Characterizing Ankle Proprioception with Embedded Sensor Balance Board

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***Abstract*— This paper focuses on the development of a balance board device designed to assist ankle-injury patients during rehabilitation through proprioception training and some initial human study results. The balance board helps in the assessment of the patient's progress by collecting real-time ankle attitude data. Using an Arduino, gyroscope, accelerometer, magnetometer, and a Bluetooth adapter, preliminary results from a human study show similarities in performance between left and right foot proprioceptive tasks.**

I. Introduction

Ankle injuries are one of the most common lower extremity injuries especially in athletes. Many sports require sudden stops and cutting movements with a significant amount of running, such as basketball and soccer. Not only do these ankle injuries result in numerous, high-cost emergency room visits and prevent full participation in sports but they can cause long-term ankle disabilities. Due to this, there is a major financial impact on health care costs and physical therapy. According to the US Consumer Products Safety Commission in 2003, the medical cost of ankle sprains in high school soccer and basketball players was $70 million. [1] Perhaps even more troubling is the long term effects and associated cost. Yeung et al. reports a recurrence rate greater than 70% in athletes. [2]

A common rehabilitation technique post injury involves a balance board for proprioception training. Proprioception training addresses motor control by examining the neuromuscular feedback mechanism that is interrupted with injury, as stated by Lephart. [3] Motor control includes spinal reflexes, cognitive programming, and brainstem activity. Proprioception contributes to the motor programming for neuromuscular control required for precision movements and muscle reflex. After the occurrence of an ankle injury, there is a decrease in sensory input from joint receptors leading to abnormal body positioning, diminished postural reflex responses, and chronic ankle instability leading to the increased probability of re-injury. With proprioception training, dynamic joint stability is obtained and the chance of a reoccurrence of an ankle injury is significantly lowered. [4]

While balance board is pervasive, other methods have been used to quantify the measurement of ankle proprioception. One method, for example, studied the positions of the ankle about three orthogonal anatomical planes as plantar-flexion, dorsiflexion, inversion, eversion, abduction, and adduction. [5] The movements were measured using a 3-Dimensional Goniometry system based on electromagnetic transmitting field. Due to the cost, complexity, and size, the subject must be in a clinical setting, precluding convenient use and monitoring at home or work setting. The device, while shown to have accurate position and pose estimates, requires set up procedures that are not practical outside a rehabilitation setting. Another technique termed Passive Ankle Joint Reposition has been studied ankle proprioception with basketball players by Fu et al [6]. The ankle is placed in various positions such as plantar flexion and dorsiflexion but does not account for the inversion and eversion plane of ankle motions. Many ankle sprains occur in these positions and therefore, this method does not appear to be suitable for full rehabilitation assessment of ankle injuries.

This work describes the development and initial results of a balance board design that is inexpensive and easy to use in a typical clinical or home setting.

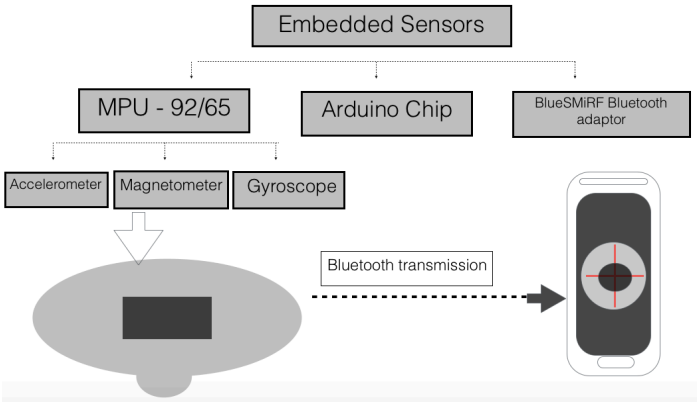

Fig. 1. Block diagram of the balance board embedded with sensor hardware and Bluetooth transmission to the Android application.

IV. Methods

A. Materials and Design Process

The materials used for this project include the Arduino Nano, BlueSMiRF Bluetooth adapter (Sparkfun), MPU9250 (Invensense), a wooden balance board platform with a 3D printed ball (see Fig. 1). The balance board device is paired with an Android device for real-time feedback to the user and data recording. The circuit constructed is placed in the center of the balance board to mitigate the need for real-time transformations of the measurements to a world reference frame. The application displays the orientation of the balance board during training period so the patient can associate the action with the proprioceptive feedback. The application stores all measured data in a comma delimited text format (CSV) for import into data analysis software packages.

B. Clinical Trials

A preliminary clinical trial, approved by the university IRB, was executed to compare ankle positional accuracy of left and right feet using common rehabilitative exercises. The study included

individuals who self-reported as having good ankle health. As a benefit of this study, the participants will be more aware of physical therapists' techniques and mechanisms of treatment for strength and proprioception of the ankle. These healthy volunteers will perform multiple movements on the balance board in a seated position and the data will be recorded based on their speed, accuracy, and repeatability of these movements. The subject will place their foot on the board in a seated position with their toes at 12 o'clock and their heel at 6 in the sitting position with hip, knee, and ankle flexed to 90 degrees. The subject is directed by the tester to look down at the round board and press down on the board so that the 12 o'clock position is touching the floor followed by the 6 o'clock position hitting the floor, using their toes and heel. The subject is directed to do this 2 consecutive times and then to stop in the neutral position. Next the tester asks the subject to replicate this motion while looking straight ahead 10 consecutive times. At this point, the data is stored to be compared to the subjects' initial motion while looking down at the board and analyzed by the tester. Next the tester replicates the prior training and testing with side motion (ankle inversion and eversion). Real-time attitude data is collected through the whole training and testing process.

III. Results

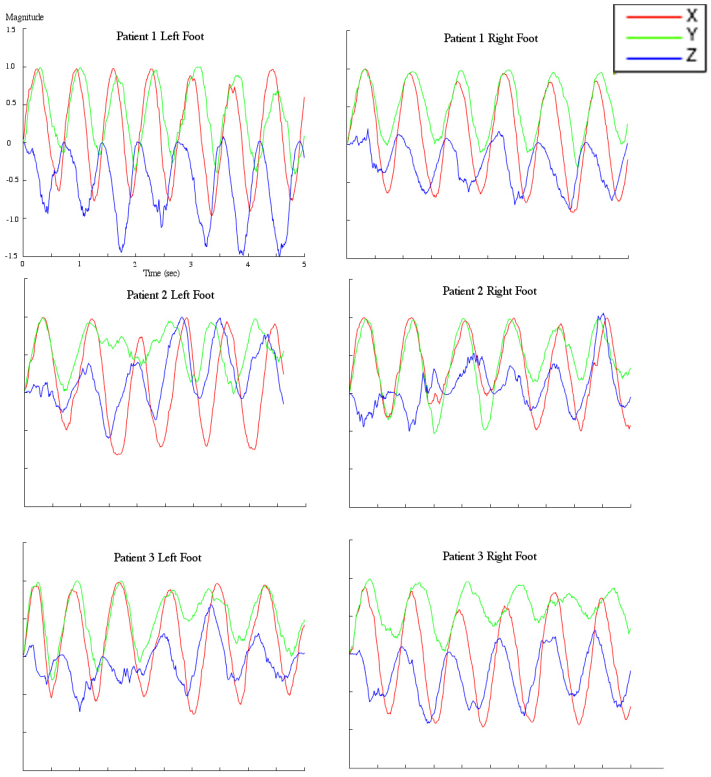

Figure 2.

The preliminary results of the study of the balance board with healthy volunteers are reported. Fig. 2 shows the X, Y, and Z coordinates of the back-and-forth motion of three participants. The right and left columns represent the patients' right and left feet, respectively.

IV. Discussion

Based on the preliminary tests done on the left and right feet of the test subjects, we can conclude that there is a trend showing more control over the right foot, for right hand dominant people. While looking at the graphs, the proper way to compare the two feet is by looking for the similarities in the X and Y coordinates, while maintaining consistency in the Z coordinates of the board. With more consistency in the Z coordinates, this shows the test subject has better control of ankle movement. While Subject 1 shows some consistency in the Z coordinates, the right foot has a greater range of motion while remaining consistent in the z-plane. Subject 2 is less smooth in moving their right foot back and forth than the left. However, like Subject 1, the coordinates of the right foot were more consistent when compared to their left foot. The third subject's right foot shows a better consistency in the Z coordinates, not only in comparison to each other but in the range of motion as well. With IRB approval for human study, further information can be gathered solidify our initial hypothesis.

The balance board is to provide an inexpensive platform for both in office and at home rehabilitation. Qualitative results from the preliminary results shown appear to allude to a correlation between handedness and performance of the corresponding foot. While using acceleration directly may not report an accurate pitch angle of the wobble board, the direction of the pitch appears to be consistent with motion exhibited. The real-time data collected from the study helps to qualitatively assess similarities between left and right feet performance, but further quantitative results are anticipated to characterize the differences in the accuracy, speed, and repeatability of the participants. Understanding normal ankle proprioception is important to diagnosing injured patients, developing procedures to quickly rehabilitate, and potentially reducing associated medical costs. This study overall will not replace a physical therapist but rather will collect knowledge on how to optimize the rehabilitation techniques. Extending prior balance board work [7], a Bluetooth interface is incorporated and self-contained power for convenience of the test administrator or physical therapist. Future work is planned to not only analyze the human study results but to improve the design for a broader field use by physical therapists and patients. In particular, the user interface needs to be improved to allow self-directed data collection, and analyze and present the recorded data for assessment by clinician.

Acknowledgements

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References

[1] McGuine, T.A. & Keene, J. S. (2006). The effect of a balance training program on the risk of ankle sprains in high school athletes. *The American journal of sports medicine*, 34(7), 1103-1111.

[2] M. S. Yeung, K. M. Chan, C. H. So, and W. Y. Yuan, "An epidemiological survey on ankle sprain.," Br. J. Sports Med., vol. 28, no. 2, pp. 112–116, Jun. 1994.

[3] Lephart, S. M., Pincivero, D. M., Giraido, J. L., & Fu, F. H (1997). The role of proprioception in the management and rehabilitation of athletic injuries. *The American journal of sports medicine*, 25(1), 130-137.

[4] Mattacola, C. G., & Dwyer, M. K. (2002). Rehabilitation of the Ankle After Acute Sprain or Chronic Instability. *Journal of Athletic Training*, *37*(4), 413–429.

[5] Abboud, R. J., Agarwal, S. K., Rendall, G. C., & Rowley, D. I. (1999). A direct method for quantitative measurement of ankle proprioception. *The foot*, 9(1), 27-30.

[6] Fu, A. S., & Hui-Chan, C. W. (2005). Ankle joint proprioception and postural control in basketball players with bilateral ankle sprains. *The American journal of sports medicine*, *33*(8), 1174-1182.

[7] B. Kotowski, M. Barbin, C. Gomes, C. Simpson, & E. Chabot, "Balance Board with Embedded Sensors for Rehabilitation of Ankle Injuries," in Northeast Bioengineering Conference (NEBEC), 2016 42nd Annual, 2016, pp. 1-2