System for Assisted Exercising and Qualitative Exercise Assessment

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Abstract— **In recently studies, as one of simpler and better solution for measuring human mobility and physical activity, Wireless Body Area Networks (WBAN) have been introduced. In order to acquire those information and due to the desire of future growth in mentioned filed, WBAN consisting of inertial and magnetic sensors was developed at our Department. The WBAN together with developed desktop application forms a unique system for assisted exercising and exercise evaluation. In exercising evaluation of patients or sportsmen, a new approach in qualitative assessment is used. New approach introduces "Exercise Signature" as a reference signal for evaluation of exercising. The main concept is that every exercise has some characteristic data which are calculated by the developed algorithm and then saved in exercise database. The mentioned application is not only used for calculating characteristic exercise data, but it also has a role in visualization of the virtual trainer which leads the person who is exercising through his personalized training. In this work, we present detailed description of the whole assisted strength exercising system and elaborate its possible applications. Endurance exercising protocols will be described elsewhere.**

Keywords— **WBAN, assisted exercising, real-time feedback, virtual trainer, signature.**

I. INTRODUCTION

Physical activity in daily life can be categorized into occupational, sports, conditions, household or other activities [1]. Because of modern sedentary lifestyle, physical inactivity is on the rise in many countries, adding to the burden of non-communicable diseases and affecting general health worldwide. People who are insufficiently active have a 20% to 30% increased risk of death compared to people who engage in at least 30 minutes of moderate intensity physical activity on most days of the week [2]. One of solutions to minimize physical inactivity is in controlled effective exercise regimen. Such type of physical activity can be used in a gym or at home with guidance of personal trainer. The aim of a trainer is to teach users how to design programs to reach specific fitness goals and how to perform exercise correctly in order to minimize the possibility of injury and to maximize positive effects of exercising. Main problem in mentioned activity is that personal trainers are not affordable to all due to the high cost [3, 4]. Rapid developed of MEMS (Micro-Electro-Mechanical Systems) in recent decade provides minimized and low-cost sensors which can be use in the detection of body posture and motion, so they present a possible solution for development of intelligent supporting devices or systems replacing private, human trainers on daily basis.

Some researches use accelerometer as the only sensor which is used for motion detection [4-7]. However, for better motion detection, using multiple types of sensors as a part of Wireless Body Area Network (WBAN) is recommended. Our research team had developed a WBAN for continuous personalized monitoring with inertial and magnetic sensors, as described in [8]. The mentioned WBAN in combination with desktop applications provides real-time exercise feedback as result of quantitative and qualitative assessment of individual exercising.

In this paper, we focus on the part of system which is responsible for determining the special characteristics of correct movements as reference values for each exercise, evaluation of movements performed by the person who is exercising and integration of both into the virtual trainer tool that guides the users through each exercise.

II. METHODS

A. System Description and Signal Processing

The WBAN is consisting of several universal integrated sensor nodes. Each sensor node has two inertial and one magnetic sensor [8]. In order to get a more precise analysis, a system based on body segment orientation estimation has been developed [9]. An orientation filter was implemented to provide a single estimate of orientation through the optimal fusion of accelerometer, gyroscope and magnetometer measurements. The sensor node microprocessor is used to collect sensor data, implement orientation filter algorithm and provide a quaternion description of orientation as output.

The gyroscope is used to measure angular velocity which is integrated over time to compute the sensor's orientation. However, the integration of gyroscope measurement errors leads to an accumulating error in the calculated orientation and therefore the gyroscope alone cannot provide an absolute measurement of orientation. An accelerometer and magnetometer are used to measure the earth's gravitational and magnetic field respectively and to provide an absolute reference of orientation. However, they are likely to be

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subject to high levels of noise; for example, accelerations due to motion corrupt measured direction of gravity. The task of the implemented orientation filter is to compute a single estimate of orientation through the optimal fusion of accelerometer, gyroscope and magnetometer measurements.

Accelerometers, gyroscopes and magnetometers provide a digital output value proportional to the measured physical quantity. The use of orientation filter requires that this value is converted to a suitable engineering unit; rad/s, m/s2 and Gauss, a typical unit of gyroscopes, accelerometers, and magnetometers respectively. These units are obtained by accounting for a calibrated bias and gain in the sensor output.

Due to the mechanical properties of a MEMS device, the characteristics of an individual sensor cannot be guaranteed during manufacturing and may be altered later during assembly of the nodes by soldering. Consequently, no two sensors may be guaranteed to be the same and each must be uniquely calibrated so an automated procedure for gyroscope and magnetometer gain and bias calculation has been developed.

B. Algorithm for Qualitative and Quantitative Assessment

The quality of exercise can be descriptively defined as exercise performing in accordance with the instructions of the personal trainer. One of the features that the system for assisted exercising must include is also tolerance on mistakes and improper execution of the exercise. At the beginning of using the system for assisted exercising, it is very important to allow users to adjust on it, therefore the tolerances to mismatch of individual movements are set wide, e.g. 30%. After the user adjusts to regular exercising, tolerances can be narrowed so requirements for movement accuracy during exercising will become more stringent and the user is expected to become more motivated and encouraged to progress. Before the implementation of the algorithm it is necessary to find good quality indicators of exercise in output signals from sensor nodes. It is important to mention that remaining signal processing is done with Euler angles, expressed through three axes which are results of conversion of Quaternion output obtained from sensor nodes [10].

In the obtained Euler angles waveforms, points that reflect the physical image of the body motion can be found. Start of motion is detected as a sudden increase/decrease of the first derivation of signal and the local minimum and maximum can be attributed to describe angles during exercise. An algorithm for detecting the start or end of repetition movement is determined on dominant axis, axis which has the largest amplitude in the signal (Fig. 1). Amplitudes of signals and edges (rising and drop downed) are the basic properties that are used for real-time exercise quality assessment.

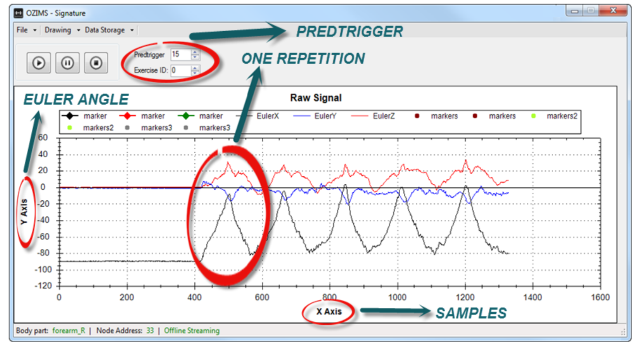

Fig. 1 Raw Euler angles waveform

In the process of calibration, for each exercise, the start and end derivation of one repetition with corresponding Euler angles in that two points are taken. Besides them also is taken the corresponding band of signal i.e. all values of signal between start and end point. At the time when the start and end is specified on the dominant axis, band of signal from other two axes is also taken. Based on these parameters, all repetitions in signals are taken (for each axis separately), they are aligned on the start trigger edge and then overlapped one over the other. The result of the calibration is displayed graphically in Fig. 2. Repetitions in Fig.2. are formed so that after start edge detection N of previous samples, all samples between start and end edge detection and N samples after end detection are stored (N is number of samples which is defined by user). The total duration of repetition is the time between the trigger edges plus 2N samples. From the first to the last sample, between selected repetitions, the maximum and the minimum value of the signal is looked for. As a result, two signals are obtained and they define the limit values of one exercise repetition (blue color in Fig. 2). Those two values define the “Exercise Signature”, the reference value for each exercise. Increasing tolerance has a twofold effect on the functioning of the system.

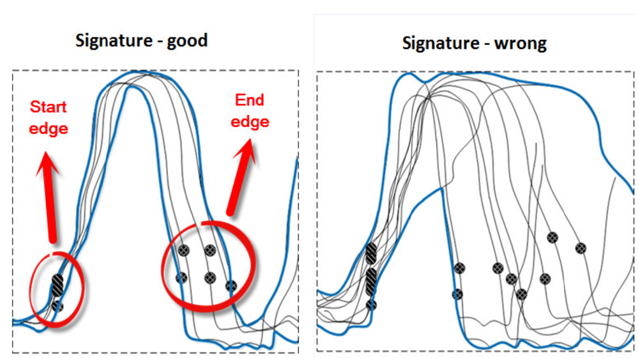

Fig. 2 Signature for dominant axis

Primarily, it allows repetition detection and motivation for work for user with poorly trained knowledge but also too much tolerance can lead to an incorrect signature (Fig. 2). Then, each waveform that falls into limits will be assessed as correct, regardless of its actual quality.

It is preferred that the Exercise signature is calculated from exercising of an expert athlete so the further exercise evaluation has higher quality.

C. Exercise Evaluation

Assessment of the quality of exercising is consisting of calculation the deviation from the thresholds and detection of crossings through the thresholds. The absolute amount of deviation is a good indicator of how much exercise waveform is corresponding to the reference waveform and does user follow up given pace of execution. Detection of crossing through the thresholds provides good information of smoothness in motion. Training level of a user is taken in consideration for quality assessment and it is stated in three levels: low, medium and high. Depending on the selected level, the user gets a protocol for strength exercising. The protocol is defined by an expert person and within a specified duration of a training T (e.g. 20 min for a low level user, 40 min for a high level user), the training consists of *n* repetitions in *m* sets of *k* exercises, where each single repetition of an exercise lasts t_{rep} seconds. In a training duration (T) it is also included pause between sets (t_{pset}) and pause between exercises (t_{pex}). T is defined in equations (1 and 2) and all parameters for one exercise are explained in Fig. 3.

$$T = \sum_{i=1}^{k}(m_i * n_i * t_{rep_i} + (m_i - 1) * t_{pset_i}), \mathrm{k} = 1 \qquad (1)$$

$$T = \sum_{i=1}^{k}(m_i * n_i * t_{rep_i} + (m_i - 1) * t_{pset_i}) + \sum_{l=1}^{(k-1)} t_{pex_l}, \qquad \mathrm{k} > 1 \qquad (2)$$

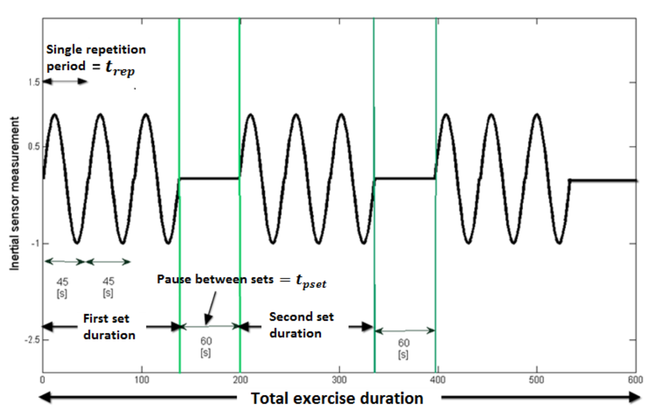

Fig. 3 Total exercise duration for one exercise

III. DESKTOP APPLICATIONS

The algorithm for the qualitative and quantitative assessment and exercise evaluation are two demanding and separated units. In order to achieve their uniqueness, connectivity and automation, certain desktop applications are implemented.

A. Application for Generation of Individual Exercise Signatures

In the application, there is a window that displays obtained Euler angles from all three axes (Fig. 1). With a simple mouse clicking characteristics data of signal (start and end threshold edge and a local minimum or maximum) are selected. In order that application independently calculates the Exercise Signature, also the number of N (explained in section 0) is needed to be defined as variable Pretrigger (Fig. 1). Calculated Exercise Signature for all three axes is shown in Fig. 4. Such obtained Signatures are stored in database and they are available to all users who have the right to it.

B. Application for Exercise Evaluation

During the exercising the user is guided by a virtual trainer that shows the proper execution and tempo of the exercise. Tempo can also be followed by moving ball (Fig. 5). Except virtual trainer user sees his movements and real-time quality assessment. Each repetition can be defined in one of three colors: green – good repetition, red – bad repetition and yellow – undefined repetition. Detailed description and functioning of virtual trainer is in paper Žulj S. [9].

IV. CONCLUSION AND FUTURE WORK

System for assisted exercising and qualitative assessment is developed. The main part of the system is developed algorithm for qualitative and quantitative assessment, which is called Exercise Signature. Algorithm as input uses Euler angles which are obtained by combining the processed signals from accelerometer, gyroscope and magnetometer. With the visual interface i.e. desktop applications the system has become a complete whole and it allows the users to track their own movement and real-time evaluation. At every second of exercising the user knows where he is and does his body movement satisfies the necessary criteria which provides him a self-control and own monitoring. All the results of exercising are stored in database and they are always available for user.

Realized system is planned to be tested on a specific population of athletes and non-athletes with goal of determining the best possible characteristics signal data, such as start and end edges of repetition. Besides signal processing, participants will have to assess how does this system motivates them to exercise because of its feedback and is there any necessary improvements in desktop applications' design.

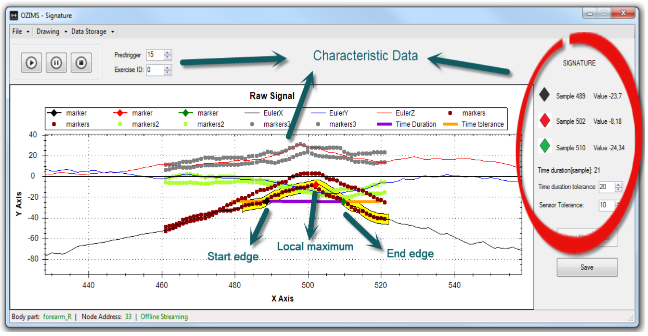

Fig. 4 Application for generation of individual Exercise signature

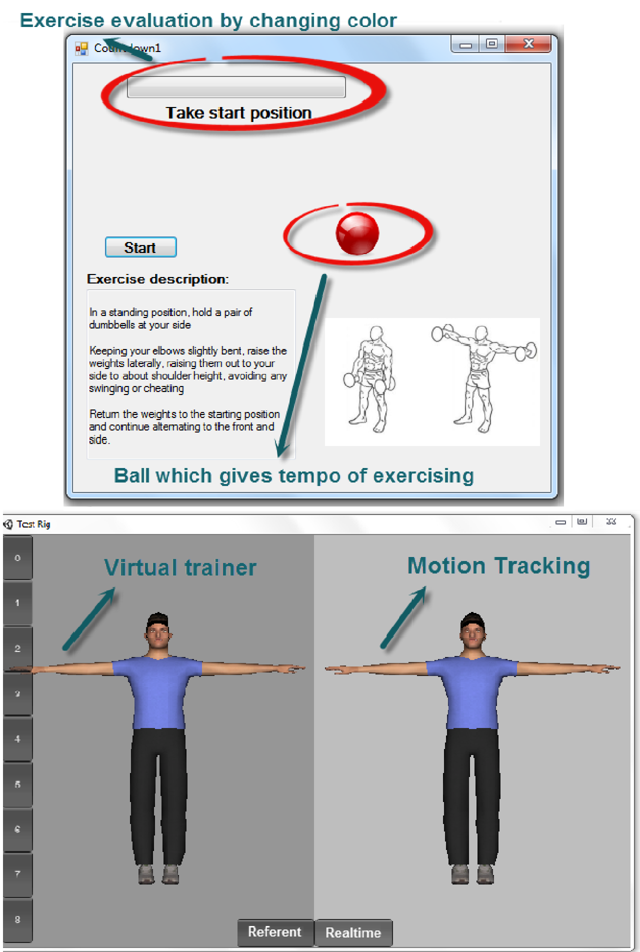

Fig. 5 Application for exercise evaluation

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCES

1. Caspersen, C. J., Powell, K. E., & Christenson, G. M. (n.d.). Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Reports (Washington, D.C.: 1974)*, *100*(2), 126–31. Retrieved from http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1424733&tool=pmcentrez&rendertype=abstract
2. Physical activity at http://www.who.int/mediacentre/factsheets/fs385/en/
3. Kumar Diwakar, P., Keun Oh, Y., Park, S.-H., & Yoon, Y.-R. (2005). Personal digital exercise trainer for managing, monitoring and recording the exercise. Conference Proceedings : ... Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Conference, 4, 3720–3. doi:10.1109/IEMBS.2005.1617291
4. Silva, B. De, Natarajan, a., Motani, M., & Chua, K.-C. C. K.-C. (2008). A real-time exercise feedback utility with body sensor networks. 2008 5th International Summer School and Symposium on Medical Devices and Biosensors, 49–52.
5. Bouten, C. V. C., Koekkoek, K. T. M., Verduin, M., Kodde, R., & Janssen, J. D. (1997). A Triaxial Accelerometer and Portable Data Processing Unit for the Assessment of Daily Physical Activity, 44(3), 136–147.
6. Haapalainen, E., Laurinen, P., Roning, J., & Kinnunen, H. (2008). Estimation of Exercise Energy Expenditure Using a Wrist-Worn Accelerometer: A Linear Mixed Model Approach with Fixed-Effect Variable Selection. 2008 Seventh International Conference on Machine Learning and Applications, 796–801. doi:10.1109/ICMLA.2008.131
7. Lee, M.-W., Khan, A. M., Kim, J.-H., Cho, Y.-S., & Kim, T.-S. (2010). A single tri-axial accelerometer-based real-time personal life log system capable of activity classification and exercise information generation. Conference Proceedings : ... Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Conference, 2010, 1390–1393.
8. Pozaic, T., Varga, M., Dzaja, D., & Zulj, S. (2013). Closed-loop system for assisted strength exercising. Information & Communication Technology Electronics & Microelectronics (MIPRO), 2013 36th International Convention on, 1314 – 1319
9. Žulj S., Šeketa G., Džaja D., Celić L. and Magjarević R. (2014). Virtual Reality System for Assisted Exercising Using WBAN. In this issue, under review
10. Conversion Quaternion to Euler at http://www.euclideanspace.com/maths/geometry/rotations/conversions/quaternionToEuler/

11. Pärkkä, J., Ermes, M., Antila, K., van Gils, M., Mänttäri, a, & Nieminen, H. (2007). Estimating intensity of physical activity: a comparison of wearable accelerometer and gyro sensors and 3 sensor locations. Conference Proceedings : ... Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Conference, 2007, 1511–1514.
12. Melzi, S., Borsani, L., & Cesana, M. (2009). The Virtual Trainer: Supervising Movements Through a Wearable Wireless Sensor Network, 00(c), 6–8.

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