Rehabilitation System for the Motion Analysis of the Wobble Board

Maros Smondrk[1], Jana Krohova[1], Martin Cerny[1], Jindrich Cernohorsky[1],
Iva Chwalkova[2], and Mariana Zadrapova[2]

[1] VSB – Technical University of Ostrava, Department of Cybernetics and Biomedical Engineering, Ostrava, Czech Republic
[2] University Hospital of Ostrava, Clinic of Rehabilitation and Physical Medicine, Ostrava, Czech Republic

Abstract— **This paper describes the design and implementation of the telemetric low energy rehabilitation system for the motion analysis of the wobble board. The balance exercises on the wobble board are used for the rehabilitation of diagnoses such as poor posture, flat foot, different types of fractures and postsurgical states of a lower extremity. In routine clinical practice the patient is under constant supervision and guidance of a physiotherapist. The physiotherapist ensures that the patient has the proper posture or that they activate the correct muscle group. The motion analysis of the wobble board could provide important information about the quality of the undertaken exercise which could for example tell us if the patient uses the correct muscle group. The proposed system was compared with the most significant related works and their advantages and disadvantages were pointed out.**

Keywords— **rehabilitation, Bluetooth 4.0, low energy platform, wobble board, orientation.**

I. INTRODUCTION

Nowadays, a large part of the population suffers from joint pain, back pain mainly in the sacral and lumbar region, various muscle imbalances, incorrect posture, incorrect movement patterns, an increased risk of accident conditions (ankle sprain, knee injury), and a risk of falls in elderly people. The most common causes of these problems are a sedentary lifestyle and lack of regular exercise. These factors are significantly involved in the formation of functional diseases of the musculoskeletal system. [1]

In many rehabilitation centers the balance exercise is used for the aforementioned problems. The balance exercise is particularly indicated for diagnoses such as lower limb fractures, instability of the knee joint, plastic of the knee joints, total hip replacement, hip and pelvic fractures, etc. The main principle of balance exercises is to balance on a rehabilitation tool, which may take different forms. The most commonly used balance tool is the wobble board. Its symmetrical shape allows the patient to move in the range from 0 to 30 degrees. This range is limited by its curvature and height. During the balance exercise the patient performs several basic exercises under constant supervision and guidance of a physiotherapist. The physiotherapist's main task is to ensure that the patient performs the exercise correctly, that they have the proper posture, that the correct muscle groups are actively involved, etc. The main problem is the compensation of the movement with the involvement of an improper muscle group. This compensation may be reflected in the rotation of the wobble board, or other body parts. The quality of the rehabilitation and progress of the patient is usually evaluated only subjectively and depends on the theoretical and practical knowledge of the physiotherapist. The standard rehabilitation program using balance exercises takes several weeks and even months to see some results. The main disadvantage of a repeated balance exercise is decreasing the motivation of the patient.

Various studies have shown improvements of postural control through the balance training, e.g.: ankle sprain prevention, the improvement of the static balance of people with the Down syndrome, etc., [2] - [4]. The determination of the correlation between postural control and strength was also found, [5]. It follows from the foregoing that the need of an objective assessment of the balance rehabilitation process and progress of the patient has reasonable importance and great benefit to the physiotherapist and patient. This type of evaluation can be achieved by simply mounting the measuring part into the wobble board in combination with visual feedback.

II. RELATED WORKS

To the best of our knowledge there are two most significant studies that use the inertial measurement unit (IMU) as a measuring part in the wobble board.

A. The E-Wobble Board

The measuring part of the E-Wobble consists of the IMU which combines a 3-axis ADXL 335 accelerometer and an ITG 3200 gyroscope, an Arduino microcontroller, an affixed sandal, actuators and a Bluetooth module (Bluetooth version 2.0). For this system, a golf game was used as therapeutic software for ankle rehabilitation. The main idea is that the patient should try to drag the ball into the hole with the appropriate motion on the wobble board. There are four different types of exercises which depend on the mutual position of the hole and the ball. Fifteen healthy

I. Lacković and D. Vasić (eds.), *6th European Conference of the International Federation for Medical and Biological Engineering*,
IFMBE Proceedings 45, DOI: 10.1007/978-3-319-11128-5_132

participants participated in this study (11 males and 4 females). Each subject took 4 sessions with a maximal angle range from 2 to 20 degrees with step 2 degrees. In this paper the average velocity and jerkiness were measured. [6]

B. The Virtual Balance Training System

This system uses the orientation tracker Xsens MTx Motion Tracker as a measuring part, which consists of a 3-axis accelerometer, a 3-axis gyroscope, a 3-axis magnetometer, and an RS-232 USB communication cable. The orientation tracker was attached to the surface with sticky tape. For this system an open source computer game "Neverball" was used. This game requires the user to tilt the base floor to roll the ball through the obstacle course and try to collect as many virtual coins as they can before the time limit is up. This system was tested on twelve healthy participants (6 females and 6 males). The participants had to fill in a computerized usability questionnaire designed specifically for the evaluation of virtual reality applications. This type of questionnaire is used for quantitative benchmarking and evaluating the interaction of potential users. [7]

The aforementioned papers have proven that using motion sensors attached to the wobble board to track movement during the rehabilitation exercise has a great potential to improve patient motivation. The authors have tested their solution on healthy subjects without taking into account injured persons who should be the main target group, and the content of the therapeutic exercises should be designed with respect to the patient's diagnosis. The authors have not taken the vertical rotation of the wobble board into consideration. Vertical rotation could provide additional information about the quality of the undertaken exercise. The main aim of our work was to develop a rehabilitation system for the motion analysis of the wobble board which will meet criteria such as: full 3D motion measurement with sufficient accuracy, wireless data transfer, a low energy and costless system, and a user friendly rehabilitation software.

III. SYSTEM DESCRIPTION

The proposed device consists of the IMU and the module platform OLP425. The OLP425 is a Bluetooth Low Energy 4.0 (BLE) platform module from connectBlue. It combines a 2.4 GHz transceiver, a microcontroller, 256 kB of in-system programmable flash memory, 8 kB of RAM, and peripherals, [8]. As the IMU we have used a commercial available 9-axis motion tracking device MPU-9150 from InvenSense. It comprises a 3-axis accelerometer, a 3-axis gyroscope, and a 3-axis magnetometer integrated in one package, [9]. The output data rate can be set at a user selectable frequency with respect to the data throughput of the BLE protocol. The average power consumption of the proposed system is 6.7 mA for the sampling frequency of 10 Hz, 10.2 mA for 25 Hz and 15.1 mA for 50 Hz. The test was performed according to the test protocol described in [10].

There are a variety of approaches for the orientation estimation under static or dynamic conditions which use a different combination of inertial sensors, [11], [12]. The orientation of the proposed system is using accelerometer and magnetometer raw data. The gyroscope was not used due to its considerable power consumption. The proposed device is embedded into the rehabilitation wobble board whose shape allows the patient to move in limited ranges. We assume that the wobble board is not affected by linear acceleration during the rehabilitation; it is affected only by rotation around one fixed point. The achievable rotation of the wobble board is in the range of ±30°in the x, y axis and a full 360° in the z axis. The orientation of the rehabilitation wobble board is represented by the Euler angles: roll, pitch and yaw (Fig. 1).

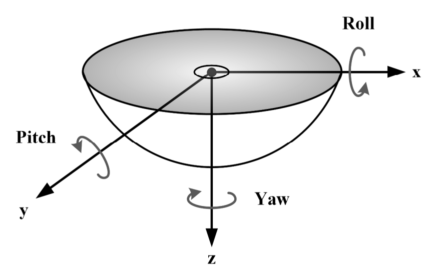

Fig. 1 Body coordinates and attitude angles. Roll is defined as the rotation around the x axis, pitch as the rotation around the y axis and yaw as the rotation around the z axis.

The accelerometer output is used for the roll and pitch estimation as follows, [13]:

$$roll = \tan^{-1}\left(A_Y / A_Z\right), \quad (1)$$

$$pitch = \tan^{-1}\left(-A_x \Big/ \sqrt{A_Y^2 + A_Z^2}\right), \quad (2)$$

where A_X , A_Y , A_Z are calibrated accelerometer readings in particular axes x, y, z. The accelerometer readings have to be preprocessed in order to calibrate its outputs. This task includes the determination of the accelerometer offset, the scale factor and the misalignment matrix between the accelerometer sensing axes and the device body axes. [13]

In order to estimate yaw, the following formula is applied to the magnetometer outputs, [13]:

$$yaw = \arctan\left(yaw_Y / yaw_X\right), \quad (3)$$

where yaw_X and yaw_Y are the horizontal components of the local earth magnetic field, namely axes x, y. They are defined as follows [13]:

$$yaw_X = M_X \cdot \cos(pitch) + M_Z \cdot \sin(pitch), \tag{4}$$

$$yaw_Y = \begin{pmatrix} M_X \\ M_Y \\ M_Z \end{pmatrix}^T \cdot \begin{pmatrix} \sin(roll)\cdot\sin(pitch) \\ \cos(roll) \\ -\sin(roll)\cdot\cos(pitch) \end{pmatrix}, \tag{5}$$

where M_X, M_Y, M_Z are calibrated magnetometer readings, namely axes x, y, z. The magnetometer raw readings also have to be calibrated in order to suppress the so-called hard-iron and soft-iron distortion and to estimate the magnetometer offset, the scale factor and the misalignment matrix with respect to the device body. The expected orientation accuracy is < 1° in pitch/roll and < 2° in yaw. [13], [14]

The proposed software consists not only of rehabilitation software, but it also comprises the firmware of the measuring part which ensures the acquisition of the measured data from the sensors and data transmission to the PC. The rehabilitation software was developed in MATLAB R2011a. It provides real-time graphical representation of the patient motion during the rehabilitation exercises. The proposed software consists of four different programs: geometric shapes (Fig. 2A), points on a circle (Fig. 2B), stability (Fig. 2C), and deflection (Fig. 2D). The rehabilitation programs were designed in cooperation with physiotherapists from the Therapeutic Rehabilitation Clinic of the University Hospital of Ostrava.

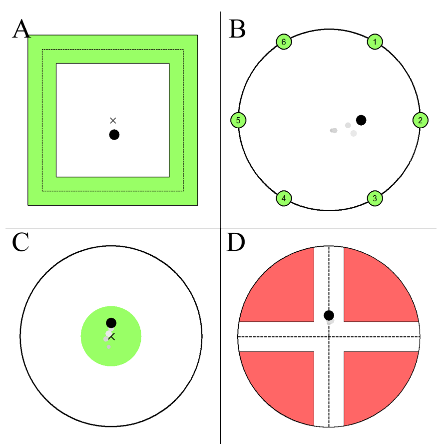

Fig. 2 The proposed rehabilitation programs.

The therapeutic software is designed for patients with poor posture, flat foot, hip arthritis, attention deficit, hyperactivity disorder, with different types of fractures, such as the pelvis fracture, ankle fracture and postsurgical states such as the plastic repair of the ligamentum cruciatum anterior and posterior, and meniscectomy. More information about the rehabilitation software can be found in [15]. Until now, more than thirty patients between the ages of 12 to 30 have participated in testing the proposed system. The preliminary testing indicates their higher intrinsic motivation towards the rehabilitation goals.

IV. DISCUSSION AND CONCLUSION

In contrast to the E-Wobble, the proposed system is based on the combination of the accelerometer and the magnetometer. Their outputs are digitized by 10-bit resolution; moreover, the gyroscope has a fixed full scale range. Therefore the sensitivity scale factor is considerably smaller than the sensitivity of the proposed system, notwithstanding the gyroscope power consumption. If we take into account the power consumption of the Bluetooth module (approx. 30 mA), the sensor module (approx. 6.85 mA) and the Arduino microcontroller (approx. 50 mA), our system has considerably lower energy requirements, [6].

The sensor part of the Virtual Balance Training System is based on the combination of the accelerometer, the gyroscope and the magnetometer. The very precise orientation estimation is achieved at the cost of notably high power consumption (approx. 70 mA) and price, [7]. The data transfer wires which are connected to the wobble board can lead to reduced patient movement during the rehabilitation exercise. A wireless solution is more suitable in this type of application.

Another common issue of the related works is that the sensor part is shifted from the axis in which the center of the board rotation is localized. This displacement, for example in the case of an accelerometer, leads to higher acceleration readings due to the presence of external linear acceleration superimposed to gravitational acceleration. This could be overcome by proper calibration or a sensor fusion algorithm which takes into account the mutual position of the sensor and the center of rotation. Otherwise it could result in the distortion of the orientation estimation.

The rehabilitation software Neverball and the golf game were tested on healthy participants. The golf game is based only on the four basic types of movement defined by the mutual position of the ball and the hole. It is mainly targeted at ankle rehabilitation. On the other hand, in our opinion, the measured averaged velocity and jerkiness provide useful information about the performed exercise. Neverball is based on free movement in 3D virtual space. It cannot provide targeted therapy for specific patient groups. Moreover, it is difficult to define a virtual line which the patient has to track. The game provides a small amount of data which can be used for the quantification of the patient's progress.

The proposed rehabilitation programs designed with the cooperation of a physiotherapist provide more specific exercise tasks depending on the patient's diagnosis and mobility. Each rehabilitation program contains a virtual line which the patient has to track. The space for movement is limited by different types of tolerance areas. The desired wobble board deflection is user selectable in the software. These types of rehabilitation tasks can provide a variety of parameters, for example maximal and minimal deflection, the required time to finish the rehabilitation task, deflection from the virtual line, jerkiness or movement sharpness, etc. These parameters can be used for the complex evaluation of the patient's progress during the rehabilitation process.

In this paper the design and implementation of an interactive low energy balance rehabilitation system has been presented. The main advantages and disadvantages of the related available solutions were also pointed and the possible parameters for the motion analysis of the wobble board were discussed. We would like to focus on the future extraction from the measured data in order to estimate and quantify the patient's progress in our future work.

ACKNOWLEDGMENT

The work and the contributions were supported by the project SV SP2014/194 "Biomedical engineering systems X" and the project "Opportunity for young researchers", reg. no. CZ.1.07/2.3.00/30.0016 supported by Operational Programme Education for Competitiveness and co-financed by the European Social Fund and the state budget of the Czech Republic.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCES

1. Dvorak R (2007) Fundamentals of kinesiotherapy. 3th ed. Olomouc: Palacky University in Olomouc
2. Clark V M, Burden A M (2005) A 4-week wobble board exercise programme improved muscle onset latency and perceived stability in individuals with a functionally unstable ankle. Physical Therapy in Sport, Volume 6, Issue 4, pp. 181-187, November 2005, DOI 10.1016/j.ptsp.2005.08.003
3. McGuine T A, Keene J S (2006) The Effect of a Balance Training Program on the Risk of Ankle Sprains in High School Athletes. American Journal of Sports Medicine, vol. 34, issue 7, pp. 1103-1111, February 2006, DOI 10.1177/0363546505284191
4. Jankowicz-Szymanska A, Mikolajczyk E, and Wojtanowski W (2012) The effect of physical training on static balance in young people with intellectual disability. *Research in Developmental Disabilities*, vol. 33, issue 2, pp. 675-681, 2012, DOI 10.1016/j.ridd.2011.11.015
5. Granacher U, Gollhofer A (2012) Is There an Association Between Variables of Postural Control and Strength in Prepubertal Children?.. Journal of Strength and Conditioning Research. 2012, vol. 26, issue 1, pp. 210-216, DOI 10.1519/JSC.0b013e31821b7c30
6. Karime A, Osman H Al, Eid M, Gueaieb W, Saddik A. El (2013) Capturing ankle benchmark kinematics using an interactive sensory wobble board. *2013 IEEE International Conference on Multimedia and Expo Workshops (ICMEW)*, pp. 1-6, 15-19 July 2013, DOI 10.1109/ICMEW.2013.6618438
7. Fitzgerald D, Trakarnratanakul N, Dunne L, Smyth B, Caulfield B (2008) Development and user evaluation of a virtual rehabilitation system for wobble board balance training. Proceedings of the 30th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS'08 - "Personalized Healthcare through Technology", art. no. 4650134, pp. 4194-4198, August 2008
8. Connectblue (2014) cB-OLP425 cB-OLS425 cB-OLS426 Electrical Mechanical Data Sheet. 31 January 2014, [Online]. Available: http://support.connectblue.com/display/PRODBTSPA/cB-OLP425+cB-OLS425+cB-OLS426+Electrical+Mechanical+Data+Sheet
9. InvenSense (2013) MPU-9150 Product Specification Revision 4.3. 8 September 2013, [Online]. Available: http://support.connectblue.com/display/PRODBTSPA/cB-OLP425+cB-OLS425+cB-OLS426+Electrical+Mechanical+Data+Sheet
10. Texas Instruments (2012) Measuring Bluetooth® Low Energy Power Consumption. [Online]. Available: http://www.ti.com/lit/an/swra347a/swra347a.pdf
11. Ahmad N, Ghazilla R A R, Khairi N M, Kasi V (2013) Reviews on Various Inertial Measurement Unit (IMU) Sensor Applications. International Journal of Signal Processing Systems, vol. 1, No. 2, pp. 256-262, December 2013. DOI 10.12720/ijsps.1.2.256-262
12. Bruckner H P, Spindeldreier C, Blume H, Schoonderwaldt E, Altenmuller E (2012) Evaluation of Inertial Sensor Fusion Algorithms in Grasping Tasks Using Real Input Data: Comparison of Computational Costs and Root Mean Square Error. 2012 Ninth International Conference on Wearable and Implantable Body Sensor Networks (BSN), pp.189-194, 9-12 May 2012, DOI 10.1109/BSN.2012.9
13. STMicroelectronics (2010) Using LSM303DLH for a tilt compensated electronic compass. August 2010, [Online]. Available: http://www.pololu.com/file/download/LSM303DLH-compass-app-note.pdf?file_id=0J434
14. Penhaker M, Stankus M, Prauzek M, Adamec O, Peterek T, Cerny M, and Kasik V (2012) Advanced Experimental Medical Diagnostic System Design and Realization. Electronics and Electrical Engineering, , vol. 117, issue 1, pp. 89-94, January 2012, DOI 10.5755/j01.eee.117.1.1060
15. Krohova J, Smondrk, M, Cerny M, Chwalkova I, Zadrapova M (2013) Interactive rehabilitation system for balance exercises on the spherical cap. In Proc. 18th International Conference on Applied Electronics 2013, pp. 145-148, September 2013

Address of the corresponding author:

Author: Jana Krohova
Institute: VSB – Technical University of Ostrava
Street: 17. listopadu 15
City: Ostrava-Poruba
Country: Czech Republic
Email: jana.krohova@vsb.cz