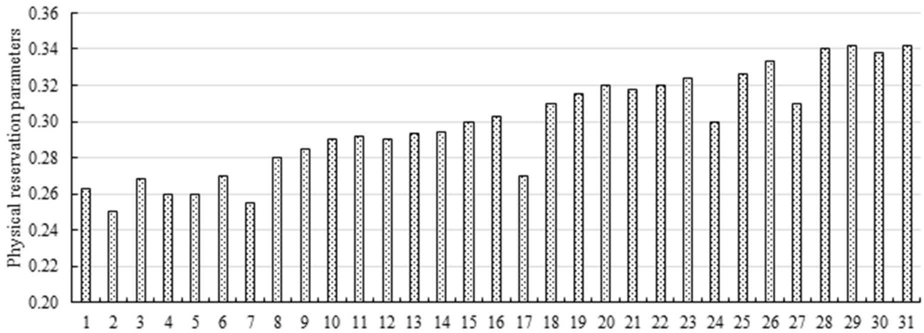

Fig. 8. Physical reservation of experimenter A in August, 2016

It can be known that after a long-term exercise, experimenter's physical reservation was improved, which meant his physical reservation was enhanced. This was comforted to human physiological feature and proved that those physical reservation parameters were reasonable.

5. Conclusion

Based on hardware and communication technology of traditional treadmill, hardware device Bluetooth 4.0 of lower power dissipation was designed, which was able to control treadmill and communicate with iPhone. IOS Client software was developed to store, operate and display relevant data. By dividing heart rate section, users can check effect of each exercise at a glance. Besides, physical reservation parameter concepts was put forwarded and was proved with a month's experiments.

References

[1] T. Bossmann: *Effects of an ultra-long distance running on selected physiological and psychological parameters as possible markers of overtraining.* Schweizerische Zeitschrift fur Sportmedizin und Sporttraumatologie *60* (2012), No. 1, 21–25.

[2] J. A. Bragada, P. J. Santos, J. A. Maia, P. J. Colaço, V. P. Lopes, T. M. Barbosa: *Longitudinal study in 3.000 m male runners: Relationship between performance and selected physiological parameters.* Journal of Sports Science & Medicine *9* (2010), No. 3, 439–444.

[3] Ł. Dziuda: *Fiber-optic sensors for monitoring patient physiological parameters: a re-*

view of applicable technologies and relevance to use during magnetic resonance imaging procedures. Journal of Biomedical Optics *20* (2015), No. 1, paper 010901.

[4] J. Del Coso, C. González, J. Abian-Vicen, J. J. M. Salinero, L. Soriano, F. Areces, D. Ruiz, C. Gallo, B. Lara, J. Calleja-González: *Relationship between physiological parameters and performance during a half-ironman triathlon in the heat.* Journal of Sports Sciences *32* (2014), No. 18, 1–8.

[5] P. G. M. da Rocha, J. L. Lopes, S. M. F. de Moraes: *Effect of environment alteration in psychological components and physiological parameters during the treadmill running in athletes.* Psicologia: Teoria e Pesquisa *26* (2010), No. 2, 381–386.

[6] A. Stankus, V. Stankus, R. Didziokas, G. Varoneckas: *High frequency filtering of 24-HOUR heart rate data.* European Journal of Scientific Research *9* (2013), No. 33.

[7] A. Jóśko, P. Irzmański, P. Figoń: *Classic, adaptive filtering techniques in the ECG signal enhancement.* Przegląd Elektrotechniczny *91* (2015), No. 7, 11–12.

[8] J. F. Ensworth, M. S. Reynolds: *Every smart phone is a backscatter reader: Modulated backscatter compatibility with Bluetooth 4.0 Low Energy (BLE) devices.* Proc. IEEE International Conference on RFID (RFID), 15–17 April 2015, San Diego, CA, USA, IEEE Conference Publications (2015), 78–85.

Received May 7, 2017