2018 April 2 - July 6

INTERNSHIP REPORT

DEVELOPMENT OF A SYSTEM TO MEASURE THE SKIN TEMPERATURE OF THE FEET AT THE UNIVERSITY OF CALGARY

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1. Preface

As part of the specialisation Mechanics of Solids, Surfaces and Systems of the master Mechanical Engineering it is obligatory to carry out a 14 weeks during internship. I decided to go overseas to Canada, where I carried out my internship in the Human Performance Lab at the University of Calgary from 2018 April 2 till 2018 July 6. This internship was the perfect possibility to live in an English speaking country and in a different culture.

During my time in Calgary I was situated in the Human Performance Lab. A lot of research into footwear and exercise is conducted there. I worked in the biomechanics group under supervision of Prof. Dr. Darren Stefanyshyn. My project was part of a bigger project conducted for Ariat International, a performance footwear and clothing brand located in the United States. I developed a system for measuring the skin temperature of the feet. To validate this system I executed a pilot study to research a correlation between the temperature and volume of the foot.

I had many opportunities to learn about different projects. Besides my own project I also participated in the Adidas Cushioning project and the Basketball Stiffness project. This was a perfect opportunity to learn more about testing and analysing results. In both projects a motion capture system was used. It was a good experience to work in a project team and helping them with their projects. On the other hand, they also helped me when I had problems. Later on, also a FILA Cushioning and Adidas Football forefoot bending stiffness were executed by our group.

I experienced as a great advantage to have the opportunity to participate in different projects, because that gives you a good opportunity to learn about the possibilities in this field. However, this report will only inform about the project that was my responsibility.

Finally I would like to thank some people. Without them it was not possible to carry out this internship successfully. Emily Cooke and Joel Varughese taught me how to use all measurement equipment. I would also like to thank my both supervisors Bill Wannop and Prof. Darren Stefanyshyn. They gave me a lot of feedback during my project. Finally I would like to thank all other visiting students from my office, who gave me a very good time and good work environment.

2. Summary

A system is developed for measuring the skin temperature of the feet inside shoes. The goal of this research was the design and validation of the system with a pilot study for relating the change in temperature to change in volume of the foot.
Seven linear thermistors were used to model the temperature change of the feet. The sensors were calibrated in an oven, where the voltage was related to the actual temperature. These sensors were located at the heel, ball, arch, big toe, instep and medial and lateral malleolus of the left foot. The sensors located at the heel, ball and big toe were embedded in the insole. Two measurement sessions were done for five subjects, all executed barefooted. Each session started and ended with a 3D footscan. The temperature measurement consisted of ten minutes sitting on a chair with both feet flat on the ground and knees in an 90° angle followed up by 30 minutes walking with 5km/h or running with 10km/h for session 1 and 2, respectively. The static trials were a measurement for the variability and repeatability. Small changes between two days indicated the measurement system is repeatable. The skin temperature of the foot showed a similar trend for both walking and running. The sensors located at the heel, ball and big toe had all a high temperature rise. The sensors attached at the upper part of the feet showed a very small change in temperature and the arch of temperature increased moderately. The amount of sensors required for modelling the foot temperature depends on the application. The temperature of some individual subjects showed a different trend, which makes it not possible to decrease the amount of sensors for all applications. If exact temperature is required at a particular spot at the foot the sensor has to be placed exactly there. A global temperature change could be measured by selecting one sensor from each group. Due to the small extent of this experiment it is not possible to draw conclusions for relating the temperature to foot volume. No significant changes were found, but more measurements are necessary to validate this outcome.

Keywords: SAFETY BOOTS; LINEAR THERMISTORS; 3D FOOTSCAN; FOOT VOLUME; GAIT;

Contents

3. Symbols & definitions

Symbol	**Definition**
NTC	Negative Temperature Coefficient
PTC	Positive Temperature Coefficient
R	Measured resistance
T	Measured temperature
SHHE	Steinhart-Hart Equation
RTD	Resistance Temperature Detector
DAQ	Data Acquisition
S	Subject
E_{out}	Output voltage
E_{in}	Input voltage
M	Slope constant
b	Constant, equal to E_{out} for $T = 0$

4. Introduction

Ariat International is interested in designing safety boots. Due to build-in protective additives a lot of heat development could take place inside the shoe. It is important to design a shoe with optimal heat dissipation by using right ventilation points in the shoe since heat production is one the key points according wearing comfort.

Some research is conducted to the heat production and its influence on the feet inside shoes. However, most of this research focusses on running shoes or diabetes patients. Regarding safety boots a small amount of information is available. To get insight in the heat development mechanism in safety boots it is important to test the heat production in safety boots during the common movements executed on the work floor. As the hottest spots in the boot are known, the producer can more easily implement ventilation in the boot. To achieve above goal a valid measurement system is required.

Currently no standard testing protocol is available. To gain information regarding the temperature a measurement device and testing protocol need to be developed. This project focusses on designing the measurement system. This includes choosing type of temperature sensors, measurement points to model the temperature of the foot and validating the system. The system is tested in a pilot study as the safety boots did not arrive in the time. In the pilot study research is done to the relation between in foot temperature rise and foot expansion by using a 3D footscan besides the temperature measurement system.

This report includes all steps executed in this study. After the introduction a more detailed description of the assignment is given. The first step was reading literature about this problem of which the important information is presented in the theoretical background. The work plan gives the testing set up and thereafter the data collected in the pilot study is analysed. The report is ended with conclusions and recommendations.

5. Problem definition

Ariat International wants to go on market with safety boots. They want to add ventilation points in their design to optimise comfort. The skin temperature of the feet has to be measured during different movements to decide where to place the ventilation in the shoe. A validated measurement system is needed. Therefore the main goal of this work was designing a temperature measurement system inside shoes. Main questions are which and how many sensors are needed and where they should be placed to model the foot temperature as complete as possible.

In safety boots internal protectives elements are added to provide the safety of the workers. At some places the insulation is increased, which has a high influence on the footwear microclimate. The footwear microclimate is defined by the state of air that is surrounding the feet. It depends on the temperature, relative humidity and movement of the air in footwear [1]. Studies have shown that efficient ventilation of the foot inside footwear highly depends on the footwear and the protective element's material [1]. The microclimate is highly dependent on the construction of the footwear, the manner of binding and the presence of additive protective elements [1].

Different studies have shown that the comfort of footwear highly depends on the temperature of the feet [2]. Besides, high temperatures could play an important role in the development of foot problems [3]. Experiments are done with measuring the temperature of both dorsal and plantar regions of the feet in different kinds of footwear.

As stated above, an important factor to take into account in the designing process is the temperature of the feet inside the footwear. Since not that much research is done on the temperature development in safety shoes, a good measurement protocol must be developed. The first problem is to define the spots on the foot that are expected as critical, to determine where the temperature sensors should be placed. The next step is choosing temperature sensors. Some difficulties pop up for choosing the sensors. They have to be small in thickness, have the desired accuracy. At the end, data collection is necessary to verify the designed system.

By designing the measurement system some requirements and desired features were formulated to obtain a good working measurement system. They are all listed below.

1. The required accuracy is 0.2°C.
2. Temperature range of the sensor has to cover 20°C till 40°C.
3. The update frequency is ideally once a minute.
4. Sensor should be able to resist load to prevent breaking.
5. The sensor is ideally small to optimise the comfort of wearing the shoe.
6. Sensor needs to measure the skin temperature.
7. Data display is ideally on a laptop.
8. The measurement system must be suitable for executing dynamic movement.

6. Theoretical background

6.1 Safety boots

In safety boots different protective elements are added to provide the safety of the worker. The type of elements depends on the hazards the worker is exposed to. The footwear is made of different material types. Internally special elements are added. Common additives are toecaps, anti-impact metatarsal, ankle protectors and/or anti-penetration inserts in the soles. The material type, mostly used are steel, aluminium, plastic and compisites, depends on the protection requirements. The materials influences the microclimate inside safety footwear [1].

It is important that the boots satisfy specific workplace criteria. All additives are focused on reducing the risk of accidents and injuries, mainly contact with objects, preventing items to pierce the sole or shoe material, friction or pressure blistering, withstanding hazardous material contact and prevention of slipping. Every application requires differences in design. For example some shoes need to be waterproof. Also the shaft height might differ, whether and where steel safety caps must be applied, where closures are needed and differences in sole stiffness and design could exist [4].

6.2 Heat development in shoes

Being active keeps the feet warm. Well-insulated shoes prevent the feet from losing heat. In previous studies is shown that the feet temperature drops quickly during inactivity. This is especially what happens in footwear with low insulation. But also in well-insulated footwear a temperature drop is seen. For example the local effects of insulation at the toes and heel are clearly noticeable at the skin temperature [5].

For maintaining comfort studies have shown that the optimal temperature of feet in the footwear is between 27°C and 33°C [6]. The air temperature in the shoe should be between 28°C and 34°C [1]. The increase of feet temperature takes place due to raise in individual body temperature, repetitive friction in the shoes, compression and stretching of material due to forces generated at the heel strike and general environmental conditions [3].

A previous study used seven sensors to represent the entire foot [6]. Four sensors were placed on the bottom of the foot, namely on the neck of the big toe, ball, arch and heel. The other three sensors were attached on the instep, medial malleolus and lateral malleolus. See Figure 6.1 for a schematic display of the sensors placement.

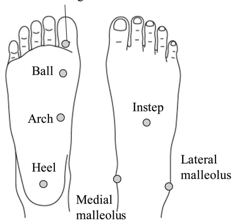


Figure 6.1: Sensor measurement points on the foot [6]

6.3 Temperature sensors

Different kinds of temperature sensors are available for temperature measurements. Several factors have to be taken into account by picking the most suitable sensor. The choice depends on the required accuracy, temperature range, desired response speed, thermal coupling, measuring environment and costs. The common electrical temperature sensors can be divided into three groups: thermocouples, RTD (Resistance Temperature Detector) and thermistors [7].

A thermocouple consists of two junctions where two different metals are joined together [8]. One is called the hot junction, the other the cold or reference junction. A thermoelectric voltage is produced and an electric current flows in the closed circuit. To measure the temperature a voltage measuring device needs to be put into the circuit. Advantages of thermocouples are the wide temperature range, low costs and high roughness [7]. Disadvantages are its nonlinear behaviour, low sensitivity, need for reference junction compensation and sensitivity to electrical noise.

The electrical resistance increases with the temperature in an RTD temperature measurement [9]. The most common used metals have an high melting point to prevent of corrosion. Advantages of RTD sensors are its linear response, wide temperature range and high stability [7]. The disadvantages include slow response time, high costs, need for a current source and high sensitivity to shock and mechanical load.

The name thermistor is the combination of the words thermal and resistor [10]. It is a temperature sensitive passive semiconductor which measures temperature by having a large change in electrical resistance by a small change of temperature [7]. A thermistor contains of metal oxides which are commonly pressed into a small bead, disk, wafer or another shape [11]. Advantages of thermistors are its fast response time, low costs, small size and large change in resistance for a small change in temperature [7]. Disadvantages are its nonlinear behaviour, need for a current source, limited temperature range and difficulties to interchange a thermistor without re-calibration.

Since size and costs are important factors and the temperature range is limited in this research project, the focus will be on thermistors in the rest of this report.

6.3.1 Thermistor

There are two types of thermistors. One works with a Positive Temperature Coefficient (PTC) and the other with a Negative Temperature Coefficient (NTC). In an PTC thermistor the resistance increases with the temperature, where in an NTC thermistor the resistance decreases as the temperature increases. Typically the resistance versus temperature relation is highly nonlinear. The temperature range in which these sensors are suitable is from $-50°$C to $+150°$C [10].

Typically thermistors require coating to protect against the environment [12]. A suitable coating depends on the temperature range in which the sensor is used. Epoxy coatings are normally used for thermistors applied in lower temperature ranges, approximately from $-50°$C till $150°$C. Glass coatings are more applicable for measurements that reach higher temperatures, like $-50°$C to $300°$C. The thermistor bead is mechanically protected against humidity and corrosion.

Thermistors have different advantages over thermocouples and RTDs. Compared to RTDs thermistors have a higher resolution, higher level of repeatability and stability, excellent interchangeability and their small size makes it possible to have a quick response to changes in temperature [12].

Thermistors require excitation. Since a thermistor is a resistance device it needs a current flowing through the thermistor in order to produce a voltage. This voltage can be measured by an Data Acquisition (DAQ) system. The most common technique is using a constant current source, see Figure 6.2a. The voltage across the thermistor could be measured using the following equation:

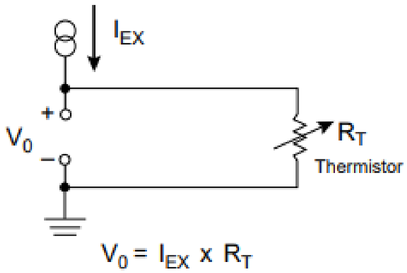
$$V_O = R_T I_{EX} \tag{6.1}$$

where V_O is the output voltage in V, R_T is the thermistor resistance in Ω and I_{EX} is the current source in A.

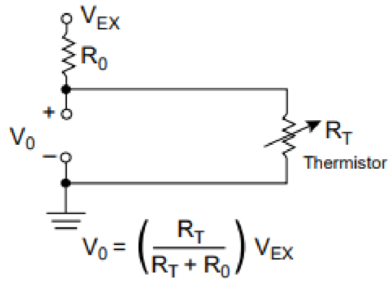
Another way for supplying the thermistor with a current is using a constant voltage source in combination with a reference resistor, see Figure 6.2b. The thermistor has to be configured with a simple voltage divider. The output voltage is:

$$V_O = \frac{V_{EX} R_T}{R_T + R_0} \tag{6.2}$$

with V_O the output voltage in Volts, V_{EX} the voltage source in Volts, R_T the thermistor resistance in Ohms and R_0 the reference resistance in Ohms.



(a) Current source [11]



(b) Voltage source [11]

Figure 6.2: Thermistor circuits with different sources

Thermistors are prone to self heating errors due to their small size and high resistance [11]. The current flow through the thermistor causes self heating inside the thermistor. Normally the manufacturer specifies the dissipation constant, which is the amount of power that will raise the thermistor temperature by 1°C.

Steinhart-Hart equation

The Steinhart-Hart equation (SHHE) relates the measured temperature (T) to the measured resistance (R) [13]. The Steinhart-Hart equation is given in Equation 6.3:

$$\frac{1}{T} = C_1 + C_2 \ln(R) + C_3(\ln(R))^3 \tag{6.3}$$

with C_1, C_2 and C_3 representing the three SHHE coefficients. These are either given by the manufacturer or have to be computed. There are three different ways to compute these constants. One of them is the 3-point method. Three data points are measured, likely within a range of 100°C to maintain a beneficial accuracy of ±0.2°C. To maintain that accuracy it is also required that T_2 is around the midpoint in the measured range [10].
Another method is calculating the coefficients with the least squares method. Where the 3-point method is more useful for less precise measurements, the least squares method gives you an higher precision [10].

A schematic overview of an SHHE based thermistor measurement is depicted in Figure 6.3 [10].

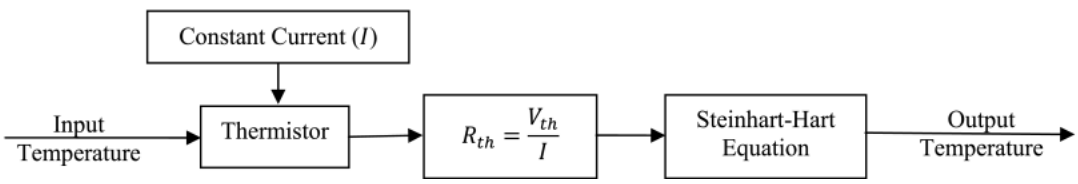


Figure 6.3: Signal processing of a thermistor based measurement [10]

Although there are also other equations describing the thermistor relationship, the advantages of the SHHE equation it that it describes the thermistor characteristics for a wider range compared to other equations. Therefore it gives a more realistic outcome. The SHHE equation has an inherent inverse thermistor characteristic since it has the temperature as output while the thermistor is measuring the difference in resistance [10].

Linearity

Thermistors also exist as part of a linear component. This contains a thermistor composite and a external resistor composite set in order to gain linearity. When these elements are connected correctly in a network there will be a varying voltage or resistance that is linear with the temperature. An example for both a linear voltage and resistance network are depicted in Figure 6.4.

For the voltage network from Figure 6.4a the output voltage (E_{out}) is characterized by the following equation:

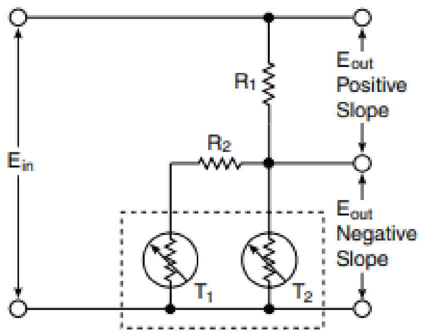
$$E_{\text{out}} = \pm MT + b \tag{6.4}$$

with M the slope in V/°, T the temperature in °C or °F and b the value of E_{out} when $T = 0°$ in V.

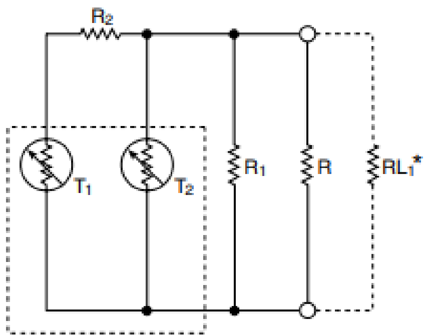
The output resistance (R_t) is given by the following equation:

$$R_t = MT + b \tag{6.5}$$

with M the slope in Ω/°, T the temperature in °C or °F and b the value of R_t in Ω when $T = 0°$.



(a) Network with a voltage output linear to temperature



(b) Network with a voltage output linear to temperature

Figure 6.4: Linear thermistor networks [14]

6.3.2 Attachment to the skin

To execute a reliable temperatrue measurement it is important that the sensor is attached properly to skin preventing it from moving. It is known that the film thickness influences the accuracy of the measurement [15]. A thicker film reduces the quality. The temperature difference between the measured and real temperature increases almost linearly with the film thickness.

Taping the sensor to the surface results always in noise due to the influenced thermo-physical processes at the surface interface. Besides, the human skin is soft, which gives an increased contact area between the sensor and skin compared to the contact area between skin and a hard surface, for example a plate. It is a challenge to keep the measurement independent from artefacts caused by the skin softness [16].

6.4 Data Acquisition

Data Acquisition (DAQ) includes measuring of an electrical or physical signal with a computer. The total measuring system consists of a sensor, an DAQ Box and a compute with software. A schematic overview of an DAQ system is depicted in Figure 6.5. An analog signal goes into the DAQ Device, which converts the analog measured signal into a digital signal to go in the computer software. An DAQ device consists of the three key components Signal Conditioning, Analog-to-Digital Converter (ADC) and Computer Bus. The Signal Conditioning part manipulates the measured signal because the signal can be too dangerous or noisy. The DAQ device can amplify, attenuate, filter or isolate the signal. The ADC chip provides the digital representation of the analog signal. The Computer Bus is the communication interface between the DAQ device and the computer, for example via an USB [17].

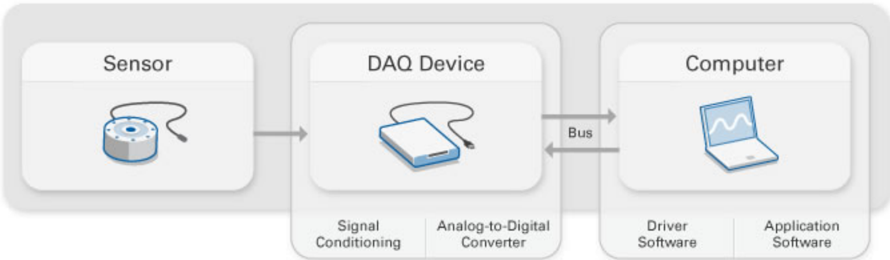


Figure 6.5: Schematic overview of a Data Acquisition System[17]

7. Work plan

7.1 System Design

7.1.1 Sensors

The chosen sensors are type OL-709 produced by OMEGA, shown in Figure 7.1 [14]. These sensors behave linearly in combination with a resistor composite set as described in subsubsection 6.3.1. The Linear Components Kit Model Number is 44202. The Thermal Composite Model Number is 44018 and the Resistor Composite Values Number is 44302. The sensor end has a diameter of 11mm and a thickness of 3.2mm. The linear deviation is ±0.15°C and the temperature range lies between −5°C and +45°C. The thermistor consists of two thermistor elements with resistances at 25°C of:

$$
\begin{aligned}
R_1 &= 6,000\Omega \\
R_2 &= 30,000\Omega
\end{aligned}
\tag{7.1}
$$

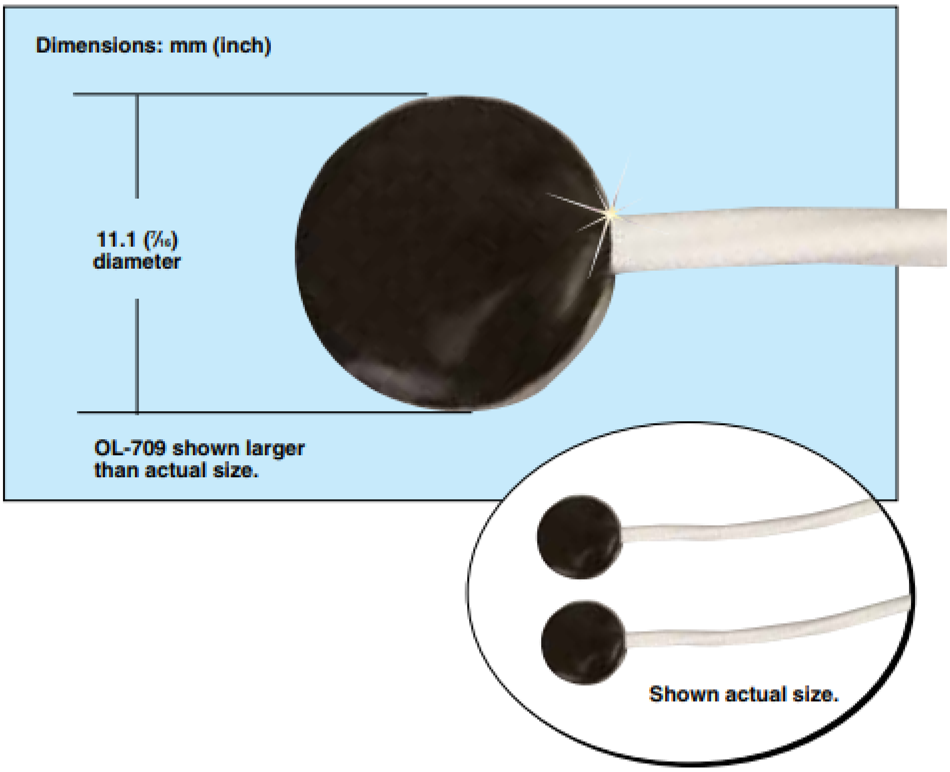


Figure 7.1: OL-709 sensor. Upper figure contains the enlarged sensor with dimensions. The bottom figure shows the sensors at actual size [18]

Since the sensor is used in combination with a Resistor Composite Set the output resistance is linear to the output temperature. The thermistor composite senses the temperature, where the external resistor composite linearises. The resistances of the Resistor Composite Set at 25°C are:

$$
\begin{aligned}
R_1 &= 5,700\Omega \\
R_2 &= 30,000\Omega
\end{aligned}
\tag{7.2}
$$

The maximum voltage input is 3.5V and the maximum current is 615μA. These are the maximums preventing self-heating errors to not enlarge the component error band, which is the sum of the linearity deviation and the probe tolerance. The load resistance is 10MΩ and the linearity deviation is ±0.065°C. The thermistor dissipation constant is 8MW/°C in stirred oil [14].

A linear equation for these sensors is:

$$E_{\text{out}} = (-0.0056846E_{\text{in}})T + 0.805858E_{\text{in}} \tag{7.3}$$

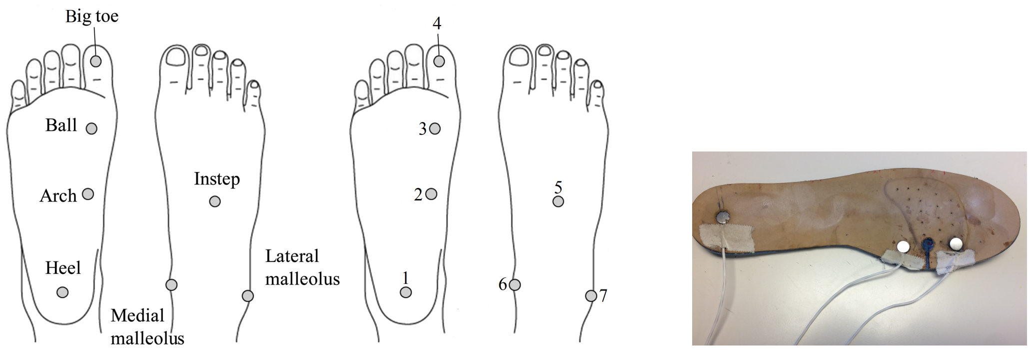
7.1.2 Data Acquisition Box

The Data Acquisition Box used is the DATAQ type DI-1110. This box has eight analog inputs, a 12-bit analog-to-digital resolution and a sample throughput rate of 160kHz. The measurement range is ±10V full scale. The seven digital ports are protected to +25V. The absolute accuracy of the analog inputs is ±12.5mV at 25°C. The Computer Bus is an USB [19]. The box is connected to a laptop of model Acer Aspire E5-571 which operates on a Windows 10 Home system. The processor is a Intel(R)Core(Tm) i7-4510U. Also the analysis is done with this system.

Figure 7.2: Data Acquisition Box type DI-1110

7.1.3 System setup

Seven sensors were picked to model the skin temperature of the whole foot at seven critical points as shown in Figure 7.3. Four sensors were located at the plantar region of the foot, of which the sensors at the heel, ball and big toe were embedded in the insole of the shoe. The sensors at the arch, instep and medial and lateral malleolus were taped on the foot. The wires of the sensors placed at the bottom of the foot were leaded underneath to leave the shoe at the medial side. Table 7.1 and Figure 7.3 give an overview of the numbering and placement of the sensors.



(a) Sensors foot (b) Numbering sensors foot (c) Insole

Figure 7.3: Sensor measurement points on the foot

Table 7.1: Numbering and placement of sensors on the left foot

Sensor	**Region**	**Location**
1	Plantar	Heel
2		Ball
3		Arch
4		Big toe
5	Top	Instep
6		Medial malleolus
7		Lateral malleolus

7.2 Experimental Protocol

7.2.1 Calibration

A calibration was executed to check the given relation between output voltage and temperature. All seven sensors and the Data Acquisition Box were placed in an oven. The oven was set at four different temperatures: 25°C, 30°C, 35°C and 40°C. A ten second measurement with a a sample rate of 1000Hz was done after stabilising for one minute at the set temperature. The first and last 10% of the measurement points were removed for the calculation so that only the data points 1001 till 9000 were taken into account. Although an equation is given, an unique linear equation is determined for all seven sensors by calculating the coefficients M and b from the equation:

$$T = M\frac{E_{\text{out}}}{E_{\text{in}}} + b \tag{7.4}$$

The results of this calculation are given in Table 7.2. The equations in the last column are used for calculating the temperature from the measured voltage. The corresponding calibration graphs for each sensor are depicted in Figure 7.4.

Table 7.2: Specific relation between temperature and output voltage for each sensor

Sensor	**M**	**b**	**Equation**
1	-174.7614	141.0390	$T = -174.7614\frac{E_{\text{out}}}{E_{\text{in}}} + 141.0390$
2	-175.9104	141.9287	$T = -175.9104\frac{E_{\text{out}}}{E_{\text{in}}} + 141.9287$
3	-176.4604	142.3669	$T = -176.4604\frac{E_{\text{out}}}{E_{\text{in}}} + 142.3669$
4	-177.0687	142.8335	$T = -177.0687\frac{E_{\text{out}}}{E_{\text{in}}} + 142.8335$
5	-176.0268	142.1993	$T = -176.0268\frac{E_{\text{out}}}{E_{\text{in}}} + 142.1993$
6	-187.6706	149.5078	$T = -187.6706\frac{E_{\text{out}}}{E_{\text{in}}} + 149.5078$
7	-177.3005	142.7649	$T = -177.3005\frac{E_{\text{out}}}{E_{\text{in}}} + 142.7649$

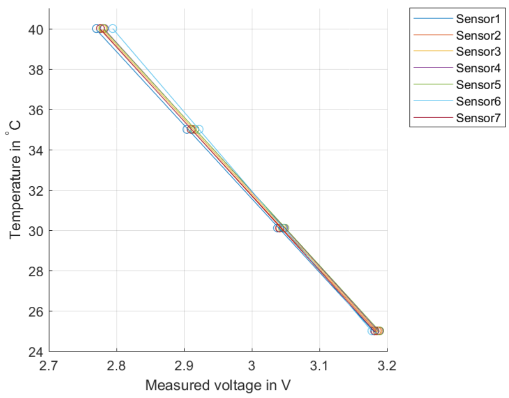


Figure 7.4: Temperature versus voltage for each individual sensor

7.2.2 Measuring protocol

Five subjects (4 male, 1 female) have done two experiments on two different days. Both experiments were started and finished with a 3D footscan by using Footscan Model 28BA0100 from RSscan International RV. The last footscan is made as soon as possible after finishing the dynamic part. After the first footscan all sensors were attached to the skin and the Adidas running shoes US men size 9 were put on. The first measurement was a 10 minute static while the person was sitting with both feet flat on the ground while the knees were in a 90° angle. In the first session the static measurement is followed up by 30 minutes walking with 3.1 mph on a treadmill. The second session consists of 30 minutes running with a speed of 6.2 mph.

8. Analysis

8.1 Static

The static trials are a measure for the variability between two days. Besides, these trials are used as a measure for the repeatability. The variability between two days is based on the absolute temperature difference between the two days within a subject. The temperature change of each sensor on day 1 is compared to day 2 for determining the repeatability. To compare the the two static trials are plotted with help of the *Matlab* code from section B.4.

The average temperature for each sensor at the end of the static trials is represented in Figure 8.1. The blue and orange bar correspond to the session at day 1 and 2, respectively. Some small changes can be noticed between the trials at the two different days, which is the variability of the foot skin temperature. Moreover, it seems that the temperature on day 2 is lower than on day 1 for each separate sensor. This is mainly caused by a higher difference for S02 and S04 between the measurement sessions. It is not a trend that has been seen for every single subject. S02 and S04 have in common that the start time of both sessions were totally different. The first measurement took place at 2pm and the second session at 8am. It requires more subjects to find out if the time of the day affects the feet temperature. Subject 5 had the same difference in start time, but the temperature trend for both days is almost similar for both days, see Figure **??**.

During the 10-minute static trial the maximum difference in average temperature change is 1.4°C for sensor 4 and the minimum difference in change is 0.2°C for sensor 6. See Figure 8.1 for the average temperature over all subjects for each sensor at the end of the static trial. These values indicate that the measurement is repeatable, but more measurements are necessary for real conclusions.

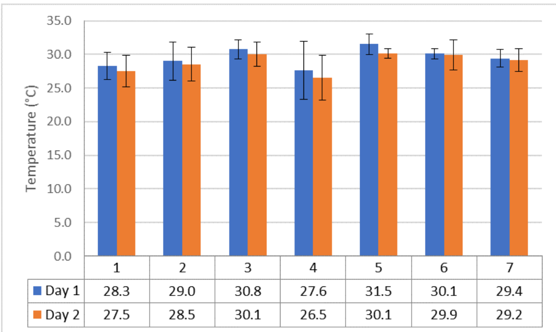
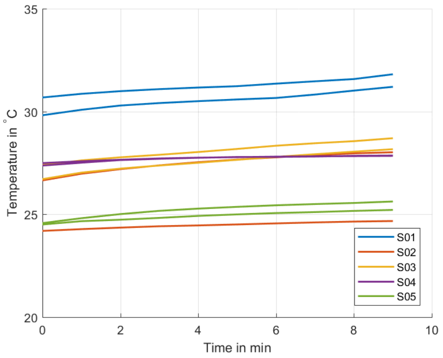


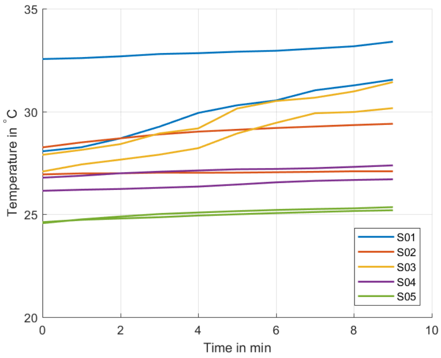
Figure 8.1: The average temperature for each sensor on day 1 and day 2 at the end of the static trial

Table 8.1: Start time measurement sessions for each subject

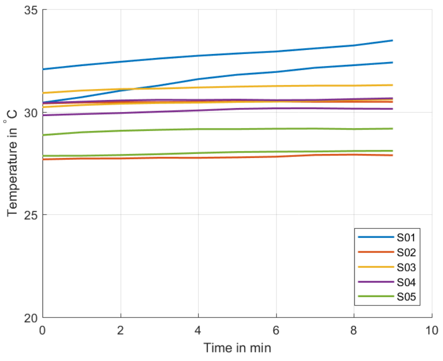
Subject	Time session 1	Time session 2
S01	1:30pm	1:30pm
S02	2:00pm	9:00am
S03	3:30pm	4:30pm
S04	2:30pm	8:00am
S05	3:00pm	9:30am



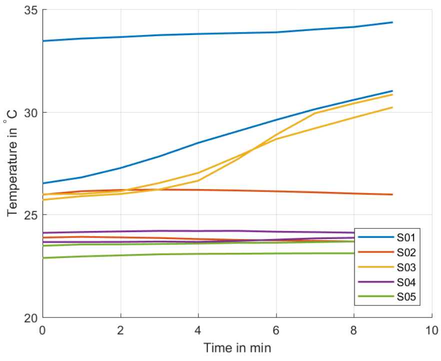
(a) Heel



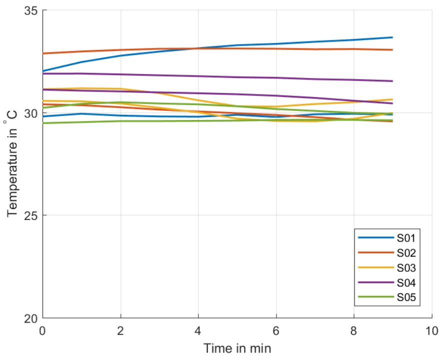
(b) Ball



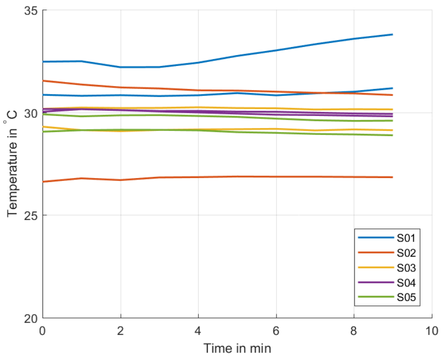
(c) Arch



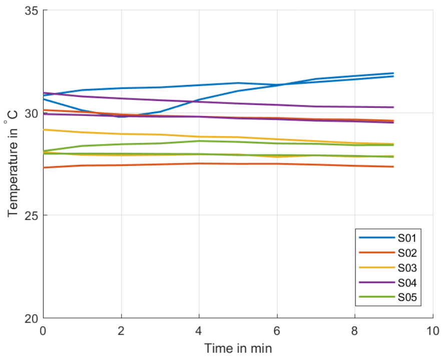
(d) Big toe



(e) Instep



(f) Medial malleolus



(g) Lateral malleolus

Figure 8.2: Temperature change of the feet for each subject during two static measurements

8.2 Dynamic

In Table 8.2 the average start and end temperatures over all subjects for each sensor with the corresponding standard deviation and rise in temperature are given. Although the absolute values in the end temperature and temperature change differ for walking and running, the same trend is visible for both. According the data it is possible to divide the sensors into three subgroups.

Group 1 contains sensor 1, 2 and 4, which have all a high temperature rise. Sensors 5, 6 and 7 can be grouped together because of their low change in temperature. Sensor 4 has a moderate temperature change. Sensor 1, 2 and 4 are the sensors direct in contact with the ground during gait. They have the highest rise in temperature due to contact forces during gait [6]. The arch of the foot is not in direct contact with the ground, which declares the smaller increase in temperature. The sensors at the upper part of the foot are more influenced by convective heat released caused by the motion of the foot. This could cause first a drop in temperature followed by an increase.

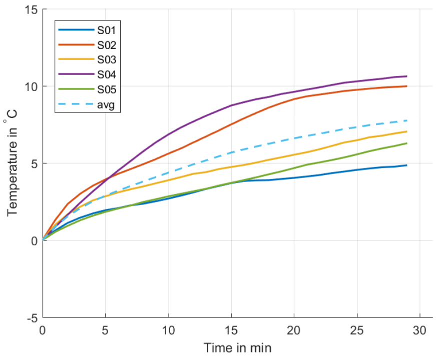
For sensor 4 the standard deviation is the highest at the start of both walking and running. This means the begin temperature at the big toe had the highest variation at the start. For the end temperature the standard deviation lies in a closer range, namely all around 2 for walking. For running the standard deviation for sensor 5 and 6 are above 3.

In Figure 8.3 and 8.4 is shown that the bottom of the foot does not reach a temperature plateau for all subjects. These figures are formed with the codes from section B.5 and B.6 respectively. This indicates that the time or intensity of the trial was not enough to reach the top temperature. A change in protocol could be made to reach a plateau.

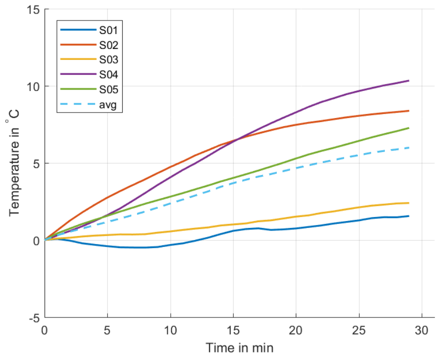
In Figure 8.4a the temperature developing line of sensor 1 looks remarkable. During the dynamic running measurement sensor 1 of subject 4 did not work correctly between minute 19 and 22. For that reason the measurements of this interval are removed from the data and replaced by a linear interpolation function using Matlab. Also between minute 11 and 16 were some small errors, which declares the small bumps in the line.

Table 8.2: The mean temperature of the feet for all sensors at the beginning and the ending of the walking and running

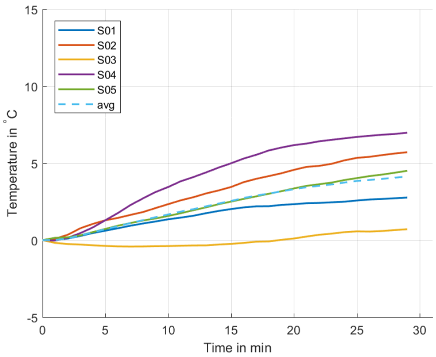
	Walking					**Running**				
	Start		**End**			**Start**		**End**		
Sensor	Mean (°C)	SD	Mean (°C)	SD	ΔT	Mean (°C)	SD	Mean (°C)	SD	ΔT
1	28.6	2,0	36.4	2.3	7.8	27.9	2.4	38.5	2.3	10.7
2	29.1	2.7	35.1	2.1	6.0	28.6	2.5	38.6	1.5	10.0
3	30.8	1.4	34.9	2.1	4.1	30.1	1.8	36.4	1.3	6.3
4	27.7	4.0	34.4	2.4	6.7	26.9	3.6	37.4	2.1	10.5
5	31.4	1.6	33.4	2.3	1.9	30.1	0.8	33.0	3.0	2.9
6	29.7	0.6	30.6	1.9	0.9	29.7	2.5	30.6	3.4	0.9
7	29.2	1.0	30.4	2.0	1.1	28.9	1.4	31.4	1.3	2.4



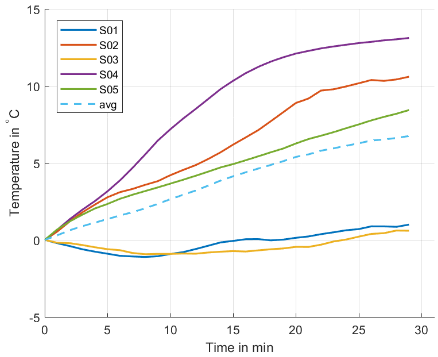
(a) Heel



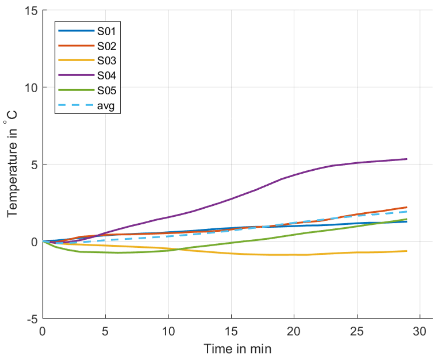
(b) Ball



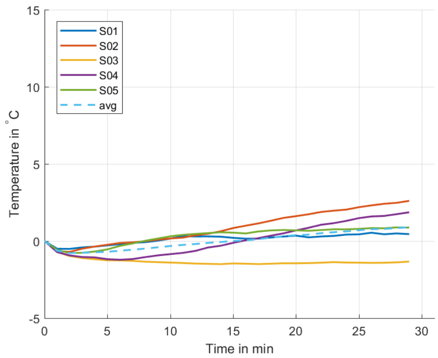
(c) Arch



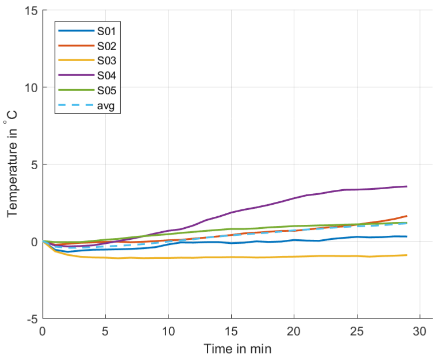
(d) Big toe



(e) Instep

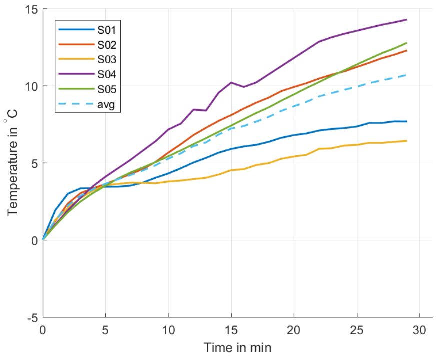


(f) Medial malleolus

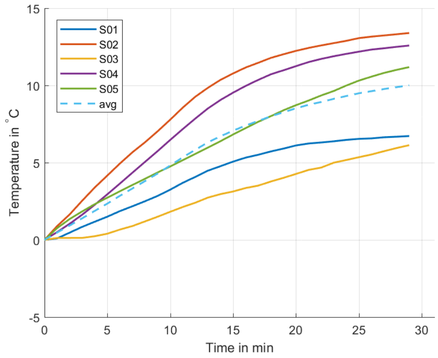


(g) Lateral malleolus

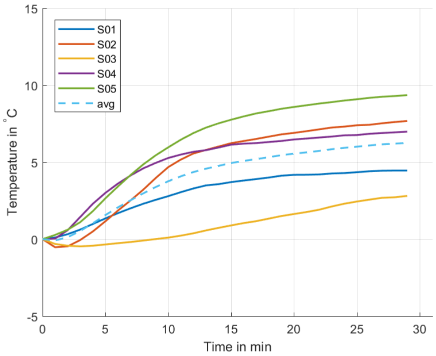
Figure 8.3: Temperature change of the feet for each subject during 30 minutes of walking



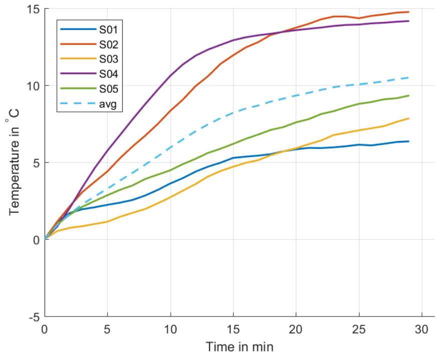
(a) Heel



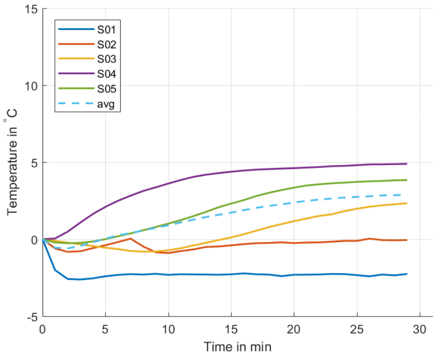
(b) Ball



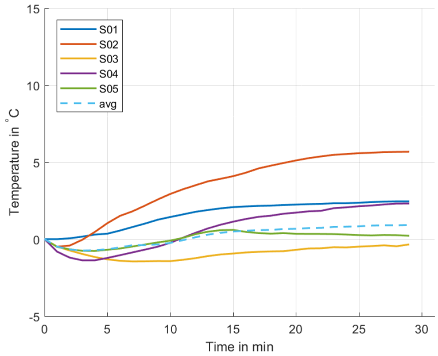
(c) Arch



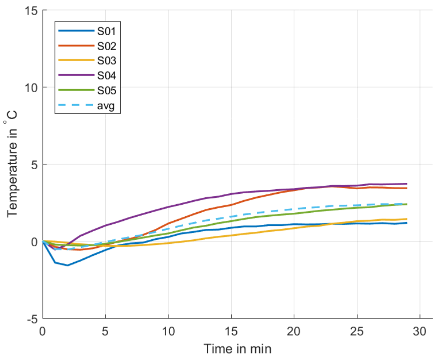
(d) Big toe



(e) Instep



(f) Medial malleolus



(g) Lateral malleolus

Figure 8.4: Temperature change of the feet for each subject during 30 minutes of running

8.3 Footscan

The t-test is executed to determine whether the data of the footscans before and after the measurement differ significantly from each other. The measures of the feet are extracted from the footscan software. The average value over the five subjects with the corresponding t-test value for each measure is given in Table 8.3. A smaller t-test number means a more significantly difference. Since this sample size is small, a t-test smaller than 0.15 is considered as be significant. The values for walking give no t-test numbers within this value, but some are approaching 0.15. Only for the foot length this is for both left and right foot. Looking to this value could mean that the foot length has a small increase after walking for half an hour. But when looking into the data of the foot length for each subject separately, it becomes clear that for three subjects for both right and left foot no change does exist.

Table 8.3: Average values and t-test footscan before and after walking

Measure	**Left**			**Right**		
	Before	After	t-test	Before	After	t-test
Arch height (mm)	17.6	18.4	0.577	17.8	19	0.208
Arch length (mm)	182.2	181.8	0.587	182.2	183	0.242
Foot length (mm)	256.4	256.8	0.178	256.4	257	0.208
Foot width (mm)	101.6	101.8	0.75	102.4	102.4	1

Table 8.4: Foot length in mm for each subject before and after walking

	Left foot (mm)		**Right foot (mm)**	
Subject	Before	After	Before	After
S01	250	251	253	254
S02	254	254	251	253
S03	249	249	249	249
S04	271	271	269	269
S05	258	259	260	260

The footscan data before and after running has two interesting measures. The t-test values for both arch height and foot width are relatively small. However, the foot width data goes in two different directions. The food width of the left foot shrinks while the food width of the right foot increases. In the arch height it might be that a trend is detected. The average arch height of both left and right foot is decreased after running. Looking into more detail of this measure, see Table 8.6, stands out that subject 1 does not fit this trend. Also subject's 2 right foot shows no decrease.

Table 8.5: Average values and t-test footscan before and after running

Measure	**Left**			**Right**		
	Before	After	t-test	Before	After	t-test
Arch height (mm)	17.6	16	0.035	19	18.4	0.305
Arch length (mm)	182.8	181.8	0.189	181.8	182.4	0.426
Foot length (mm)	256.6	256.4	0.374	256.8	257.2	0.374
Foot width (mm)	102.6	101.6	0.230	102.4	104.2	0.195

Table 8.6: Arch height in mm for each subject before and after walking

	Left foot (mm)		**Right foot (mm)**	
Subject	Before	After	Before	After
S01	15	15	17	18
S02	19	18	22	22
S03	24	22	24	22
S04	14	12	18	17
S05	16	13	14	13

9. Conclusions

The main goal of this experiment was designing a valid skin temperature measurement system to model the feet temperature inside shoes. According the comparison between two different static trials for each subject the measurement system works. Only small temperature changes are seen between two days. The seven chosen spots to measure the temperature were sufficient to model the foot temperature inside running shoes during gait. The measured changes in temperature at the different spots can be split into three groups. The heel, ball and big toe show a high rise in temperature due to ground reaction force at the beginning of gait. The arch shows a moderate rise due to bellows ventilation and the sensors at the upper part of the foot show a very low change in temperature due to convective heat release. The exact amount of sensors needed depends on the purpose of the measurement. When only a global overview of the temperature development is required, the amount of sensors could be reduced to three. A choice should be made between the sensors at the heel, ball and big toe, the arch sensor should be picked and it is recommended to pick the sensor at the instep. When someone is interested in the temperature at a specific region of the foot, the sensor should be placed at that specific spot to get an accurate measurement.

It is not possible to relate the change in temperature of the feet to a change in volume according the collected data in this experiment. Since only five subjects were participating in this study, it is not possible to conclude if the volume of the foot really does not change by increasing temperature. Further analysis is required.

10. Recommendations

Different parts of this work could be improved or require further research. In this chapter some recommendations will be given.

All requirements formulated in chapter 5 are achieved, only the accuracy is not tested. It should be tested if it is below the required 0.2°C.

The calibration technique was not perfect. In this measurement system surface temperature sensors were used. By placing the sensors in the oven, the sensors were measuring the air instead of surface temperature. It was not possible to calibrate in a different way due to lack of equipment. It is highly recommended to redo the calibration for follow up studies.

A plateau in temperature is not reached during the dynamic trials. After a certain amount of time the skin temperature should reach a steady state. The time and/or intensity were not sufficient to come into this steady state. Increasing the duration of walking and running is one option to improve. This option has the limitation that not everybody is capable of running more than 30 minutes. Another way is higher the intensity of walking and running by increasing the speed. Walking at 6km/h and running at 12km/h could already help a lot. Exact numbers should be determined by pilot testing.

Initially this system was designed for measuring the temperature inside safety boots. This measurement system is not tested in safety boots yet, but they are tested in a pair of low running shoes. Determining which of the seven sensors are required to model the skin temperature inside safety boots requires pilot measurements with safety boots. Protective elements at the toes and the high ankle cover could influence the temperature development differently. The sensors at the medial and lateral malleolus are not needed if the running shoes are worn. The high ankle protective elements could change this.

The foot temperature is strongly influenced by socks since socks increase the insulation [5]. The temperature measurement was executed barefooted. It was impossible to wear socks since three sensors were embedded in the insole of the shoe to protect them against loading forces. It is recommended to do research into the exact influence of socks for a more accurate analysis in the foot temperature development. Changes in the measurement protocol are required to be able to measure the influence.

The temperature is highly influenced by moisture. The combination of convection and moisture could reduce the footwear insulation up to 45% [5]. Furthermore the feet are dense in sweat glands. High temperatures generate sweating of the feet [6]. In this measurements moisture and sweat production is not taken into consideration. Since they influence temperature development by reducing the insulation it is suggested to do a follow up study with taking moisture and sweating into account.

The environmental temperature was not controlled during the data collections. This could have a high influence on the static trials and could declare differences found between two days. The temperature of the lab is not measured, which would have been possible with an ambient thermometer. A higher accuracy could be reached when the temperature of the room can be controlled. The same experiment should be repeated in a controlled temperature room to validate the results from this experiment.

The foot size of the subject could influence the measurement since three sensors were embedded in the insole of the shoe. The foot size determined where the sensors meant for the ball and big toe were located exactly. In the pilot testing the subjects had a foot size within a range from US Men 8 (EURO40.5) to US Men 9 (EURO42), which is a difference of approximately 1cm. This could have influenced the accuracy of the results negatively. It is also known that the fitting and room inside the footwear affect the air ventilation [6]. This influences the temperature inside the shoe by heat transfer between the inside and the outside of the shoe. In this experiment exact fitting of the shoes is not taken into account.

Influence of the time of the day is not considered in the measurements. The measured data gives the idea that the time of the measurement could matter. But this should also be checked by measuring the environmental temperature. A separate study for the influence of the time on the temperature of the foot could give more insight in this matter.

Regularly foot temperature drops quickly during inactivity after doing exercise. In prior studies a static temperature measurement is mostly done for about ten minutes after the dynamic measurement. However, in this study it was wanted to do a footscan as quickly as possible after the dynamic measurement. For this reason it was essential to take off the sensors immediately after the dynamic measurement making it impossible to continue measuring the temperature profile. Depending on the purpose of the study a choice should be made. Splitting each measurement in two sessions could be a solution when interested in both mechanisms.

The reproducibility and repeatability is not researched yet. It is necessary to do further analysis since this are important measures for the validity and quality of the results. Only for the repeatability some measurements are done, although not under the exact same conditions. In a controlled temperature chamber at the exact same time of the day measurements on the same persons with the same instruments must be repeated. For the reproducibility another person should repeat the experiment under the same conditions with the same instruments.

The number of subjects was very small in this study. To improve the accuracy of the results and in order to see whether trends are real trends more subjects are required.

The footscan data is hard to make conclusions on. In this experiment some small changes were visible, but not consistent in both feet. It is assumed the right foot behave the same as the measured left foot. Even the visible changes could be due to multiple things. The variations were so small that they could be caused by a subject standing in a different position for example. This could highly influence the arch height. According the knowledge from this study it is only possible to conclude that no changes in foot shape are observed. For a more substantiate conclusion more detailed research on more subjects is required.

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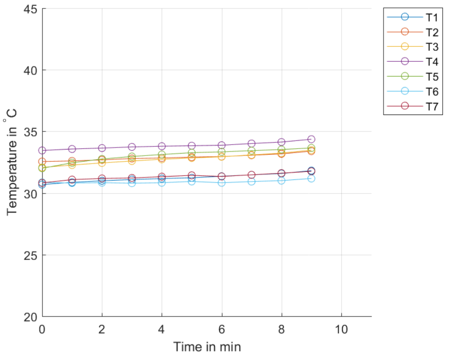
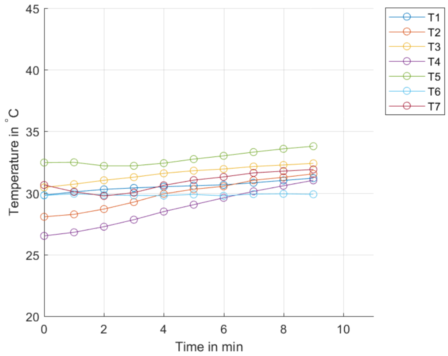
A. Results

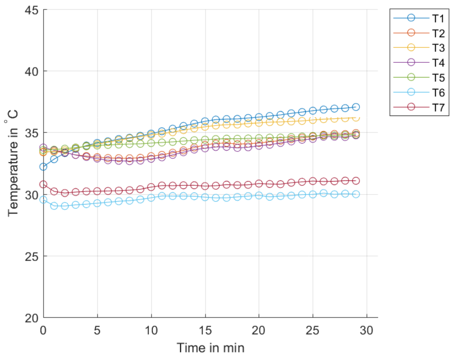
A.1 Subject 1



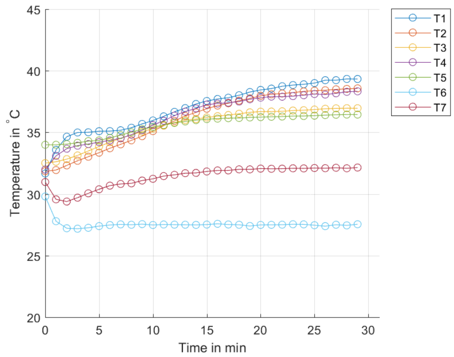
(a) 10 minute static measurement before walking



(b) 10 minute static measurement before running



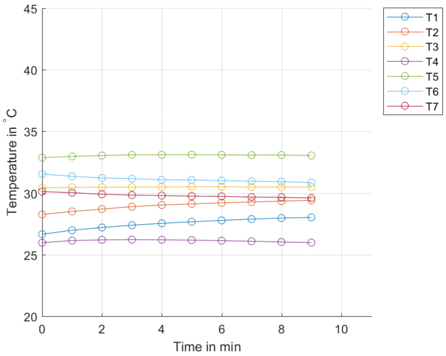
(c) 30 minute measurement during walking



(d) 30 minute measurement during running

Figure A.1: Temperature change over time subject 1

A.2 Subject 2



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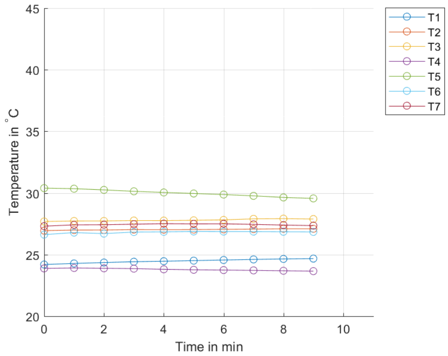

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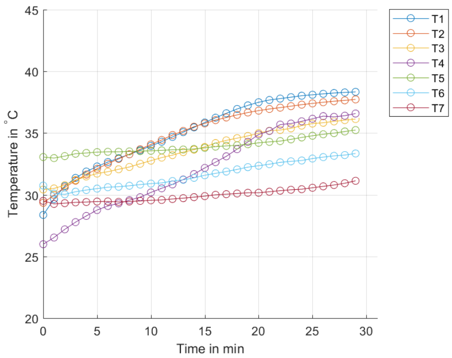
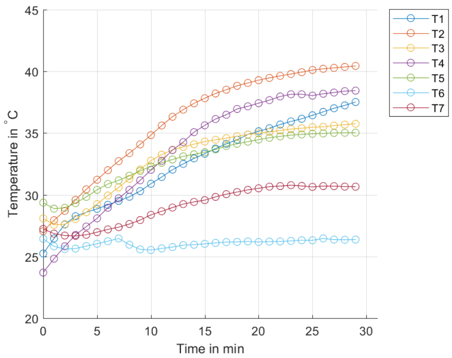


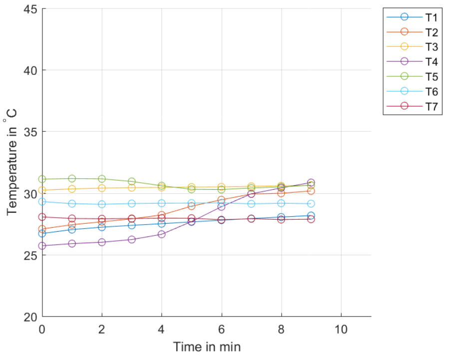
(c) 30 minute measurement during walking



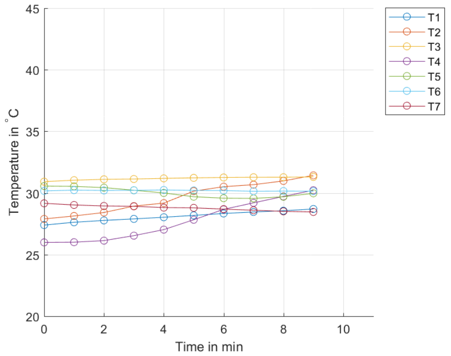
(d) 30 minute measurement during running

Figure A.2: Temperature change over time subject 2

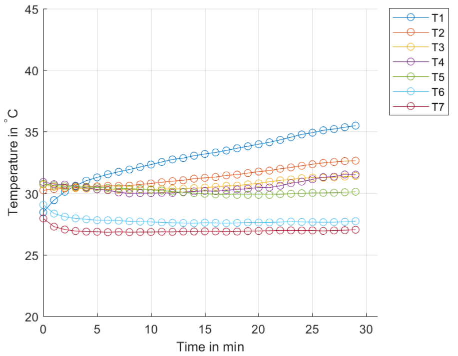
A.3 Subject 3



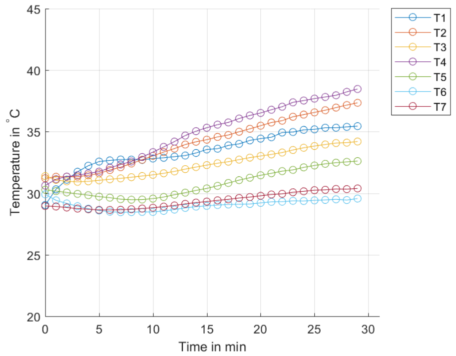
(a) 10 minute static measurement before walking



(b) 10 minute static measurement before running



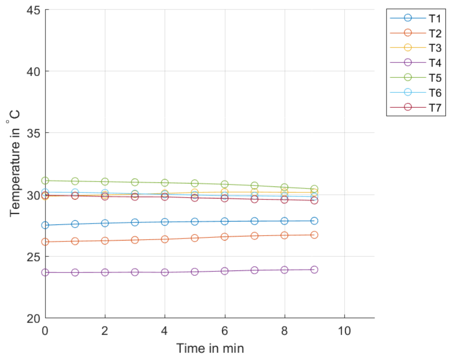
(c) 30 minute measurement during walking



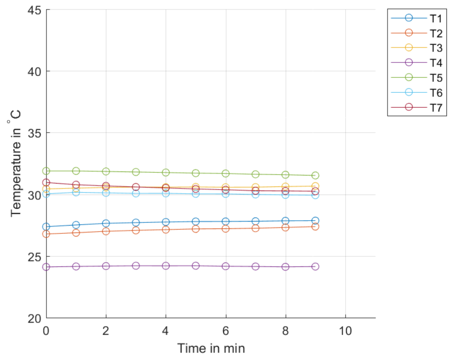
(d) 30 minute measurement during running

Figure A.3: Temperature change over time subject 3

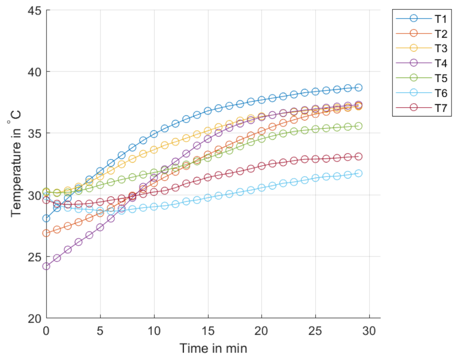
A.4 Subject 4



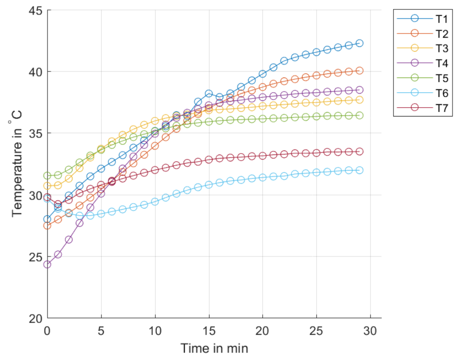
(a) 10 minute static measurement before walking



(b) 10 minute static measurement before running



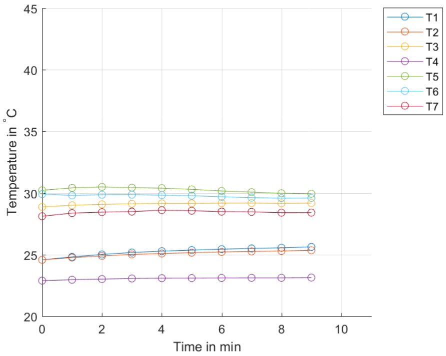
(c) 30 minute measurement during walking



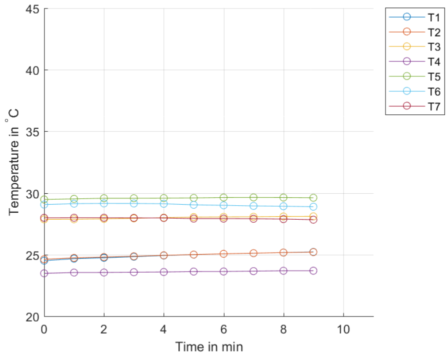
(d) 30 minute measurement during running

Figure A.4: Temperature change over time subject 4

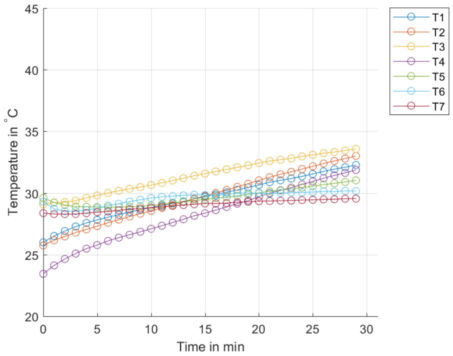
A.5 Subject 5



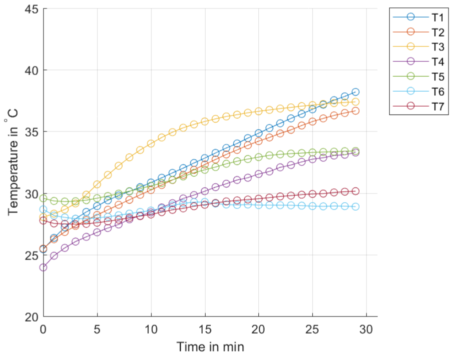
(a) 10 minute static measurement before walking



(b) 10 minute static measurement before running



(c) 30 minute measurement during walking



(d) 30 minute measurement during running

Figure A.5: Temperature change over time subject 5

A.6 Footscan

Table A.1: Arch height in mm for all subjects for left and right foot before and after both walking and running

	Start	**End**	**Start**	**End**
Walking				
Subject	Left (mm)		Right (mm)	
1	16	15	18	17
2	19	19	19	22
3	23	22	22	22
4	15	15	17	20
5	15	21	13	14
Mean	17.6	18.4	17.8	19
Running				
1	15	15	17	18
2	19	18	22	22
3	24	22	24	22
4	14	12	18	17
5	16	13	14	13
Mean	17.6	16	19	18.4

Table A.2: Arch length in mm for all subjects for left and right foot before and after both walking and running

	Start	**End**	**Start**	**End**
Walking				
Subject	Left (mm)		Right (mm)	
1	175	174	178	179
2	179	178	181	183
3	185	183	185	187
4	189	189	186	186
5	183	185	181	180
Mean	182.2	181.8	182.2	183
Running				
1	179	176	177	177
2	179	178	181	181
3	184	183	186	185
4	190	189	185	186
5	182	183	180	183
Mean	182.8	181.8	181.8	182.4

Table A.3: Foot length in mm for all subjects for left and right foot before and after both walking and running

	Start	**End**	**Start**	**End**
Walking				
Subject	Left (mm)		Right (mm)	
1	250	251	253	254
2	254	254	251	253
3	249	249	249	249
4	271	271	269	269
5	258	259	260	260
Mean	256.4	256.8	256.4	257
Running				
1	250	250	253	253
2	254	254	253	253
3	250	249	249	251
4	271	271	268	268
5	258	258	261	261
Mean	256.6	256.4	256.8	257.2

Table A.4: Foot width in mm for all subjects for left and right foot before and after both walking and running

	Start	**End**	**Start**	**End**
Walking				
Subject	Left (mm)		Right (mm)	
1	102	102	102	103
2	100	101	101	101
3	94	92	93	94
4	106	107	110	107
5	106	107	106	107
Mean	101.6	101.8	102.4	102.4
Running				
1	104	103	103	101
2	102	100	100	101
3	94	91	93	98
4	107	107	111	114
5	106	107	105	107
Mean	102.6	101.6	102.4	104.2

B. Matlab codes

B.1 Calibration

```
clear; clc;close all;
%With this script the calibration for the 7 sensors is executed. The .mat
%files consists the average output voltage from the middle 80% for each
%sensor. The same is for the input voltage (E_in).

%Initialise the matrices V and E_in.
V = [];
E_in = [];

%Fill matrices V and E_in
for i = 25:5:40
    filename = ['V',num2str(i), '.mat'];
    load(filename)
    V_cal(i/5-4,:) = V;
    E_in_cal(i/5-4,:) = E_in;
 end

%Temperature vector at which the oven was set for calibration
T = [25 30.1 35 40];

%Call color matrix with default color order Matlab
C = get(gca,'colororder');

%Create figure
figure(1)
axis([2.7 3.2 24 41])
grid on
hold on
xlabel('Measured voltage in V')
ylabel('Temperature in ^{\circ}C' )
%Plot data points of the output voltage versus the temperature
for k= 1:7
  h(k) = plot(V_cal(:,k),T,'o','color',C(k,:));
  coeffs(k,:) = polyfit(V_cal(:,k)',T ,1);
end

%Plot a linear fit through the plotted data points
for k = 1:7
  y(k,:) = polyval(coeffs(k,:),V_cal(:,k));
  p(k)=plot(V_cal(:,k),y(k,:),'-','color',C(k,:));
  legendInfo{k} = ['Sensor' num2str(k)];
end

%Create legend figure
legend(p,legendInfo,'Location','bestoutside')

%Calculate the mean of E_in to determine the coefficients M and c for the
%linear relation between the temperature and output voltage
E_in_mean = mean(E_in_cal);
M = coeffs(:,1)*E_in_mean;
c = coeffs(:,2);

%Initialise temperature check vector
T_check = [];

%Check if the temperature outcome are indeed 25, 30.1, 35 and 40 degrees %Celsius
for k =1:7
    T_check(:,k) = M.*V(:,k) + c;
end

%Save figures as png file in specified folder
fpath = ['C:\Users\AnkeNB\Dropbox\UniversiteitTwente\Studie\MasterMechanicalEngineering\'...
    'Internship\Calgary\Report\images\Calibration'];
```

```
filename = 'Calibration_sensors';
saveas(gcf,fullfile(fpath,filename), 'png')
```

B.2 Running code

```
%Example program for the DataqSDK.NET control with a DI-1110 in MATLAB.
%Prerequisites: WinDaq software installed, DI-1110 hardware installed,
%DATAQ SDK installation must be newer than 12/8/17.
%Please submit any questions about this program online at: http://www.dataq.com/ticket/

%Make the .NET DATAQ SDK assembly visible to MATLAB
%The file path for the .dll's will vary depending on your OS and installation version.
%The dll's will only need to be added the first time you run the program

clc,clear
NET.addAssembly('C:\Windows\Microsoft.NET\assembly\GAC_MSIL\Dataq\v4.0_2.1.0.0__9767f47f9c295223\Dataq.dll
NET.addAssembly('C:\Windows\Microsoft.NET\assembly\GAC_MSIL\Dataq.Devices\v4.0_2.1.0.0__9767f47f9c295223\D
NET.addAssembly('C:\Windows\Microsoft.NET\assembly\GAC_MSIL\Dataq.Devices.Main\v4.0_2.1.0.0__9767f47f9c295
NET.addAssembly('C:\Windows\Microsoft.NET\assembly\GAC_MSIL\Dataq.Platforms\v4.0_2.1.0.0__9767f47f9c295223
NET.addAssembly('C:\Windows\Microsoft.NET\assembly\GAC_MSIL\Dataq.Protocols\v4.0_2.1.0.0__9767f47f9c295223
%
clc

%Fill in before running script
activity = 'running';                    %walking or running
trial = 'dynamic';                       %static or dynamic
K = 30;                                  %number of minutes. Static case is 10min, dynamic 30min.
subject = '01';                          %subject number

Fs = 1000;                       %Sampling Freq
Fn = Fs/2;                       %Nyquist frequency
Fc =100;                         %Cutoff Freq
Wb = Fc/Fn;
[b,a] = butter(4,Wb);

%Create figure to live monitor the temperature during the measurement
figure
axis([0 31 20 40])
grid on
hold on
title('Average temperature of the feet in degrees Celsius per minute')
xlabel('Time in min' )
ylabel('Temperature in ^{\circ}C')

for i = 1:K
%Locate your DI-1110 by the Serial Number
%CHANGE SERIAL NUMBER TO THE SERIAL NUMBER ON THE BOTTOM OF YOUR DEVICE
DIHardware = Dataq.Misc.Discovery.BySerialAsync('5AE8612D');
%
%Connect to your DI-1110
myDI1110 = DIHardware.Result;
try
    myDI1110.ConnectAsync.Result;
catch ME
    disp(ME.message);
end
%
%Display the properties and methods of the Dataq.Devices.DI1110.Device
%class
% properties(myDI1110)
% methods(myDI1110)

%Display device information
% disp('Manufacturer: ')
% disp(myDI1110.Manufacturer)
% disp('Model: ')
```

```
% disp(myDI1110.Model)
% disp('Serial: ')
% disp(myDI1110.Serial)
%
%Demonstrate how to set the LED color, LED will flash blue once acquisition starts
%Red -
myDI1110.Protocol.SetLedColorAsync(Dataq.Protocols.Enums.LedColor1.Red)
%Black - myDI1110.Protocol.SetLedColorAsync(Dataq.Protocols.Enums.LedColor1.Black)
%Blue - myDI1110.Protocol.SetLedColorAsync(Dataq.Protocols.Enums.LedColor1.Blue)
%Green - myDI1110.Protocol.SetLedColorAsync(Dataq.Protocols.Enums.LedColor1.Green)
%Cyan - myDI1110.Protocol.SetLedColorAsync(Dataq.Protocols.Enums.LedColor1.Cyan)
%Magenta - myDI1110.Protocol.SetLedColorAsync(Dataq.Protocols.Enums.LedColor1.Magenta)
%Yellow - myDI1110.Protocol.SetLedColorAsync(Dataq.Protocols.Enums.LedColor1.Yellow)
%White - myDI1110.Protocol.SetLedColorAsync(Dataq.Protocols.Enums.LedColor1.White)
%
%Initialize the device
myDI1110.Channels.Clear()

%Get supported channel types for the 1110.
SupportedChannelTypes = myDI1110.SupportedChannels.GetEnumerator();
SupportedChannelTypes.MoveNext();
AnalogVoltageIn = SupportedChannelTypes.Current.Key();
SupportedChannelTypes.MoveNext();
DigitalIn = SupportedChannelTypes.Current.Key();
SupportedChannelTypes.MoveNext();
DigitalOut = SupportedChannelTypes.Current.Key();
SupportedChannelTypes.MoveNext();
FrequencyIn = SupportedChannelTypes.Current.Key();
SupportedChannelTypes.MoveNext();
CounterIn = SupportedChannelTypes.Current.Key();

%Configure the Analog Channels
%Analog Channel 1
myDI1110.ChannelFactory(AnalogVoltageIn,1);
%Analog Channel 2
myDI1110.ChannelFactory(AnalogVoltageIn,2);
%Analog Channel 3
myDI1110.ChannelFactory(AnalogVoltageIn,3);
%Analog Channel 4
myDI1110.ChannelFactory(AnalogVoltageIn,4);
%Analog Channel 5
myDI1110.ChannelFactory(AnalogVoltageIn,5);
%Analog Channel 6
myDI1110.ChannelFactory(AnalogVoltageIn,6);
%Analog Channel 7
myDI1110.ChannelFactory(AnalogVoltageIn,7);
%Analog Channel 8
myDI1110.ChannelFactory(AnalogVoltageIn,8);

%
%Display the sample rate per channel
myDI1110.SetSampleRateOnChannels(1000);
FirstChannel = myDI1110.Channels.Item(0);
disp('Sample Rate per Channel: ')
disp(FirstChannel.GetSampleRate(myDI1110))
%

%
%Configure the device as defined
try
    myDI1110.InitializeAsync.Result;
catch ME
    disp(ME.message);
end

%Start scanning
try
    myDI1110.AcquisitionStartAsync.Result;
```

```
catch ME
    disp(ME.message);
end

%Define the data array
DI_TempDataArray = {};

%Set an amount of time you want to collect data until the loop exits
DIRuntime = 10; %Time in seconds to acquire data
timerID = tic;  %Start a clock and return the timer ID

%Read data and display in Command Window
while myDI1110.IsAcquiring() && (toc(timerID) < DIRuntime);
    try
        %Refresh the buffer DataIn with new data
        %ReadDataAsync moves data from a small, temp buffer between USB hadrware and Windows
        %into the SDK's DataIn buffer. ReadDataAsync should be called frequently to prevent a buffer
        %overflow at the hardware level. However, buffer DataIn can grow to the size of available RAM if n
        myDI1110.ReadDataAsync.Result;
    catch ME
        disp(ME.message);
        break
    end

%Initialize temporary array to hold new data
DI_TempDataArray = [];

%Convert .NET array data to a double array with a
%column for each enabled channel.
        for ColumnChan = 1:myDI1110.Channels.Count %this is the column (channel) counter
            ch = myDI1110.Channels.Item(ColumnChan-1);
            DI_NewData = ch.DataIn.ToArray;
            %DI_NewData = ch.DataIn(0).ToString;
            %temp1 = CType(ch, Dataq.Devices.IChannelIn).DataIn(index).ToString
            DI_NewData = reshape(DI_NewData.double,[],1);
            if ColumnChan == 1
                DI_TempDataArray = DI_NewData;
            else
                DI_TempDataArray(:,ColumnChan) = DI_NewData;
            end
            %Clear data from the buffer
%             ch.DataIn.Clear;
        end

        %Display the data in the command window
%         disp(DI_TempDataArray);
end

%Stop scanning
myDI1110.AcquisitionStopAsync.Result;

%It is important to disconnect from the device.  If you have connected
%successfully to the device, but do not disconnect you may need to unplug
%your hardware from the USB cable before you can connect again.
myDI1110.Dispose;
DIHardware.Dispose;

%Create a datestring with the date and time in hours, minutes and seconds
D = datestr(now, 'dd-mmm-yyyy_HH:MM:SS');

%Check if the number of DataPoints is correct. If not, save the data with a
%different name to make it easy to check afterwards
if size(DI_TempDataArray,1) == DIRuntime * 1000
    FileName=['S',subject,'_',trial,'_',activity,'_',num2str(i)];
    PathName = ['C:\Users\AnkeNB\Dropbox\UniversiteitTwente\Studie\MasterMechanicalEngineering\'...
        'Internship\Calgary\Matlab\Results'];
    matfile = fullfile(PathName,FileName);
    save(matfile, 'DI_TempDataArray', 'DI_NewData', 'ColumnChan', 'i', 'timerID', 'DIRuntime','D' )
```

```
else
    disp('Output not similar to frequency input');
    FileName=['S',subject,'_',trial,'_',activity,'_',num2str(i),'_diff'];
    PathName = ['C:\Users\AnkeNB\Dropbox\UniversiteitTwente\Studie\MasterMechanicalEngineering\'...
        'Internship\Calgary\Matlab\Results'];
    matfile = fullfile(PathName,FileName);
    save(matfile, 'DI_TempDataArray', 'DI_NewData', 'ColumnChan', 'i', 'timerID', 'DIRuntime','D' )
end

%Extract the middle 80% (DataPoints 1001 till 9000) of the raw voltage data for
%each separate sensor. This is for each 10 seconds of every minute.
%Sensor 1
V1_raw = DI_TempDataArray(1001:9000,1);
%Sensor 2
V2_raw = DI_TempDataArray(1001:9000,2);
%Sensor 3
V3_raw = DI_TempDataArray(1001:9000,3);
%Sensor 4
V4_raw = DI_TempDataArray(1001:9000,4);
%Sensor 5
V5_raw = DI_TempDataArray(1001:9000,5);
%Sensor 6
V6_raw = DI_TempDataArray(1001:9000,6);
%Sensor 7
V7_raw = DI_TempDataArray(1001:9000,7);
%Matrix V_raw
V_raw = [V1_raw V2_raw V3_raw V4_raw V5_raw V6_raw V7_raw];

%Extract the middle 80% (DataPoints 1001 till 9000) of the raw input voltage
E_in_raw = DI_TempDataArray(1001:9000,8);
%Filter the output voltage
V_filt = filtfilt(b,a,V_raw);
%Filter the input voltage
E_in_filt = filtfilt(b,a,E_in_raw);

%Take the average of the V_filt to determine the output voltage
%Sensor 1
V1 = mean(V_filt(:,1));
%Sensor 2
V2 = mean(V_filt(:,2));
%Sensor 3
V3 = mean(V_filt(:,3));
%Sensor 4
V4 = mean(V_filt(:,4));
%Sensor 5
V5 = mean(V_filt(:,5));
%Sensor 6
V6 = mean(V_filt(:,6));
%Sensor 7
V7 = mean(V_filt(:,7));
%Average of the input voltage
E_in(i,:) = mean(E_in_filt);

%Output voltage vector
V(i,:) = [V1 V2 V3 V4 V5 V6 V7];

%Coefficient vector M
M = [-174.7614 -175.9104 -176.4604 -177.0687 -176.0268 -187.6706 -177.3005];
%Coefficient vector c
c = [141.0390  141.9287  142.3669  142.8335  142.1993  149.5078  142.7649];

%Temperature vector out of linear relation with V and E_in
T(i,:) = M.*V(i,:)./E_in(i,:) + c;

%Plot the temperature versus the time for each sensor
for k = 1:7
        plot(T(:,k),'-o')
        legendInfo{k} = ['T' num2str(k)];
```

```
end
%Create legend
legend(legendInfo,'Location','southeast')

%Pause the code for 50 seconds
pause(50)

end
```

B.3 Function voltage to temperature

```
function [T,V, E_in] = volttotemp(K,subject,trial,activity)
%Function to extract the average value of the output and voltage from the
%measured data. To obtain an update every minute the average value of the
%1st 10 seconds of every minute is taken. The first and last 10% of the
%data is removed to delete errors from the measurement. This average output
%voltage will be converted into temperature with this function.

Fs = 1000;                                      %Sampling Freq
Fn = Fs/2;                                      %Nyquist frequency
Fc =100;                                        %Cutoff Freq
Wb = Fc/Fn;
[b,a] = butter(4,Wb);                           %Butterworth filter coefficients

V = [];                                         %Initialize matrix V
T = [];                                         %Initialize matrix T

for k = 1:K

%Load the files corresponding to the right subject with correct trial and
%activity
filename = ['S',subject,'_',trial,'_',activity,'_',num2str(k)];
PathName = ['C:\Users\AnkeNB\Dropbox\UniversiteitTwente\Studie\MasterMechanicalEngineering\'...
    'Internship\Calgary\Matlab\Results\S',subject,'\',activity];
matfile = fullfile(PathName,filename);
load(matfile)

%Extract the middle 80% (DataPoints 1001 till 9000) of the raw data for
%each separate sensor. This is for each 10 seconds of every minute.
%Sensor 1
V1_raw = DI_TempDataArray(1001:9000,1);
%Sensor 2
V2_raw = DI_TempDataArray(1001:9000,2);
%Sensor 3
V3_raw = DI_TempDataArray(1001:9000,3);
%Sensor 4
V4_raw = DI_TempDataArray(1001:9000,4);
%Sensor 5
V5_raw = DI_TempDataArray(1001:9000,5);
%Sensor 6
V6_raw = DI_TempDataArray(1001:9000,6);
%Sensor 7
V7_raw = DI_TempDataArray(1001:9000,7);

%Put all the output voltage data in one matrix
V_raw = [V1_raw V2_raw V3_raw V4_raw V5_raw V6_raw V7_raw];

%Extract DataPoints 1001 till 9000 from the raw input voltage
E_in_raw = DI_TempDataArray(1001:9000,8);

%Create filtered
V_filt = filtfilt(b,a,V_raw);
E_in_filt = filtfilt(b,a,E_in_raw);

%Calculate the average voltage output over the 8 seconds during the first
%10 seconds of each minute.
```

```
%Sensor 1
V1 = mean(V_filt(:,1));
%Sensor 2
V2 = mean(V_filt(:,2));
%Sensor 3
V3 = mean(V_filt(:,3));
%Sensor 4
V4 = mean(V_filt(:,4));
%Sensor 5
V5 = mean(V_filt(:,5));
%Sensor 6
V6 = mean(V_filt(:,6));
%Sensor 7
V7 = mean(V_filt(:,7));

%Calculate average voltage input and store it in the kth place of the
%input voltage vector
E_in(k,:) = mean(E_in_filt);

%Store each output voltage in the kth row of the output voltage vector
V(k,:) = [V1 V2 V3 V4 V5 V6 V7];

%Specify coefficient vectors  M and c for equation to convert voltage to
%temperature
M = [-174.7614 -175.9104 -176.4604 -177.0687 -176.0268 -187.6706 -177.3005];
c = [141.0390  141.9287  142.3669  142.8335  142.1993  149.5078  142.7649];

%Relation between output temperature, output voltage, input voltage and
%coefficients M and c. Temperature will be stored at the kth row of the
%temperature matrix T
T(k,:) = M.*V(k,:)./E_in(k,:) + c;

end
```

B.4 Compare two trials

```
clear; clc; close all;

%Fill in for running script to compare 2 trials of the same person
trial = 'static';                   %Static or dynamic
K = 10;                             %10 for static, 30 for dynamic

%Time vector
t = 1:K;

%Determine the temperature output for each subject for both static trials
%Subject 1
[TW1,VW1, E_inW1] = volttotemp(K,'01',trial,'walking');
[TR1,VR1, E_inR1] = volttotemp(K,'01',trial,'running');

%Subject 2
[TW2,VW2, E_inW2] = volttotemp(K,'02',trial,'walking');
[TR2,VR2, E_inR2] = volttotemp(K,'02',trial,'running');

%Subject 3
[TW3,VW3, E_inW3] = volttotemp(K,'03',trial,'walking');
[TR3,VR3, E_inR3] = volttotemp(K,'03',trial,'running');

%Subject 4
[TW4,VW4, E_inW4] = volttotemp(K,'04',trial,'walking');
[TR4,VR4, E_inR4] = volttotemp(K,'04',trial,'running');

%Subject 5
[TW5,VW5, E_inW5] = volttotemp(K,'05',trial,'walking');
[TR5,VR5, E_inR5] = volttotemp(K,'05',trial,'running');
```

```
%Create matrices TW for walking and TR for running that contain the data
%of all subjects
TW = [TW1(end,:); TW2(end,:); TW3(end,:); TW4(end,:); TW5(end,:)];
TR = [TR1(end,:); TR2(end,:); TR3(end,:); TR4(end,:); TR5(end,:)];

%Take the mean values of TW and TR
T_W = mean(TW);
T_R = mean(TR);

%Create a matrix T that contains the temperature of both walking and
%running
T = [T_W; T_R];

%Call matrix with default color order
C = get(gca,'colororder');

%Specify folder to save files
fpath = ['C:\Users\AnkeNB\Dropbox\UniversiteitTwente\Studie\MasterMechanicalEngineering\'...
    'Internship\Calgary\Report\images\Static'];

%Plot all trials for all subject in 1 graph for each sensor separately
for ii = 1:7
figure(ii)
axis([0 K 20 35])
grid on
hold on
xlabel('Time in min' )
ylabel('Temperature in ^{\circ}C')

%Subject 1 walking
h1 = plot(t-1,TW1(:,ii),'color',C(1,:));
%Subject 1 running
h2 = plot(t-1,TR1(:,ii),'color',C(1,:));
%Subject 2 walking
h3 = plot(t-1,TW2(:,ii),'color',C(2,:));
%Subject 2 running
h4 = plot(t-1,TR2(:,ii),'color',C(2,:));
%Subject 3 walking
h5 = plot(t-1,TW3(:,ii),'color',C(3,:));
%Subject 3 running
h6 = plot(t-1,TR3(:,ii),'color',C(3,:));
%Subject 4 walking
h7 = plot(t-1,TW4(:,ii),'color',C(4,:));
%Subject 4 running
h8 = plot(t-1,TR4(:,ii),'color',C(4,:));
%Subject 5 walking
h9 = plot(t-1,TW5(:,ii),'color',C(5,:));
%Subject 6 running
h10 = plot(t-1,TR5(:,ii),'color',C(5,:));

%Set the line width to 1.5
set([h1 h2 h3 h4 h5 h6 h7 h8 h9 h10],'LineWidth',1.5);

%Specify legend info and location
legendInfo = ['S01'; 'S02'; 'S03'; 'S04'; 'S05'];
legend([h1 h3 h5 h7 h9],legendInfo,'Location','southeast')

%Save the figure as png file in the specified folder fpath
figTfile = ['T_',trial,'_all','_sensor_',num2str(ii)];
saveas(gcf,fullfile(fpath,figTfile), 'png')

end
```

B.5 Temperature rise per sensor for walking

```
clear; clc; close all;
```

```
%Fill in before running script
activity = 'walking';                    %walking or running
trial = 'dynamic';                       %static or dynamic
K = 30;                                  %number of minutes. Static case is 10min, dynamic 30min.

%Specify time range
t = 1:K;

%Specify location of legend in graphs
Location = 'northwest';

%Use the function volttotemp to convert the measured output voltage into
%the corresponding temperature
%Subject 1
[Ts1,Vs1, E_ins1] = volttotemp(K,'01',trial,activity);
%Subject 2
[Ts2,Vs2, E_ins2] = volttotemp(K,'02',trial,activity);
%Subject 3
[Ts3,Vs3, E_ins3] = volttotemp(K,'03',trial,activity);
%Subject 4
[Ts4,Vs4, E_ins4] = volttotemp(K,'04',trial,activity);
%Subject 5
[Ts5,Vs5, E_ins5] = volttotemp(K,'05',trial,activity);

%Substract the first value of the temperature vector to obtain the rise in
%temperature
%Subject 1
Ts1 = Ts1 - Ts1(1,:);
%Subject 2
Ts2 = Ts2 - Ts2(1,:);
%Subject 3
Ts3 = Ts3 - Ts3(1,:);
%Subject 4
Ts4 = Ts4 - Ts4(1,:);
%Subject 5
Ts5 = Ts5 - Ts5(1,:);

T_all = [Ts1 Ts2 Ts3 Ts4 Ts5] ;

%Get mean temperature
T = Ts1 + Ts2 + Ts3 + Ts4 + Ts5;
T = T/5;

%Put all data in 1 matrix
T_all = [Ts1 Ts2 Ts3 Ts4 Ts5] ;

%Get mean output voltage
V = Vs1 + Vs2 + Vs3 + Vs4 + Vs5 ;
V = V/5;

%Get mean input voltage
E_in = E_ins1 + E_ins2 + E_ins3 + E_ins4 + E_ins5;
E_in = E_in/5;

%Specify the folder in which file will be saved
fpath = ['C:\Users\AnkeNB\Dropbox\UniversiteitTwente\Studie\MasterMechanicalEngineering\'...
    'Internship\Calgary\Report\images\Walking'];

%Plot the temperature relative to the time in minutes for each sensor and
%the average of all subjects
for ii = 1:7

    figure
    axis([0 K+1 -5 15])
    grid on
    hold on
    xlabel('Time in min' )
```

```
    ylabel('Temperature in ^{\circ}C')

    %Plot the temperatures
    %Subject 1
    h1 = plot(t-1,Ts1(:,ii));
    %Subject 2
    h2 = plot(t-1,Ts2(:,ii));
    %Subject 3
    h3 = plot(t-1,Ts3(:,ii));
    %Subject 4
    h4 = plot(t-1,Ts4(:,ii));
    %Subject 5
    h5 = plot(t-1,Ts5(:,ii));
    %Average
    h6 = plot(t-1,T(:,ii),'--');

    %Set the linewidth to 1.5 instead of deafault 1
    set([h1 h2 h3 h4 h5 h6],'LineWidth',1.5);

    %Specify legend and location
    legendInfo = ['S01'; 'S02'; 'S03'; 'S04'; 'S05';'avg'];
    legend(legendInfo,'Location',Location)

    %Save the figure as png file in the specified folder fpath
    figTfile = ['T_rise',activity,'_',trial,'_sensor_',num2str(ii)];
    saveas(gcf,fullfile(fpath,figTfile), 'png')

end

%Create tables of the temperate data
Ttab = array2table(T_all,  ...
     'VariableNames', ...
     {'T_1_heel_1','T_2_ball_1','T_3_arch_1','T_4_big_toe_1',...
     'T_5_instep_1','T_6_medial_malleolus_1','T_7_lateral_malleolus_1', ...
     'T_1_heel_2','T_2_ball_2','T_3_arch_2','T_4_big_toe_2',...
     'T_5_instep_2','T_6_medial_malleolus_2','T_7_lateral_malleolus_2',...
     'T_1_heel_3','T_2_ball_3','T_3_arch_3','T_4_big_toe_3',...
     'T_5_instep_3','T_6_medial_malleolus_3','T_7_lateral_malleolus_3',...
     'T_1_heel_4','T_2_ball_4','T_3_arch_4','T_4_big_toe_4',...
     'T_5_instep_4','T_6_medial_malleolus_4','T_7_lateral_malleolus_4',...
     'T_1_heel_5','T_2_ball_5','T_3_arch_5','T_4_big_toe_5',...
     'T_5_instep_5','T_6_medial_malleolus_5','T_7_lateral_malleolus_5'}  );

%Specify the folder in which the table will be saved
fpath2 = ['C:\Users\AnkeNB\Dropbox\UniversiteitTwente\Studie\MasterMechanicalEngineering\'...
    'Internship\Calgary\Matlab\Results\Excel'];

%Create and save the table in the specified folder
fileT = ['T_rise_',activity,'.xls'];
TTabname = fullfile(fpath2,fileT);
writetable(Ttab,TTabname,'WriteRowNames',true);
```

B.6 Temperature rise per sensor for running

```
clear; clc; close all;
%This script plots the results of the tempeature measurement of 5 subjects.
%For all 7 sensors there is an independent plot, in where the measurement
%and mean value of all subjects is plotted. All plots are directly saved in
%the correct folder.

%Fill in before running script
K = 30;                                 %number of minutes. Static case is 10min, dynamic 30min.
activity = 'running';                   %walking or running
trial = 'dynamic';                      %static or dynamic

%Specify time range
```

```
t = 1:K;

%Specify location of legend in graphs
Location = 'northwest';

%Use the function volttotemp to convert the measured output voltage into
%the corresponding temperature
%Subject 1
[Ts1,Vs1, E_ins1] = volttotemp(K,'01',trial,activity);
%Subject 2
[Ts2,Vs2, E_ins2] = volttotemp(K,'02',trial,activity);
%Subject 3
[Ts3,Vs3, E_ins3] = volttotemp(K,'03',trial,activity);
%Subject 4
[Ts4,Vs4, E_ins4] = volttotemp(K,'04',trial,activity);
%Subject 5
[Ts5,Vs5, E_ins5] = volttotemp(K,'05',trial,activity);

%Substract the first value of the temperature vector to obtain the rise in
%temperature
%Subject 1
Ts1 = Ts1 - Ts1(1,:);
%Subject 2
Ts2 = Ts2 - Ts2(1,:);
%Subject 3
Ts3 = Ts3 - Ts3(1,:);
%Subject 4
Ts4 = Ts4 - Ts4(1,:);
%Subject 5
Ts5 = Ts5 - Ts5(1,:);

%Sensor stopped working correctly between minute 19 and 22 for subject 4.
%Set datapoints to NaN to avoid plotting them. Fill them up with a linear
%fit.
Ts4(19:22,1) = NaN;
Ts4 = fillmissing(Ts4,'linear');

%Get mean temperature
T = Ts1 + Ts2 + Ts3 + Ts4 + Ts5;
T = T/5;

%Put all data in 1 matrix
T_all = [Ts1 Ts2 Ts3 Ts4 Ts5] ;

%Get mean output voltage
V = Vs1 + Vs2 + Vs3 + Vs4 + Vs5 ;
V = V/5;

%Get mean input voltage
E_in = E_ins1 + E_ins2 + E_ins3 + E_ins4 + E_ins5;
E_in = E_in/5;

%Specify the folder in which file will be saved
fpath = ['C:\Users\AnkeNB\Dropbox\UniversiteitTwente\Studie\MasterMechanicalEngineering\'...
    'Internship\Calgary\Report\images\Running'];

%Plot the temperature relative to the time in minutes for sensor 1 to 4.
%Sensor 5 and 6 are interchanged for subject 1, so they are plotted
%separately. Same is done for sensor 7.
for ii = 1:4

    figure
    axis([0 K+1 -5 15])
    grid on
    hold on
    xlabel('Time in min' )
    ylabel('Temperature in ^{\circ}C')
```

```
    %Plot the temperatures
    %Subject 1
    h1 = plot(t-1,Ts1(:,ii));
    %Subject 2
    h2 = plot(t-1,Ts2(:,ii));
    %Subject 3
    h3 = plot(t-1,Ts3(:,ii));
    %Subject 4
    h4 = plot(t-1,Ts4(:,ii));
    %Subject 5
    h5 = plot(t-1,Ts5(:,ii));
    %Average
    h6 = plot(t-1,T(:,ii),'--');

    %Set the linewidth to 1.5 instead of deafault 1
    set([h1 h2 h3 h4 h5 h6],'LineWidth',1.5);

    %Specify legend and location
    legendInfo = ['S01'; 'S02'; 'S03'; 'S04'; 'S05';'avg'];
    legend(legendInfo,'Location',Location)

    %Save the figure as png file in the specified folder fpath
    figTfile = ['T_rise_',activity,'_',trial,'_sensor_',num2str(ii)];
    saveas(gcf,fullfile(fpath,figTfile), 'png');

end

%Plot temperatures sensor 5
figure(5)
axis([0 K+1 -5 15])
grid on
hold on
xlabel('Time in min' )
ylabel('Temperature in ^{\circ}C')
%Subject 1
h1 = plot(t-1,Ts1(:,5));
%Subject 2
h2 = plot(t-1,Ts2(:,6));
%Subject 3
h3 = plot(t-1,Ts3(:,5));
%Subject 4
h4 = plot(t-1,Ts4(:,5));
%Subject 5
h5 = plot(t-1,Ts5(:,5));
%Average
h6 = plot(t-1,T(:,5),'--');

%Set the line width to 1.5
set([h1 h2 h3 h4 h5 h6],'LineWidth',1.5);

%Specify legend info and location
legendInfo = ['S01'; 'S02'; 'S03'; 'S04'; 'S05';'avg'];
legend(legendInfo,'Location',Location)

%Save the figure as png file in the specified folder fpath
figTfile = ['T_rise_',activity,'_',trial,'_sensor_5'];
saveas(gcf,fullfile(fpath,figTfile), 'png');

%Plot temperatures sensor 6
figure(6)
axis([0 K+1 -5 15])
grid on
hold on
xlabel('Time in min' )
ylabel('Temperature in ^{\circ}C')
%Subject 1
h1 = plot(t-1,Ts1(:,6));
%Subject 2
```

```
h2 = plot(t-1,Ts2(:,5));
%Subject 3
h3 = plot(t-1,Ts3(:,6));
%Subject 4
h4 = plot(t-1,Ts4(:,6));
%Subject 5
h5 = plot(t-1,Ts5(:,6));
%Average
h6 = plot(t-1,T(:,6),'--');

%Set the line width to 1.5
set([h1 h2 h3 h4 h5 h6],'LineWidth',1.5);

%Specify legend info and location
legendInfo = ['S01'; 'S02'; 'S03'; 'S04'; 'S05';'avg'];
legend(legendInfo,'Location',Location)

%Save the figure as png file in the specified folder fpath
figTfile = ['T_rise_',activity,'_',trial,'_sensor_6'];
saveas(gcf,fullfile(fpath,figTfile), 'png');

%Plot temperature sensor 7
figure(7)
axis([0 K+1 -5 15])
grid on
hold on
xlabel('Time in min' )
ylabel('Temperature in ^{\circ}C')
%Subject 1
h1 = plot(t-1,Ts1(:,7));
%Subject 2
h2 = plot(t-1,Ts2(:,7));
%Subject 3
h3 = plot(t-1,Ts3(:,7));
%Subject 4
h4 = plot(t-1,Ts4(:,7));
%Subject 5
h5 = plot(t-1,Ts5(:,7));
%Average
h6 = plot(t-1,T(:,7),'--');

%Set the line width to 1.5
set([h1 h2 h3 h4 h5 h6],'LineWidth',1.5);

%Specify lenged info and location
legendInfo = ['S01'; 'S02';'S03'; 'S04'; 'S05'; 'avg'];
legend(legendInfo,'Location',Location)

%Save the figure as png file in the specified folder fpath
figTfile = ['T_rise_',activity,'_',trial,'_sensor_7'];
saveas(gcf,fullfile(fpath,figTfile), 'png');

%Create tables of the temperate data data
Ttab = array2table(T_all,  ...
     'VariableNames', ...
     {'T_1_heel_1','T_2_ball_1','T_3_arch_1','T_4_big_toe_1',...
     'T_5_instep_1','T_6_medial_malleolus_1','T_7_lateral_malleolus_1', ...
     'T_1_heel_2','T_2_ball_2','T_3_arch_2','T_4_big_toe_2',...
     'T_5_instep_2','T_6_medial_malleolus_2','T_7_lateral_malleolus_2',...
     'T_1_heel_3','T_2_ball_3','T_3_arch_3','T_4_big_toe_3',...
     'T_5_instep_3','T_6_medial_malleolus_3','T_7_lateral_malleolus_3',...
     'T_1_heel_4','T_2_ball_4','T_3_arch_4','T_4_big_toe_4',...
     'T_5_instep_4','T_6_medial_malleolus_4','T_7_lateral_malleolus_4',...
     'T_1_heel_5','T_2_ball_5','T_3_arch_5','T_4_big_toe_5',...
     'T_5_instep_5','T_6_medial_malleolus_5','T_7_lateral_malleolus_5'}  );

%Specify the folder in which the table will be saved
fpath2 = ['C:\Users\AnkeNB\Dropbox\UniversiteitTwente\Studie\MasterMechanicalEngineering\'...
```

```
    'Internship\Calgary\Matlab\Results\Excel'];

%Create and save the table in the specified folder
fileT = ['T_rise_',activity,'.xls'];
TTabname = fullfile(fpath2,fileT);
writetable(Ttab,TTabname,'WriteRowNames',true);
```

B.7 Temperature per subject

```
clear; clc; close all;

%Fill in before running script
activity = 'running';               %walking or running
trial = 'dynamic';                  %static or dynamic
K = 30;                             %number of minutes. Static case is 10min, dynamic 30min.
subject = '04';                     %subject number

%Time vector
t = 1:K;

%Calculate the temperature T, output voltage V and input voltage E_in using
%the functin volttotemp
[T,V, E_in] = volttotemp(K,subject,trial,activity);

%%% Uncomment lines 17 and 18 for subject 4 in case of running
T(19:22,1) = NaN;            %Set these data points to NaN to avoid plotting them
T = fillmissing(T,'linear');

%Plot the temperature relative to the time in minutes for all sensors in
%one graph
figure
axis([0 K+1 20 45])
grid on
hold on
xlabel('Time in min' )
ylabel('Temperature in ^{\circ}C')

%k=1:7 for walking and subject 2 till 5 for running. In case of running for
%subject 1 this has to be changed to k=1:4
for k = 1:7
        plot(t-1,T(:,k),'-o');
        legendInfo{k} = ['T' num2str(k)];
end

%%%uncomment this for running subject 1
% plot(t-1,T(:,6),'-o');
% plot(t-1,T(:,5),'-o');
% plot(t-1,T(:,7),'-o');
% legendInfo = ['T1'; 'T2'; 'T3'; 'T4'; 'T5'; 'T6'; 'T7'];

%Specify legend info and location
legend(legendInfo,'Location','bestoutside')

%Specify the folder in which files will be saved
fpath = ['C:\Users\AnkeNB\Dropbox\UniversiteitTwente\Studie\MasterMechanicalEngineering\'...
    'Internship\Calgary\Report\images\S',subject];

%Save the figure as png file in the specified folder fpath
figTfile = ['S',subject,'_T_',activity,'_',trial];
saveas(gcf,fullfile(fpath,figTfile), 'png')

%Plot the input voltage relative to time every minute
figure
axis([0 K+1 4.5 5])
grid on
hold on
```

```
xlabel('Time in min' )
ylabel('Voltage in Volt')
plot(t-1,E_in,'-o')

%Save the figure in the folder defined by fpath
fpath = 'C:\Users\AnkeNB\Dropbox\UniversiteitTwente\Studie\MasterMechanicalEngineering\Internship\Calgary\
figEfile = ['S',subject,'_Ein_',activity,'_',trial];
saveas(gcf,fullfile(fpath,figEfile), 'png')
```

C. Description of University of Calgary

This internship was carried out at the University of Calgary (UofC). The U of C is located in the province of Alberta in Canada. They are founded in 1966 and they had an exponential growth the last years [20]. Nowadays the UofC has around 30,000 students, from which 25,000 are undergraduates, 6,000 are graduates and 500 of the are PhD students.

This internship was carried out at the faculty of Kinesiology. This faculty is located at the main campus, which is located in Calgary's northwest quadrant. The kinesiology complex is located on the northwest side of the main campus and is connected the Olympic oval.

In the Human Performance Lab (HPL) different research groups are working. One of them is the group of biomechanics, the research group I was working for. The biomechanics group is under supervision of Prof. Dr. Darren Stefanyshyn. They conduct a lot of research for different companies like Adidas, Fila, Ariat and MMA. Most research is focused on footwear.

D. Reflection

This internship was for me a great opportunity to explore myself. Working independently on a project, but on the other hand also working in a team gave me lots of possibilities. Before I arrived in the Human Performance Lab I wanted to achieve a couple of goals. I made progress in all things, however improvements can still be made.

I am still searching for the research field I am interested in. So one of my objectives was getting more insight in the kind of work and topics I would like to continue working in. Executing my project and talking with different people did help me a lot. My project consisted of experimental work and I was also involved in other experiments for other projects. I liked it to think about the possible outcomes and test whether the hypothesis is true. Furthermore I had a lot of possibilities to learn about other projects during my internship. It was very helpful to see what kind of research was going on to decide which topics have my interest. Sports relating projects are something to think of in the future.

Being more confident in talking to other people was one of my main points of improvement. In the last 14 weeks I made steps forward, but I experienced also moments something was holding me back. In contrast to the other research groups working in the lab, my group did not have any scheduled individual meetings. When I needed some information all initiative for contact with my supervisor was depending on me. In the beginning I had some problems dealing with it. I could postpone going to my supervisor for several days, which was slowing down my project. But this also forced me to improve. A wait-and-see attitude did not help me further. In terms of developing myself this experience made me more resolute. In the last week of my internship I did not hesitate showing my results or asking questions immediately anymore. All people seem very helpful to help you.

Another point of improvement is being more confident in myself. A lot of times I feel insecure about my work even if I know the work I did is correct. This is also holding me back from showing my results or work to someone else and asking for feedback. It is important for me to find a way to deal with it. This internship contributes to this process since I got positive comments and I was working in an environment where many people asking each other for help or feedback. One of my subgoals was getting more confident in English. Speaking English every day and also making phone calls in English improved my English a lot.

In the second half of my internship we had several group meetings, because new projects were kicked off. During this group meetings I was was not familiar with the measuring equipment used and the specific topics it was hard to deliver a valuable contribution. In the future it might be helpful to say more during meetings.

I ended my work with a final presentation about my project. Since I am not good in presenting and I always feel insecure while speaking in front of a group, it was good to practise my presentation skill. Beforehand I was worried about presenting in English, but that did not give me any problems. In the Human Performance Lab someone is presenting his/her work in seminar on Thursday every week. From that I got a lot of input what is a good and not good to do in a presentation. All steps in preparing will be very helpful in my further education and work. In general, the structure of my presentation was well-organised and repetition of important points were sufficient. I also learned the way you present your results is critical in understanding. Every choice defines which information you highlight and which information will be lost. After my presentation I got very useful tips from my supervisor. But of most importance is knowing exactly where you are talking about and how every single component in your story works.

Overall I learned a lot during my time at the University of Calgary. I am glad I had the chance to work in this lab with great people. I had the chance to execute a project individually, getting input of good researchers, improving my Matlab skill, analysing results, improving my communication skills and practise my presentation skill. It was very good to go away from my familiar environment and to come out my comfort zone.