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Footstrike pattern determination

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Report submitted in partial fulfilment of the requirements of the module Project (E) 448 for the degree Baccalaureus in Engineering in the Department of Electrical and Electronic Engineering at Stellenbosch University.

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I would like to thank my dog, Muffin. I also would like to thank the inventor of the incubator; without him/her, I would not be here. Finally, I would like to thank Dr Herman Kamper for this amazing report template.

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Abstract

English

The English abstract.

Contents

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Nomenclature

Variables and functions

$p(x)$	Probability density function with respect to variable x.
$P(A)$	Probability of event A occurring.
ε	The Bayes error.
ε_u	The Bhattacharyya bound.
B	The Bhattacharyya distance.
s	An HMM state. A subscript is used to refer to a particular state, e.g. s_i refers to the i^{th} state of an HMM.
$\mathbf{S}$	A set of HMM states.
$\mathbf{F}$	A set of frames.
$\mathbf{o}_f$	Observation (feature) vector associated with frame f.
$\gamma_s(\mathbf{o}_f)$	A posteriori probability of the observation vector $\mathbf{o}_f$ being generated by HMM state s.
μ	Statistical mean vector.
Σ	Statistical covariance matrix.
$L(\mathbf{S})$	Log likelihood of the set of HMM states $\mathbf{S}$ generating the training set observation vectors assigned to the states in that set.
$\mathcal{N}(\mathbf{x}\|\mu, \Sigma)$	Multivariate Gaussian PDF with mean μ and covariance matrix Σ.
a_{ij}	The probability of a transition from HMM state s_i to state s_j.
N	Total number of frames or number of tokens, depending on the context.
D	Number of deletion errors.
I	Number of insertion errors.
S	Number of substitution errors.

Acronyms and abbreviations

AE	Afrikaans English
AID	accent identification
ASR	automatic speech recognition
AST	African Speech Technology
CE	Cape Flats English
DCD	dialect-context-dependent
DNN	deep neural network
G2P	grapheme-to-phoneme
GMM	Gaussian mixture model
HMM	hidden Markov model
HTK	Hidden Markov Model Toolkit
IE	Indian South African English
IPA	International Phonetic Alphabet
LM	language model
LMS	language model scaling factor
MFCC	Mel-frequency cepstral coefficient
MLLR	maximum likelihood linear regression
OOV	out-of-vocabulary
PD	pronunciation dictionary
PDF	probability density function
SAE	South African English
SAMPA	Speech Assessment Methods Phonetic Alphabet

Chapter 1

Introduction

In the modern day, jogging is one of the most popular physical activities. People all over the world partake in this physical activity. One would think that jogging is a simple exercise and there are no major injury or health concerns. However, there are some major concerns as jogging has a high injury rate. Over the past few years, there has been an increasing interest in this subject and many studies have been conducted on how these injuries can be analyzed. Strike patterns during running has been acknowledged as potential way of identifying injuries or risk of injury.

1.1. Problem Statement

Develop an application that can use data from a prototype device and display the foot strike patterns from this data. Do additional calculations to show the ground force applied with each step. The raw data should be processed and saved to be displayed and used in useful manners such as videos and graphs.

1.2. Objectives

The objective of this project is to use a prototype wearable device that captures the pressure applied to a grid of pressure sensing resistors. The prototype has been build by a previous student and is capable of capturing the data from FSR cells and transmitting the data via BLE. An mobile application should then be developed to receive this data, process it and display or save it in useful ways.The application can then be used by medical experts to assist in medical assessments like the Gait analysis.

1.3. Scope and Limitations

The scope of this project is to only design and develop an andriod application that displays the foot strike patterns captured by the prototype device. As the device was built by a predecessor there are some design flaws that had to be considered:

- Very large device

- The Arduino used does not have enough ADC channels and an extra component was added taking up more space.
- The battery of the device is very large and adds a large amount of weights to a device that should be wearable.
- The charging circuit is not in working order and the battery had to be manually charged.

1.4. Overview of the report

Chapter 2 Lit review
Chapter 3 System design
Chapter 4 Detailed design
Chapter 5 Tests
Chapter 6 Summary conclusions

1.5. Section heading

This is some section with two table in it: Table 1.1 and Table 1.2.

Table 1.1: Performance of the unconstrained segmental Bayesian model on TIDigits1 over iterations in which the reference set is refined.

Metric	1	2	3	4	5
WER (%)	35.4	23.5	21.5	21.2	22.9
Average cluster purity (%)	86.5	89.7	89.2	88.5	86.6
Word boundary F-score (%)	70.6	72.2	71.8	70.9	69.4
Clusters covering 90% of data	20	13	13	13	13

Table 1.2: A table with an example of using multiple columns.

	Accuracy (%)		
Model	Intermediate	Output	Bitrate
Baseline	27.5	26.4	116
VQ-VAE	26.0	22.1	190
CatVAE	28.7	24.3	215

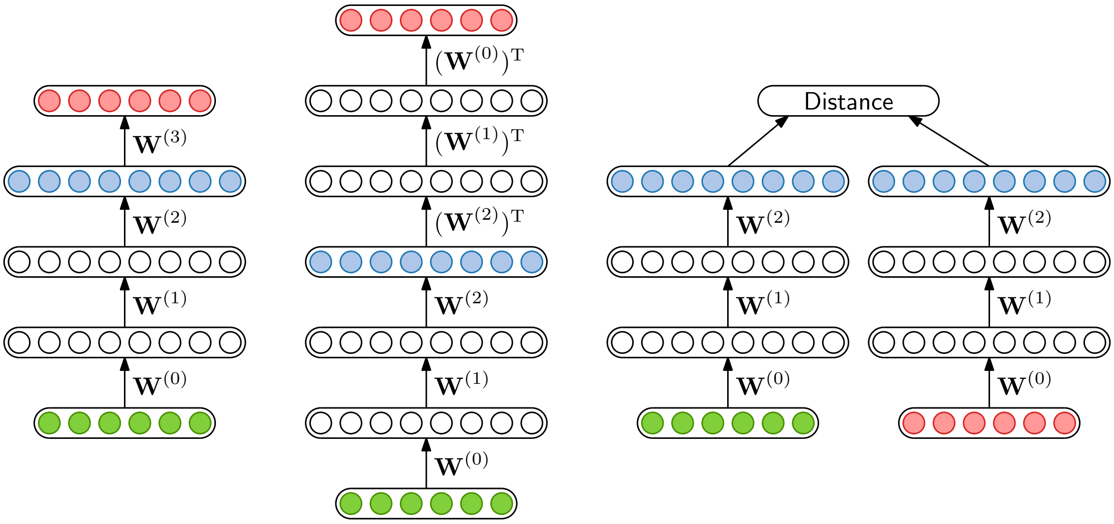

Figure 1.1: (a) The cAE as used in this chapter. The encoding layer (blue) is chosen based on performance on a development set. (b) The cAE with symmetrical tied weights. The encoding from the middle layer (blue) is always used. (c) The siamese DNN. The cosine distance between aligned frames (green and red) is either minimized or maximized depending on whether the frames belong to the same (discovered) word or not. A cAE can be seen as a type of DNN [2].

This is a new page, showing what the page headings looks like, and showing how to refer to a figure like Figure 1.1.

The following is an example of an equation:

$$P(\mathbf{z}|\boldsymbol{\alpha}) = \int_{\boldsymbol{\pi}} P(\mathbf{z}|\boldsymbol{\pi})\, p(\boldsymbol{\pi}|\boldsymbol{\alpha})\, \mathrm{d}\boldsymbol{\pi} = \int_{\boldsymbol{\pi}} \prod_{k=1}^{K} \pi_k^{N_k} \frac{1}{B(\boldsymbol{\alpha})} \prod_{k=1}^{K} \pi_k^{\alpha_k - 1}\, \mathrm{d}\boldsymbol{\pi} \tag{1.1}$$

which you can subsequently refer to as (1.1) or Equation 1.1. But make sure to consistently use the one or the other (and not mix the two ways of referring to equations).

Chapter 2

Literature Review

2.1. Foot strike patterns and Gait analysis

Running is a popular everyday physical activity across the world. Many statics proves this [3]. Although running is a simple activity it involves complex movements an integration of muscles, joints and varies body parts. This leads to running being a common physical activity that commonly cause injuries. In depth studies on foot strike patterns elsewhere [4], [5], [6], [7] review the basics of foot strike patterns and the biomechanics of running. This is beyond the scope of this technical report, but these reviews do provide relevant information to better understand what cause s these injuries. These studies do indicate that considering the foot and foot motion during walking and running is very crucial to understanding why running can commonly lead to injuries. It has been proven in studies such as [8] that running performance, energy requirements and musculoskeletal stresses are directly related to foot strike patterns and action-reaction force between the limb and the ground. Many factors like foot strike patterns, footwear conditions, running speed and environment conditions can have many effects on the biomechanics of a human during running. According to [6] there are three primary foot strike patterns namely: forefoot, rearfoot (heel strike) and midfoot. Forefoot striking is when the antrerior region of the foot strikes the ground first. Midfoot striking is when the posterior and anterior parts of the foot hit the ground simultaneously, and rearfoot or heel strike is when the heel or posterior area of the foot strikes the ground initially. According to [9] and [6] there is a high prevalence of heel strikers for both mid-distance and ling-distance runners. This would explain why running shoes are heavily padded at the heel part of the shoe. This makes the landing proses more comfortable.

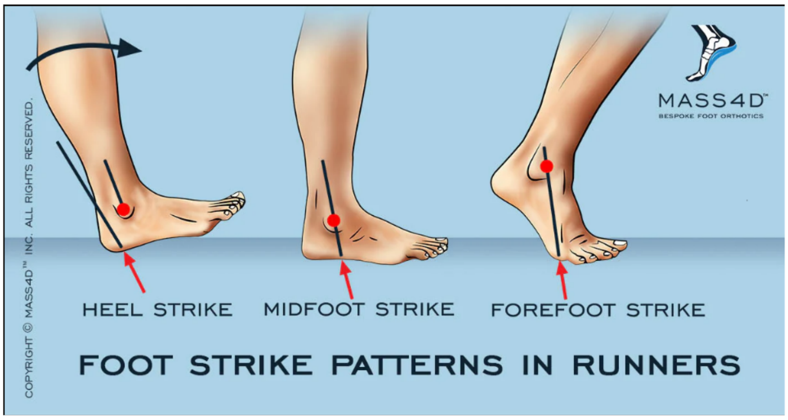

Figure 2.1: Image found in an online article [1] illustrating the Foot Strike Patterns in Runners.

2.2. Technology used for Gait analysis

2.3. Bluetooth Low Energy BLE

2.3.1. How Does BLE Work?

When using Bluetooth Low Energy it is important to know the roles of each device. In all BLE application there are two roles which are the **central** and the **peripheral** devices. The peripheral device will be the device that broadcasts or advertises information and the central device will be scanning for information. A good visual representation of how BLE works is to think of an advertising board where the peripheral device keeps pinning new info onto the board and the central device scans the board and uses the information available. These two devices have their own unique addresses. The peripheral will be advertising information to any near devices while the central will for any device or devices that are advertising information. When the central device finds the advertised information a connection attempt is made. Once a connection is established, the central device can start read and writing information from and to the peripheral device.

2.3.2. Services, Characteristics and Descriptor

The information transfer system for BLE can be seen in the following hierarchical order. A service is a collection of characteristics and each characteristic has a descriptor that describes the characteristic. See the basic illustration below 2.3.

Each **service** has its own unique identifying code called a UUID. This is to allow one peripheral device to have multiple services. This code can be 128-bit long for each service. A service can also be seen as a group of capabilities. For example, a smartwatch that can measure hart rate, temperature and track your GPS location. These three

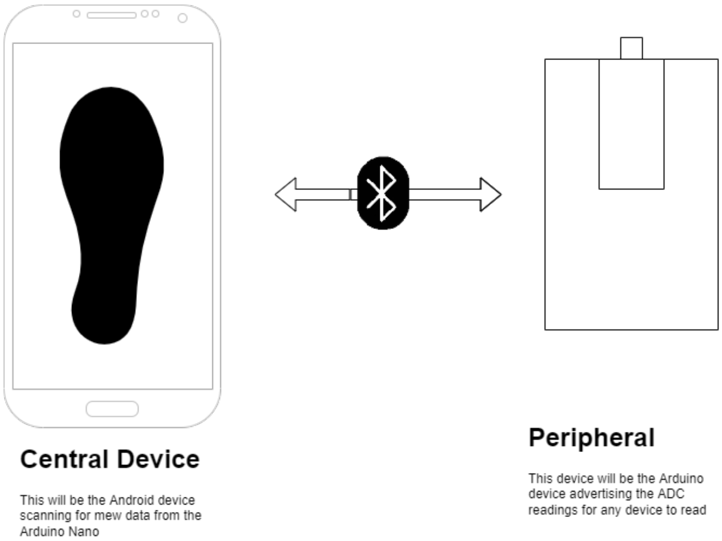

Figure 2.2: Basic BLE overview

Service		
Characteristic 1	Characteristic 2	Characteristic 3
Descriptor	Descriptor	Descriptor

Figure 2.3: Basic hierarchy of BLE

capabilities can be grouped under one service and can be called the activity service. This method of grouping information allows the central device to better understand and use the information that the peripheral is advertising.

The capabilities mentioned in the above example are better known as **characteristics**. Each characteristic has its own unique identifying code called a UUID. This is to allow one service to have multiple characteristics. A characteristic can be seen as a single capability. For example, the characteristic of measuring heart rate. This characteristic can be seen as a single capability of the activity service.

Each characteristic can have a **descriptor** that describes the characteristic. A descriptor can be seen as a single piece of information about the characteristic. For example, the descriptor of the characteristic of measuring heart rate can be the range of the heart rate measurement. This descriptor can be seen as a single piece of information about the characteristic of measuring heart rate.

2.4. Force Sensitive Resistors

A Force Sensitive Resistor (FSR) is a material which changes resistance when a force is applied. A FSR typically consists of 3 layers; a top resistive polymer layer, a bottom thin film polymer layer with conductive traces and a middle spacer layer separating the top and bottom layers. The three layers are often enclosed in a flexible polymer. When there is no pressure applied the top resistive layer and bottom conductive layer are completely separated by the spacer and act as an open circuit (infinite resistor). As pressure is applied to the FSR the top resistive layer is pressed against the bottom conductive layer causing the resistance to decrease.

2.5. Open GLES for android

OpenGL is an open source, graphics library for high performance 2D and 3D graphics rendering. OpenGL—ES is flavor of OpenGL specifically intended for embedded and mobile devices. OpenGL—ES is a cross-plaftorm high performance graphics API that can be used by Android devices. Android supports both the framework API and the Native Development Kit (NDK) of OpenGL.

Chapter 3

System Design

3.1. System overview

The prototype foot sensor device was designed and built by Jared Adams who is the predecessor of this skripsie topic. The LiFePO4 battery supplies power to all the components of the prototype device. These components are an Arduino Nano 33 Ble, an ADS115 ADC module and the IEE foot sensor. The battery has a nominal voltage of 3.2VDC and is charged by a battery charge management controller namely, the MCP73123.

The prototype device will then use BLE to transmit ADC data to an Android device. The Android device will make use of this data via an application written in Java. This application will consist of various methods that do calculations with the data, display the data in various ways and save the data.

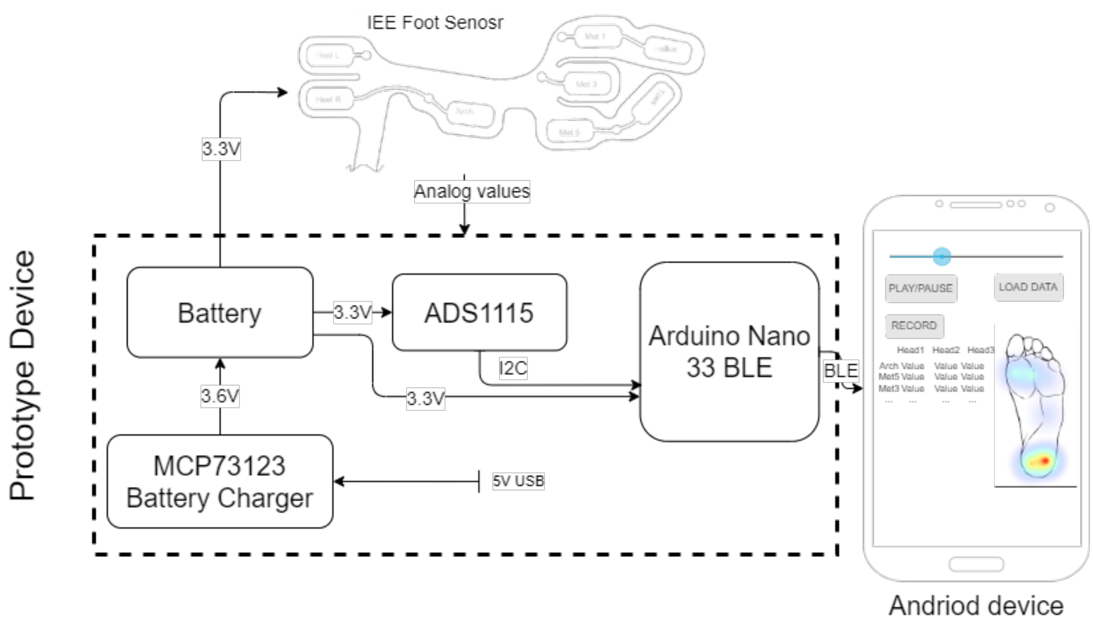

Figure 3.1: System Diagram

3.2. Device components

3.2.1. Arduino Nano 33 BLE

The Arduino Nano 33 BLE is small Arduino Nano device ideal for wearable devices. The Nano 33 BLE has a powerful processor, the nRF52840 from Nordic Semiconductors, a 32-bit ARM Cortex-M4 CPU running at 64 MHz. The main processor also includes Bluetooth Low Energy for a low power consumption solution to transmit data wirelessly. The board also contains 8 3v3 12bit analog input pins (2 of which are designated for I^2C pins) and 14 digital input?output pins.

3.2.2. LiFePO4 Battery

A lithium iron phosphate battery is a type of rechargeable battery. The battery specifically uses LiFePO4 as cathode material and graphitic carbon electrodes as the anode.The LiFePO4 battery has a maximum charge cut-off of 3.65V and a minimum charge cut-off of 2.5V. LiFePO4 batteries has flat discharge curve with a nominal output voltage of 3.2V. This battery was used to provide a stable supply voltage for the system and a stable reference voltage for the ADCs.

3.2.3. IEE Smart Footwear Sensor

The IEE Smart Footwear Sensor consists of 8 separate high-dynamic FSR cells. The foot sensor has 1 pins1- 1 supply voltage pin, 2 ground pins and 8 output pins. The structure of the foot sensor is essentially a resistive divider network with a fixed resistor Rfix, made from conductive ink with a value in range of 2 kΩ < Rfix < 4 kΩ . The foot sensor is supplied with power by the LiFePO4 Battery.

3.3. App components

The main feature of the application is the heatmap. This feature allows users to see their foot strike patterns in a visual way. Along with this the user can see the approximated force exerted on each FSR cell as well as the distribution across the whole of the 8 IEE Smart Footwear sensor. All of this data and info can be recorded in a csv format and video format. The csv file can also be played back for the user in app.

Chapter 4

Detailed Design

4.1. Software

4.1.1. Arduino Code

Setup

When using Arduino devices there will be a setup() method which will run once only when the device starts. The Serial communications and baud-rate are specified with the Serial.begin() function. Thereafter the Arduino pin modes are configured to activate the internal pull up as this is needed for measuring the analog values from the IEE foot sensor. The pin mode can be configured using the pinMode(). This function takes two arguments which is the pin number and the mode. To use the ADC readings send by the ADS1115 via I2C, An object of the Adafruit_ADS1115 class was created and called ads. Now within the setup() method ads.begin method can be triggered to do all the necessary I2C setup for the ADS1115.

Next, the BLE setup commences. Arduino has a good library namely, ArduinoBLE.h, which provides all the needed function to setup BLE for the Arduino device. See code snippet 4.1

```
  // BLE setup
  BLE.setLocalName("Arduino Nano 33 BLE (Peripheral)");
  BLE.setAdvertisedService(gaitService);
  gaitService.addCharacteristic(gaitCharacteristic1);
  gaitService.addCharacteristic(gaitCharacteristic2);
  BLE.addService(gaitService);
  BLE.advertise();
  if (!BLE.begin()) {
    Serial.println("BLE error-Ble could not start");
    while (1);
  }
```

Listing 4.1: BLE Setup

The ”gaitService”, ”gaitCharacteristic1” and ”gaitCharacteristic2” object, used in code snippet 4.1, are created outside the setup() function. The ArduinoBLE library provides the

BLEService and BLECharacteristic classes to create these objects. The BLEService class only requires the service UUID as an argument to create an object. The BLECharacteristic class requires the characteristic UUID, the properties of the characteristic and the size of the value that the characteristic will represent. The properties can be specified by doing or operation with predefined constants provided by the ArduinoBLE library.

ADC

Unfortunately the Arduino NANO 33 only has 6 ADC pins and therefor an external ADC module, the ADS1115, was used to send the other 2 ADC values across I2C. The Adafruit library has a class with a method called readADCSingleEnded(). This method is used to get the ADC reading from the ADS1115. This method requires the pin number of the ADS1115 as a property. The ADS1115 has a 16 bit resolution and therefor it is required to use the map() function to scale the 16 bit ADC value down to 12 bit. The remaining 6 ADC readings can be retrieved using the analogRead() function and passing the pin number as an argument.

All the ADC operations that need to happen are within the getReadings() function. This function stores 8 analog readings in 8 floats which is then copied across two byte arrays each having a length of 16 bytes. The is to minimize the use of characteristics to only two characteristics.

BLE

In the main loop() function the Arduino will continuesly wait for a connection from a central device. An if statement has a BLEDevice object as condition and the condition will be true as soon as an connection is established. Within the if statement is a while loop which will loop while the central device is connected. Inside the while loop the getReadings() function is called to get all the ADC readins then these readings are written to each characteristic with the writeValue method from the BLECharacteristic class objects that were created. These characteristics are now advertising data to the central device

4.1.2. Android application code

HeatMap

To give a good graphical

4.1.3. Overview of user interface

4.2. Hardware

Chapter 5

Summary and Conclusion

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Appendix A

Project Planning Schedule

Date	Week	Description
Jul 18-23	1	Project planning and scope
25-30	2	Study prototype devices and how it can be used.
Aug 01-6	3	Literature study on the topic at hand. This is everything that is correlated to running and foot strike patterns
8-13 15-20	4 5	Start developing the Arduino code for the device. Try to get basic ADC readings from the IEEE foot sensor The previous student could not provide previously written code.
22-27	6	Reach BLE and how it can be used to transmit data from an Arduino device. Start developing the code as soon as I have good understanding of BLE for Arduino
Aug 29 - Sept 3	7	Test Week
5-10	8	Recess
12-17 19-24	9 10	Start building the Android application and understand BLE regarding Android devices. Display the data transmitted from the Arduino in a text view
26- 1 Oct 3-8	11 12	Build a heatmap view using OpenGL—ES. This requires a good understanding of OpenGL—ES and custom Android views
10-15	13	Use the previous students calibrations to build another custom view that displays the force exerted in newton on each cell
17-22	14	Test the application. This includes using the device on difference surfaces and walking up or down a hill. See if temperature has an effect on the cell readings
24-29	15	Present application to a person who has knowledge of foot strike patterns to see if an application of such would be of use in the industry and reflect on findings
31 October 2022	16	Report Deadline. Prepare for oral examination

This is an appendix.

Appendix B

Outcomes Compliance

This is another appendix.