Smart Shoe

Medical Engineering, Project Course
Hardi Hamshin, Federica Carmen Maruccio, Mahyar Mehr, Rohit Nareshkumar, Phuong Huy Nguyen.
October 2021

Abstract

In the area of digital health, there is a huge demand of collecting data about an individual's gait deviations, such as in pathological subjects like parkinsonians, hemiplegics or choreiforms as well as in elderly people. Gait analysis using an instrumented treadmill, which is the commonly used method produces a noisy signal due to the friction in a belt [1]. Considering this, a smart shoe could be a solution for a more reliable gait analysis. Equipped with force sensitive resistors and IMUs, it can be used to keep track of the foot pressure distribution and several gait parameters.

Introduction

Smart wearable technologies, with potential to gather information through sensors [2], has shown to have the possibility to improve one's life either in a reactive way or a preventive way [3]. There is a huge demand of collecting data about an individual's gait deviations, for instance in pathological subjects like parkinsonians, hemiplegics or choreiforms as well as in elderly people to check their posture or joint health. Furthermore, the extraction of pressure and gait parameters can be exploited also by fitness users who want to track their training sessions through steps count and visualize their progress on mobile devices.

The concept of a smart shoe for reliable gait analysis has already been implemented with several different methods, one approach is through data gathering from pressure sensors, accelerometers and gyroscopes [4].

As such, the purpose of this project is to create a Bluetooth enabled sole with force sensitive resistors and IMUs which can be used to keep track of the foot pressure distribution and several gait parameters.

Design

The Smart Shoe is a wireless, wearable and low-cost monitoring system that enables a real-time gait analysis, transmission and logging of the acquired data to a MATLAB application. It comprises of an instrumented insole inside the patient's shoe and a shoe attachment containing the circuit board positioned on the ankle. The insole and shoe module contains:

- a generic shoe insole compatible with any shoe;
- five Force Sensitive Resistors (FSR04CE-ND) that measure continuous pressure;
- two 9-axis IMU (LSM9DS1) containing a 3D magnetometer, a 3D accelerometer and a 3D gyroscope with I2C and SPI for the analysis of the kinematic motion of the foot;
- an Arduino NANO 33 BLE with the nRF52840 microcontroller and a Bluetooth Low Energy connection;

A block diagram of the system architecture is shown in figure 1.

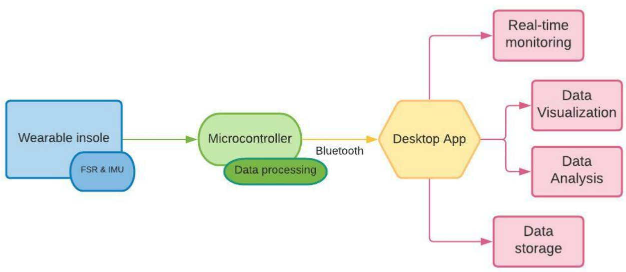

Figure 1: System architecture and data processes

Hardware implementation: The force sensors have a change in resistance based on the applied force. The hardware implementation to measure this consists of an opamp circuit in inverting configuration to measure the current through the resistor as a voltage. The output of the opamps are connected to the ADC pins, and both of the IMUs over the I2C bus. A circuit board was milled to contain the analog circuit, shown in figure 5.

Software implementation: The embedded software is developed using ARM mBed. The data is filtered and aggregated in a packet, sent over BLE to a computer. A MATLAB script is used to log the data and post process foot pressure distribution and gait parameters.

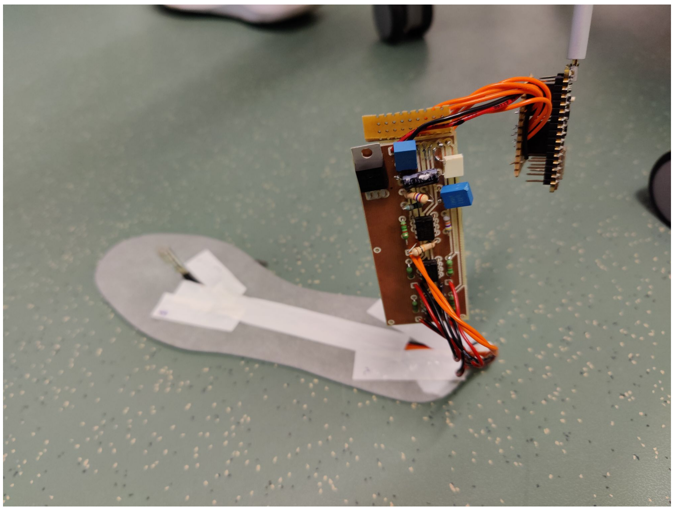

Figure 2: Prototype

Evaluation

IMU data processing: Firstly, we compensate the sensor inaccuracies such as zero level offset, scaling, and misalignment in three axes of the accelerometer and gyroscope contained in the two IMUs. Stančin e Tomažič refinement [5] is used for this purpose. The process involves rotating the real axis of the IMU into the axis of the leg vector.
Once the IMU has been calibrated, initial and final foot contacts (IC and FC) are estimated using Trojanello method [6]. Time intervals of trusted swing (T_{SW}) and of trusted stance (T_{ST}) are identified and the remaining time intervals are used as IC and FC search intervals (T_{IC} and T_{FC}).

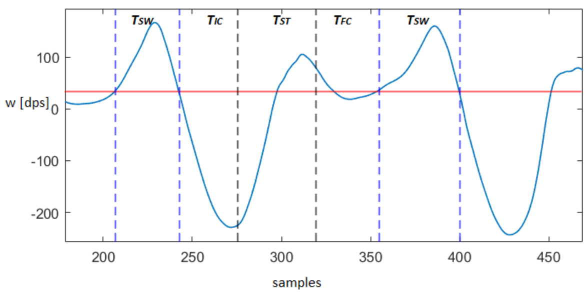

Figure 3: IC and FC estimation

Once the ICs and FCs are identified, Stride Time, Step Time, Swing Time and Stance Time are calculated per gait cycle. Furthermore, spatial parameters could be estimated using a method named Trusted Events and Acceleration Direct and Reverse Integration along the direction of Progression ($TEADRIP$) [7].

Pressure data processing The force sensor produces a response curve resulting in a drop in resistance proportional to the force applied. The sensor has an accuracy of about 5%, and so cannot be used for absolute measurements. However, the relative forces give us the weight distribution between heel and foot as well as the transverse distribution. Studies have shown that aging related anatomical effects on the foot can be diagnosed using the pressure distribution during the various gait phases [8]. The forces sensors also help in segmenting the gait into the different phases - this timing information is used to verify the segmentation of IMU data. The differences in amplitude of force graphs are used to detect femoral anteversion, internal tibial torsion, and matetarsus adductus (in-toe and out-toe).

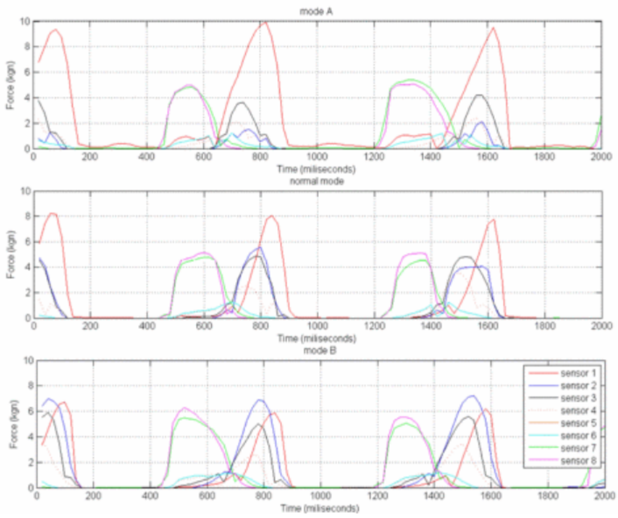

Figure 4: Force sensor response for in-toe and out-toe (not our data)

Conclusion

In conclusion, we outlined the considerations for the design and fabrication of a smart shoe sole to analyse gait parameters for monitoring, diagnosis and rehabilitation. The sole offers low cost and portable alternative to visual analysis or the use of pressure plates while circumventing some of their drawbacks. Beyond m-health, this device also has applications in fitness tracking, gait correction, and geriatric care and monitoring.

References

[1] Brian K Higginson. “Methods of running gait analysis”. In: *Current sports medicine reports* 8.3 (2009), pp. 136–141.

[2] Eskofier B. M.; Lee S. I.; Baron M.; Simon A.; Martindale C. F.; Gaßner H.; Klucken J. “An overview of smart shoes in the internet of health things: gait and mobility assessment in health promotion and disease monitoring”. In: *Applied Sciences* 7(10) (2017), p. 986.

[3] Glaros C.; Fotiadis D. I. “Wearable devices in healthcare. In Intelligent paradigms for healthcare enterprises”. In: *Springer* (2005), pp. 237–264.

[4] Sunarya U.; Sun Hariyani Y.; Cho T.; Roh J.; Hyeong J.; Sohn I.; Park C. “Feature analysis of smart shoe sensors for classification of gait patterns”. In: *Sensors* 20(21) (2020), p. 6253.

[5] Sara Stančin; Sašo Tomažič. “Time- and Computation-Efficient Calibration of MEMS 3D Accelerometers and Gyroscopes”. In: *Sensors* 14 (2014), pp. 14885–14915.

[6] Diana Trojaniello; Andrea Cereatti; Gabriele Paolini; Andrea Ravaschio; Ugo Della Croce. “Temporal gait parameters determination from shank-worn MIMU signals recorded during healthy and pathological gait”. In: (2013).

[7] Matilde Bertoli; Andrea Cereatti; Diana Trojaniello; Laura Avanzino; Elisa Pelosin; Silvia Del Din; Lynn Rochester; Pieter Ginis; Esther M. J. Bekkers; Anat Mirelman; Jeffrey M. Hausdorff; Ugo Della Croce. “Estimation of spatio-temporal parameters of gait from magneto-inertial measurement units: Multicenter validation among Parkinson, mildly cognitively impaired and healthy older adults”. In: *BioMedical Engineering OnLine* (2018).

[8] Mary Josephine Hessert et al. “Foot pressure distribution during walking in young and old adults”. In: *BMC geriatrics* 5.1 (2005), pp. 1–8.

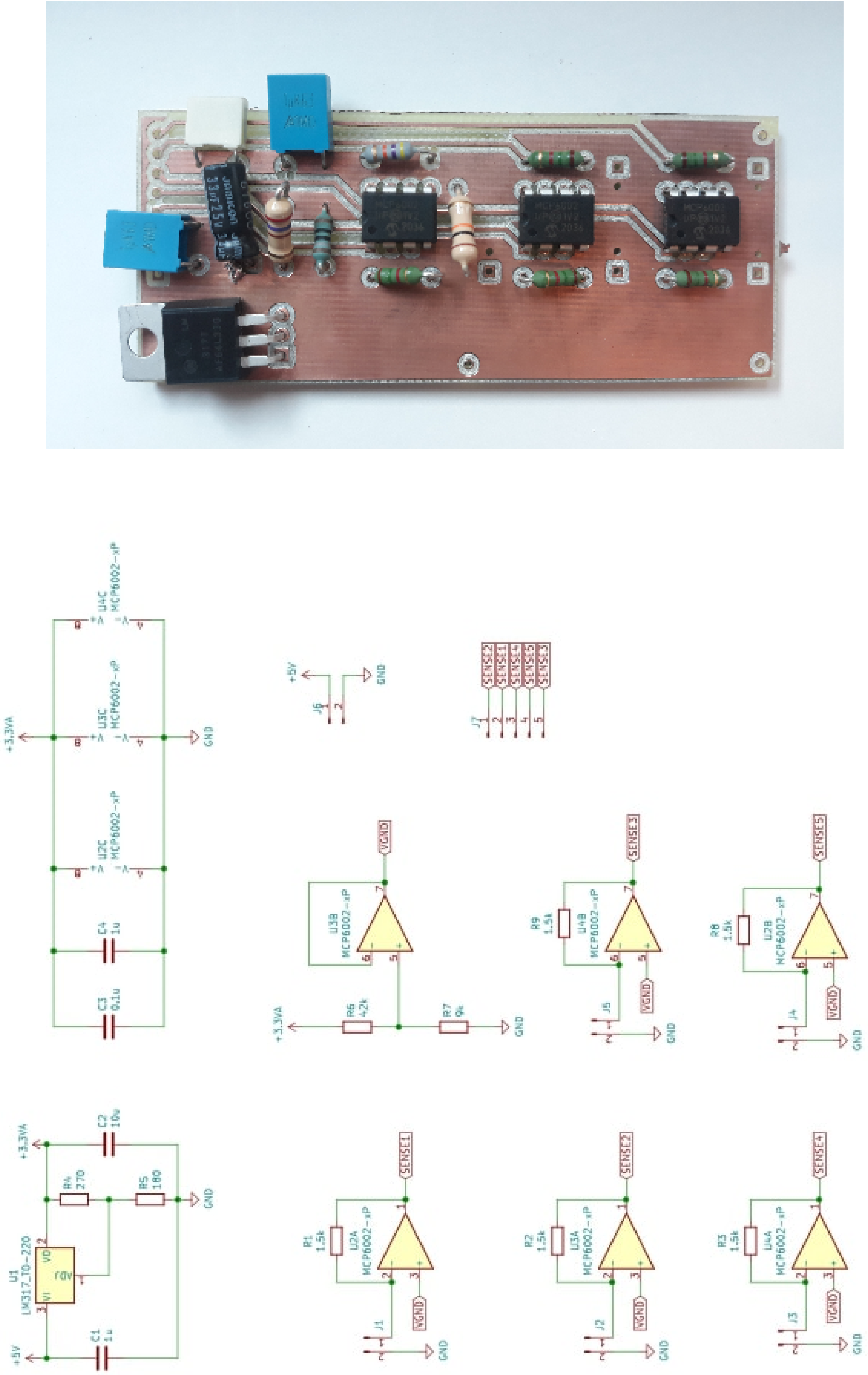

Figure 5: Schematic and circuit board