DIABETIC FOOT DETECTOR

By

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FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

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Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
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December 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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Mohd Hanafi bin Mustaffa

ABSTRACT

Diabetic foot detector is a device use to detect human foot pressure especially for diabetic patient. The abnormality of the foot pressure is an early indication of the diabetic foot. Diabetic patient with this symptom cannot control the pressure applied to the feet resulting tissue injury to the foot even for a short distance walking. The most common cases occur in the peak plantar surfaces since the transfer of high peak pressure from heel area to the forefoot area. The data acquisition device embedded to the shoe sole to collect real time foot pressure. This data acquisition system is constructed using force sensor and negative feedback circuit. The pressure of the foot is detected using the force sensor which uses resistance to represent the foot pressure as the detection system. The voltage from the negative feedback output is then sent to the microprocessor using radio frequency transmission to convert it to the real value before the data is transferred to the user interface.

ACKNOWLEDGEMENTS

First of all, there were many people, individuals and parties that involved while working for my final year project which has contributed immeasurable and invaluable amount of help, guidance, assistance, advice, supports, and also supervision.

Special thanks to Miss Salina Mohmad, my final year project supervisor for her support and guidance. I also like to say thank you again to her for given me many supportive, constructive advices, and sharing her technical knowledge. Without her guidance, the project cannot be completed.

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CHAPTER 1

INTRODUCTION

1.1 Background of study

The foot pathology (diabetic foot) is the common diabetic complication that requires the patient to be hospitalized. The total cost of the diabetic foot in the United State alone is estimated to approach $4 billion annually mostly on ulcer care and amputations [2,3]. It is presume that the increase in the body weight and the diabetes lead to increment of the pressure to the foot peak plantar [2,3]. The high foot peak plantar and incapable to control the applied to the foot pressure due to the neuropathy (peripheral sensory neuropathy & autonomic and motor neuropathy) causes the development of the foot ulceration [2,3]. The wound cannot be healed in the normal way and the diabetic ulcer will stay in the inflammatory stage of wound repair [2,3]. The abnormal foot pressure can be one of the factors leading to the diabetic foot [2,3]. This project aims to collect the data of the foot pressure of the diabetic patient to monitor any abnormality that can cause diabetic foot to occur [2,3].

1.2 Problem statement

Diabetes mellitus is a disease due to the high blood sugar (glucose) levels. This high blood sugar (glucose) levels are because of defect in insulin secretion or insulin action or both. Insulin is a hormone that occur is produced in the pancreas, used to control the blood glucose level in the blood [2,3]. For normal person, pancreas will release the insulin to the blood when the blood glucose level is high in order to compensate it. Diabetic can be controlled but it lasts a lifetime [2,3]. One of the major complications of the diabetes is the diabetic foot ulceration (foot pathology) [2,3]. This occurs when the feet become pain insensitivity and the development of the trauma to the feet (high pressure to the feet during walking). Since the patient with diabetes has impaired wound healing, this complication will lead to the development of chronic ulceration and amputation of the lower extremity [2,3]. One method to detect loss of sensation is using the 5.07/10g Semmes-Weinstein monofilament but it requires the patient to be hospitalized and costly since the treatment can only be done by the neurologist. The most frequent sites of loss of sensation are:

i. Heel
ii. Second metatarsal
iii. Dorsum of the little toe
iv. The head of the first and third metatarsal

Figure 1: The usage of 5.07/10g Semmes-Weinstein monofilament [12]

1.3 Objective

The objectives for this project are:

1. To construct the data acquisition for the foot pressure in the real time by interface the pressure sensor with the microcontroller.
2. To create the communication between data acquisition module and the user interface using the radio transmission.
3. To develop the interface to monitor the foot pressure for the monitoring purpose.
4. To develop interface between the microcontroller and the user using liquid crystal display.

1.4 Scope of study

This project focuses on the data acquisition of the foot pressure in the real time. The data is collected by the pressure sensor. The process for data acquisition is done using pressure sensor and the data is process using microprocessor into the digital data. Then, the data is transmitted to the receiver using the radio frequency. These sensors are located at high pressure areas over heel, metatarsal heads and hallux of each foot. The propose placement of the sensors are at heel and the all five metatarsal heads. The sensor will be connected to the radio frequency module to make wireless connection between microprocessor. The microprocessor at data acquisition module will be programmed to interpret the data into the digital form and display on user interface. The data collected can be analyzed to determine test subject is having peripheral neuropathy. This will help to analyzed the diabetic patient quickly and more accurate.

CHAPTER 2

LITERATURE REVIEW

2.1 Diabetic foot

The sensory neuropathy associated with pain insensitivity is the first indication of the diabetic foot. The existence of trauma is plantar tissue stress and injury that result from the development of high foot pressure during walking cause the development of ulceration. The impaired wound healing and reduced blood flow in the ulcer area prevent wound healing lead to chronic ulceration and sometimes amputation [2,3]. Figure 2 shows the most frequent sites of loss of sensation are.

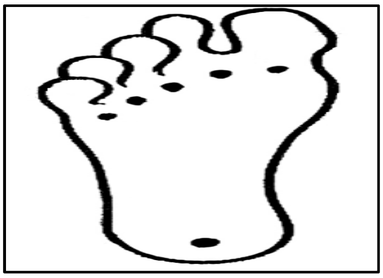

Figure 2: Frequent sites of loss of sensation [13]

Figure 3 show the formation of ulcers on first and second metatarsal head on diabetic foot patients.

Figure 3: Ulcers formation on diabetic foot patients [14]

The preventions actions for those who are prone to have diabetic foot are [15]:

i. Good diabetes control by controlling the insulin levelin blood.
ii. Regular leg and foot self-examinations to detect any trauma on foot.
iii. Obtain knowledge on how to recognize problems related to the diabetic foot

iv. Choose proper footwear with a high and wide toe box to prevent chafing and pinching that can harm the toes. The shoe should protect the feet from blisters, bleedings and lesions.

v. Regular exercise.

vi. Avoid injury by keeping footpaths clear.

These prevention actions only reduce the chance for the diabetic patients to have diabetic foot. Monitoring patient foot pressure is a better solution where the medical practitioner able to monitor any abnormality of foot pressure.

2.2 Force Sensor

The force sensor acts as a force sensing (foot pressure) resistor in an electrical circuit. The resistance will determine the force applied to the sensor. When there is no force applied on the sensor, the resistance is very high (close to open circuit) and the resistance value is decreased when the force is applied [4]. In this project the pressure sensor is customized using the conductive sponge and conductive material. The layout of the sensor is shown in Figure 4.

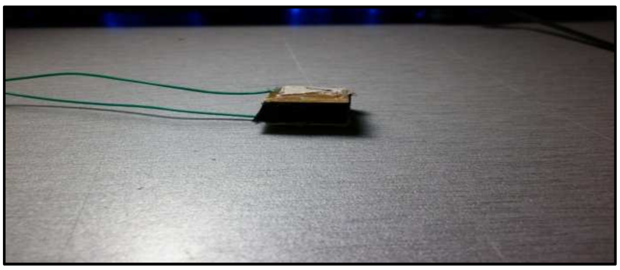

Figure 4: Force Sensor

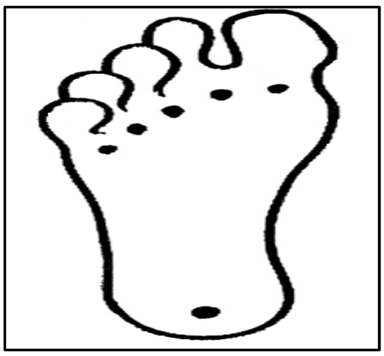

Figure 5: Sites for sensors placement [13]

The increment of force causes the output voltage to increase since the resistance of the sensor decrease as shown in the Figure 25. This conversion is done using negative feedback operation amplifier. This output voltage is the will be fed to the microprocessor to convert into the real foot pressure value. Figure 5 show the placement of the sensor with regard to the high pressure are on foot.

2.3 Microcontroller

The recommended microprocessor in this project is PIC18F Microcontroller Series. The PIC18F-series microcontroller is developed by the Microchip Inc and use real-time operating system (RTOS). In this project, the microcontroller that will be used is PIC18F452. The program memory for this microcontroller is 32 Kbytes and the data memory is 32 Kbytes. There are 5 ports for this microcontroller and the 8 analog to digital converter channels. The analogue digital conversion modules consist of AN0 to AN7 and convert the analogue input to the 10 bits digital data. The microcontroller receives analog value from the sensor circuit and converts it into digital value for data interpretation.

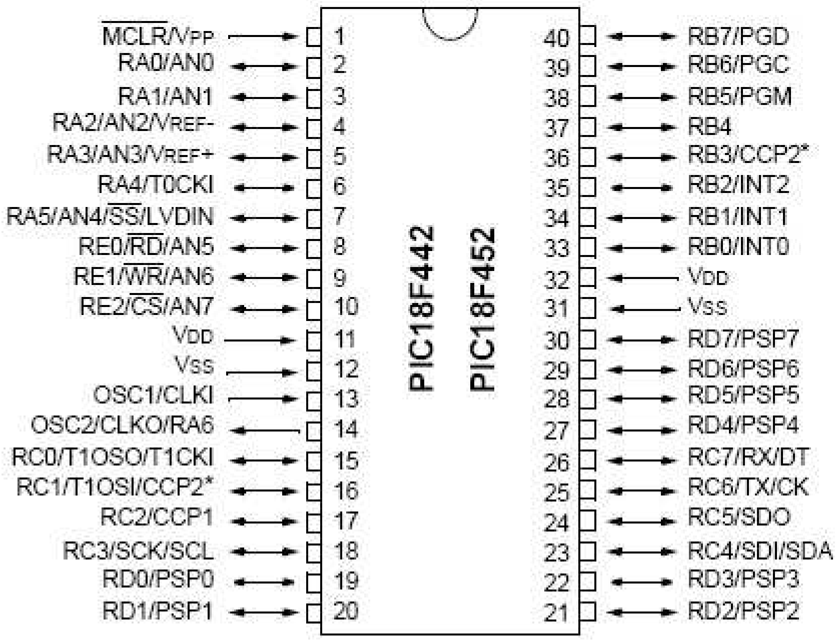

Figure 6: PIC18F452 microcontroller DIP pin configuration

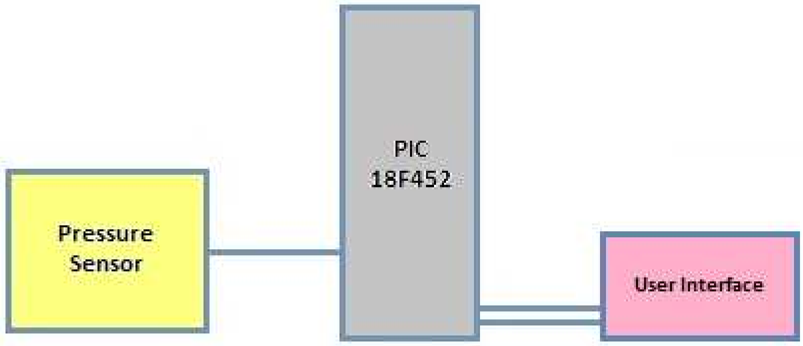

Figure 7: Connection between the Microcontroller and the user interface

Figure 7 show the connection between microcontroller and the user interface using liquid crystal display. Pressure sensor consists of pressure sensor and sensor circuit (negative feedback amplifier circuit) will send analog data in voltage ranging from 0 V to 5 V. The analogue digital converter of the microcontroller will convert the analog data to digital data into 10 bits digital data. These data will be converted into mass applied to the foot using the equations obtain from the graph resistance vs. mass and resistance vs. output voltage. The result of the conversion will be sent to the liquid crystal display (LCD) using The American Standard Code for Information Interchange (ASCII) format.

2.4 Radio Frequency (RF) Transmission

The wireless transmission in this project is done using radio frequency (RF) transmission. The transmitter that will be used is FSK Radio Transmitter with Crystal Oscillator (FM-RTFQ1-433) and the receiver that will be used is FSK Superhet Receiver with Crystal Oscillator (RRFQ1-433) [10]. The working frequency for this module is the 433.92 MHz [10]. FM Radio Transmitter & Receivers specifications are:

1. Transmission range up to 250 m[10].
2. The data link for this module is upto 40 Kbit/s at distances 75 metres in-building and 300 metres open ground[10].

The sizes of both modules are small to make sure it is mobile and do not constraint the user. The power dissipation for the transmitter is very low about 6.8mA for while operate and 100nA while standby [10]. This is important since the transmitter module is mobile. The range of the transmission can be increase by using multi node wireless link.

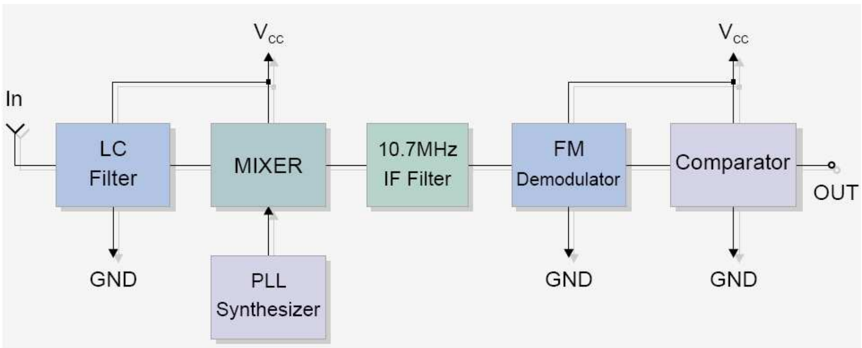

Figure 8: RTF Block Diagram

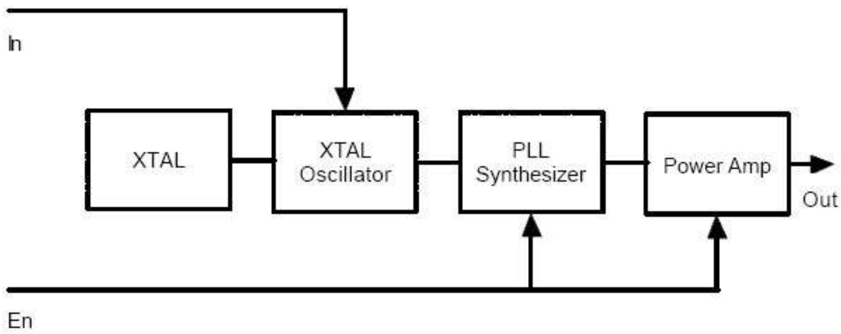

Figure 9: RRF Block Diagram

2.5 Liquid Crystal Display (LCD)

The display chose in this project is the HD44780U dot-matrix liquid crystal display controller and driver LSI displays alphanumeric. A single HD44780U can display up to one 8-character line or two 8-character lines. This display use low power supply (2.7V to 5.5V)

Figure 10: 16x2 Liquid Crystal Display (LCD)

Table 1: 16x2 Liquid Crystal Display Pin Descriptions

Pin No.	Name	Description
1	Vss	Ground
2	Vdd	Positive Supply
3	Vee	Contrast
4	RS	Register Select
5	R/W	Read/Write
6	E	Enable
7	D0	Data bit 0
8	D1	Data bit 1
9	D2	Data bit 2
10	D3	Data bit 3
11	D4	Data bit 4
12	D5	Data bit 5
13	D6	Data bit 6
14	D7	Data bit 7

The function if each connection is shown in table 1. Pin 7 to 14 are the eight data bus lines (D0 to D7). Data can be transferred to and from the display, either as a single 8-bit byte or as two 4-bit “nibble”. In this project only the upper four data line (D4 to D7) is used.

2.6 Diabetic foot detector

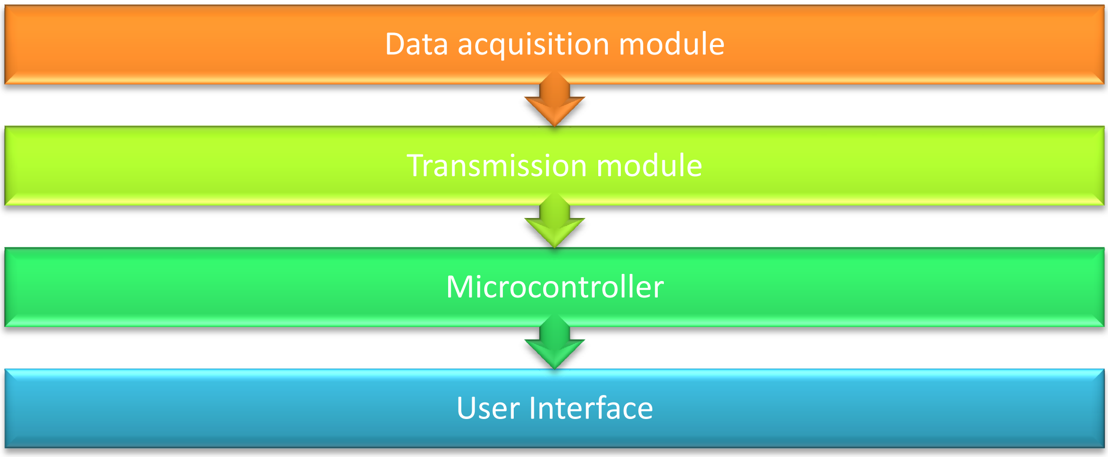

Figure 11: Diabetic foot detector

The data acquisition module consists of three main components. The first component is the force sensor. The function of the force sensor is to measure the force applied to the foot. The output of the sensor will be connected to the transmitter for transmission purpose. The receiver will accept the data and send the data to the microcontroller. The microcontroller will convert the data into the real value and send to the user interface.

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

To achieve the objective of the project, research and study need to be based on journal, technical paper and sources from internet. Information on sensor and microcontroller need to be taken so the best combination with less cost and high performance can be achieved.

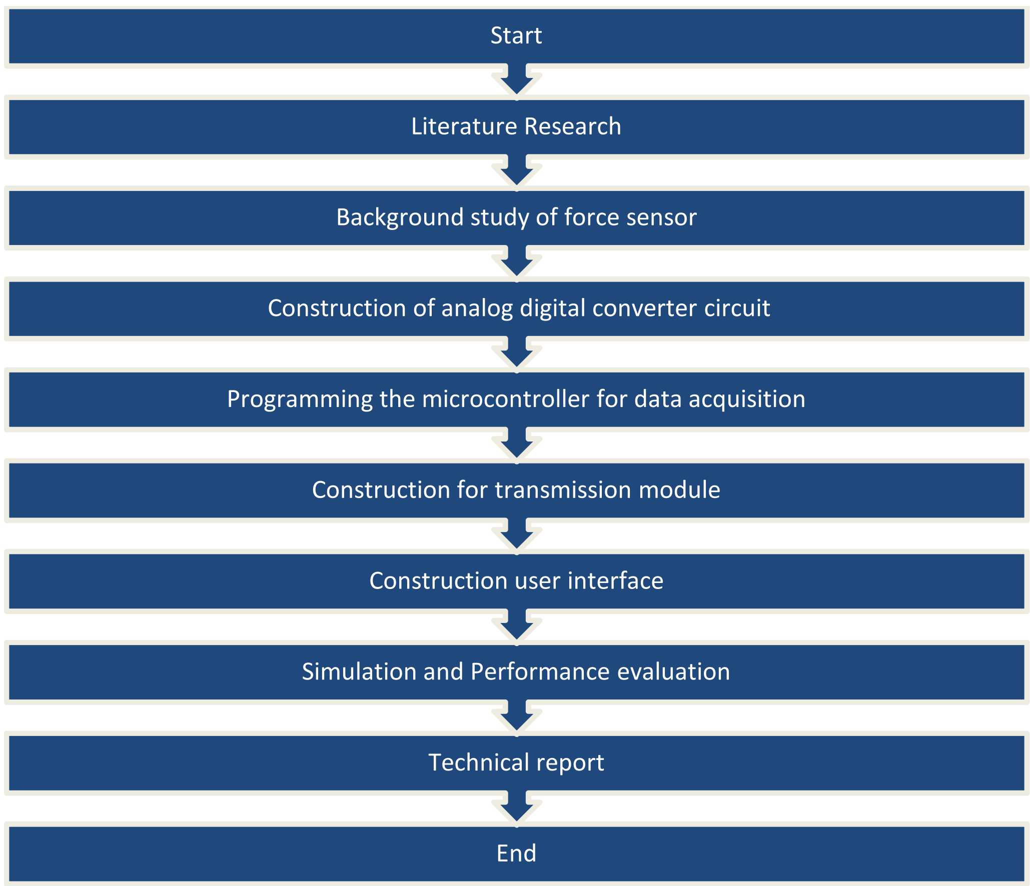

Figure 12: Process Flow

3.2 Pressure Sensor Testing

The characteristic of the pressure is tested to identify the range of the resistivity when the mass is applied on the sensor for different value. Figure 13 show the assembly for sensor testing.

The sensor is pressure using the mass on top on the ground level to make sure that no external factor will disrupt the result of the experiment. The resistance value is measured using the digital multimeter. Figure 14 show the initial value of the multimeter and the maximum mass that can be applied before the multimeter is short circuited.

Figure 13: Mass is applied to the pressure sensor and the sensor testing

Figure 14: The resistance reading before the mass is applied and maximum mass

3.3 Sensor circuit simulation

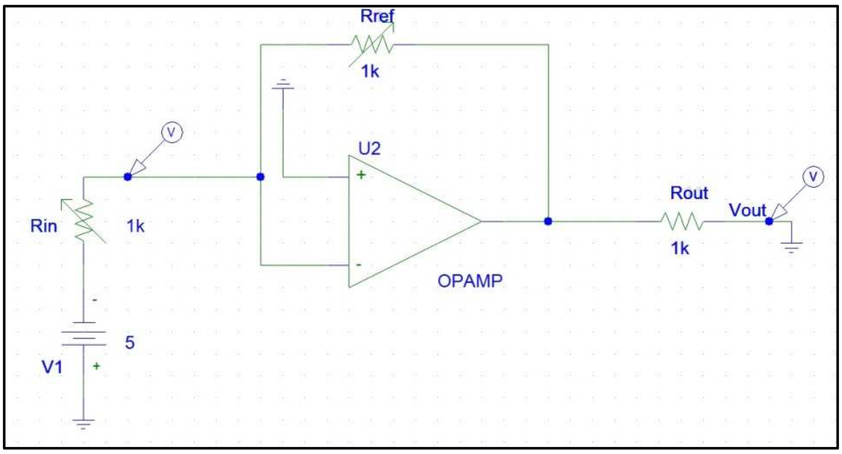

Figure 15: Simulation sensor circuit

The result in the sensor test is simulated using the Pspice to verify the linearity of the output voltage. The circuit in Figure 15 is driven by a -5 VDC excitation voltage and uses an inverting operational amplifier arrangement to produce an analog output based on the sensor resistance and a fixed reference resistance (R_{ref}) [4]. The sensitivity of the sensor is adjusted by changing the reference resistance (RF) and/or drive voltage (VT) [4]. The low value of the reference resistance will make the sensor less sensitive and increase the active force range [4]. The output of the circuit (neglect the output resistor) will be connected to the microcontroller. Part of the simulation result for this circuit is shown in Figure 16.

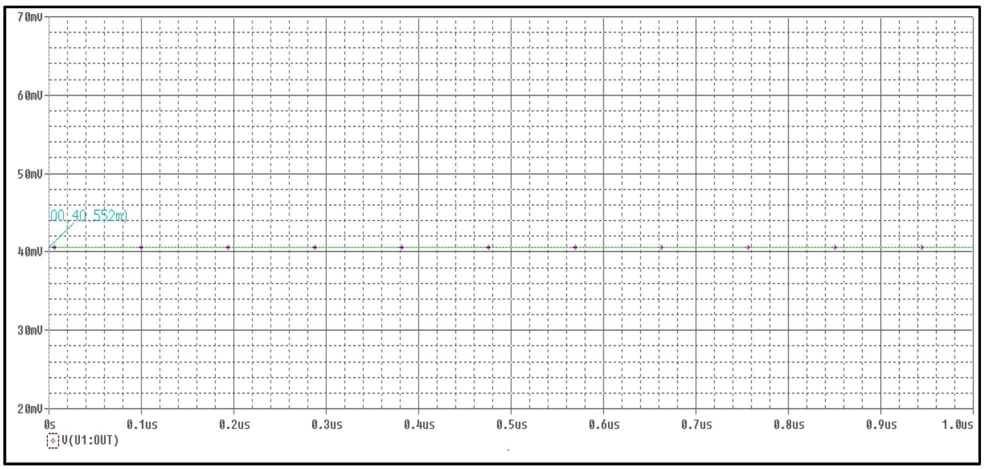

Figure 16: Simulation result for Sensor A (123.3 kΩ)

3.4 Sensor circuit testing

The actual sensor circuit is built to test whether the actual circuit can perform similar to the simulation result. Figure 17 show the actual circuit based on the simulation circuit.

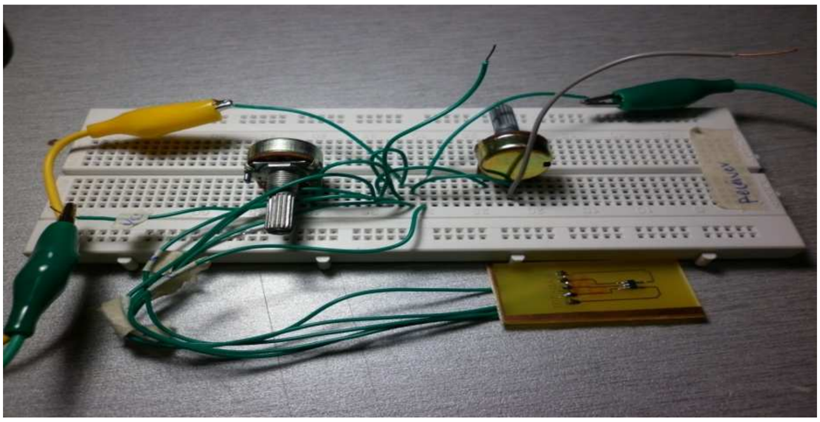

Figure 17: Sensor circuit

The pressure sensor is replaced with the variable resistor (100kΩ) to obtain more accurate resistance during the test. The sensor circuit is then connected to the supply and tested to get the resulting voltage over difference resistance. The output voltage of the circuit is measured using the digital multimeter as shown in figure 18.

Figure 18: Maximum voltage of the circuit reading

3.5 Microcontroller programming

The microcontroller uses in this project is 18F452. The compiler use in this project is mikroC pro for pic. The microcontroller is programmed to convert the input from the receiver (analog data) into the digital data using analog data converter. The compiler then will convert the data to the string and send it to the liquid crystal display (LCD) for display. The flowchart for the program is shown in Figure 19.

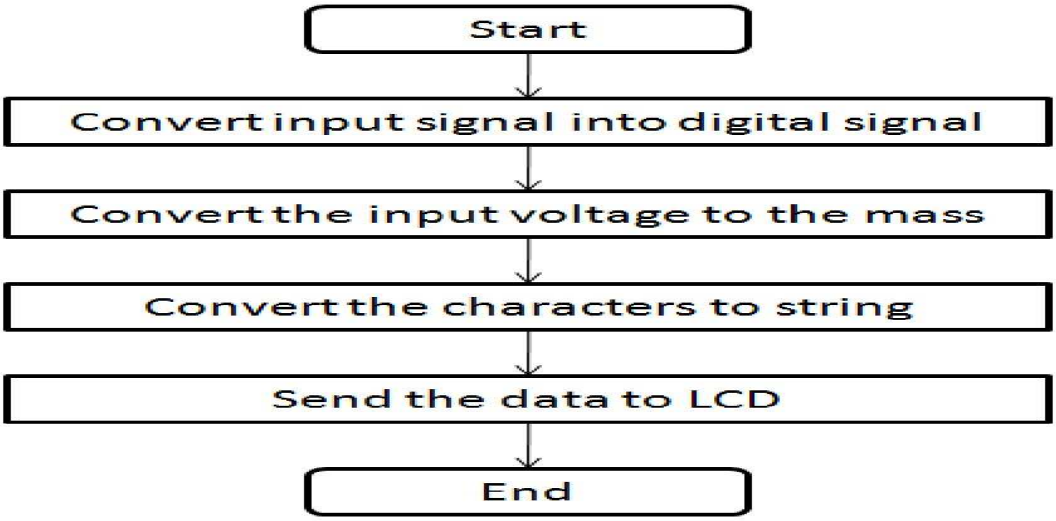

Figure 19: Programming Flow Chart

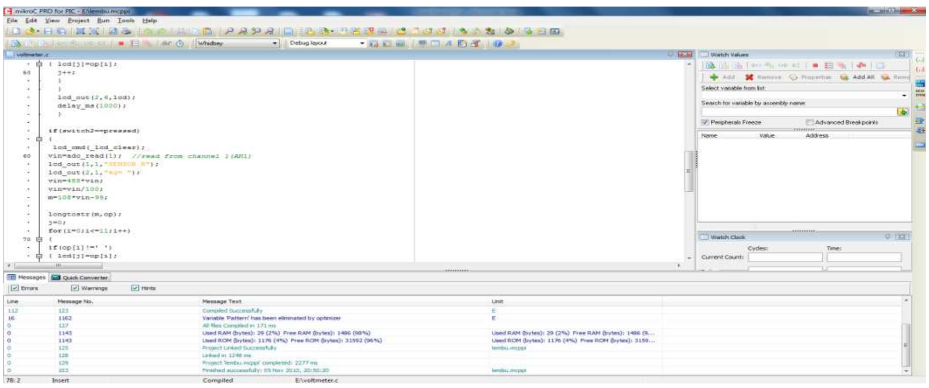

Figure 20: MikroC C compiler integrated development environment (IDE)

3.6 Product testing

The product testing is done by checking the output of the sensor when the user wears the shoe. The testing will determine the resistance produces by the force sensor when the mass is applied to the sensor. Figure 21 show the setup of the testing.

Figure 21: Sensor testing

When the user walks, the resistance output will determine how much force is applied to the sensor section (heel, 1st and 2nd metatarsal head). During this testing, the resistance value is determined using digital multimeter. The transmission system of the data is also tested to determine reliable data transmission. Figure 22 show the setup of the testing.

Figure 22: Data transmission testing

Based on Figure 22, the left side of the picture is the transmitter and the right side is the receiver. The data is fed to the transmitter and the output of the transmitter is measured to determine the reliability of the transmission.

The microcontroller of this project is also being tested to justify the operation of the microcontroller. Voltage range from 0-5V is fed to the microcontroller and the liquid crystal display (LCD) will show the result of the operation. Figure 22 show the testing of the microcontroller operation.

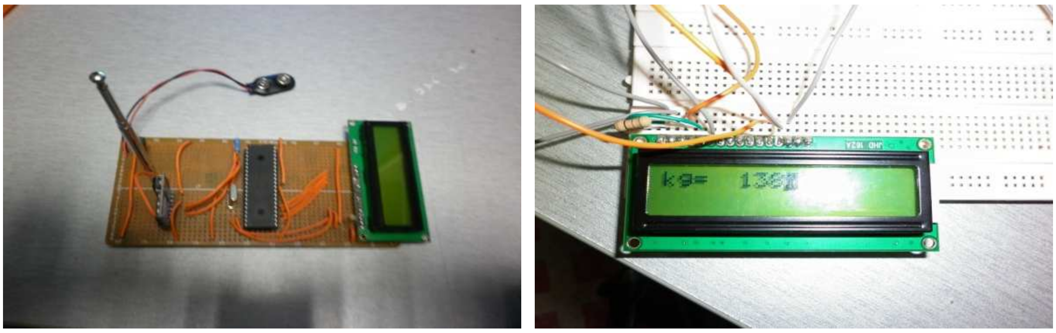

Figure 23: Microcontroller testing

Based on figure 23, the actual microcontroller circuit is on the left picture. Microcontroller will convert the analog data from the receiver (replace by the supply voltage from the dc supply) and convert to the digital data. The data will be converted to the string and display on the LCD (refer to figure 23 right picture). The display will show the value of the voltage in term of the mass.

3.7 Project Flow

This project will function according to the flowchart in figure 24.

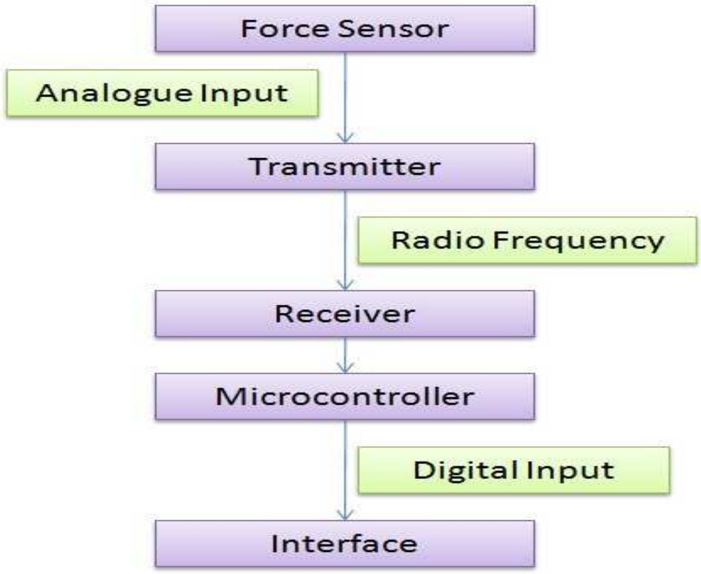

Figure 24: Project flow

The output of the sensor will be fed to the transmitter for transmission via radio frequency. The receiver will receive the output voltage from the transmitter and the send to the microcontroller for the analyzing purpose. The microcontroller will convert the output voltage to real value and send the data to liquid crystal display for monitoring

CHAPTER 4

RESULT AND DISCUSSION

4.1 Force sensor analysis

Pressure sensor analysis is done by providing mass on the top of the force sensor to measure the resistance of the sensor for the specified mass. The testing process is explained in part 3.2. The result of the pressure sensor testing is shown in table 1.

Table 2: Resistance for difference mass

Mass (Kg)	Sensor A(Ω)	Sensor B(Ω)	Sensor C(Ω)
10	0.73 M	0.545 M	0.404 M
20	123.0 K	58.2 K	56.0 K
30	50.3 K	25.0 K	18.8 K
40	23.2 K	16.4 K	9.07 K
50	15.02 K	11.0 K	6.8 K
60	8.93 K	7.7 K	4.8 K
70	7.06 K	6.08 K	4.0 K
80	4.2 K	5.0 K	3.26 K
90	3.95 K	4.04 K	2.7 K
100	3.70 K	3.65 K	2.47 K
110	3.33 K	3.34 K	2.22 K
120	3.07 K	2.98 K	1.9 K
130	2.47 K	2.45 K	1.73 K

The result is plotted in graph shown in figure 25. The vertical axis of the graph is the resistance and the horizontal axis is the mass applied to the sensor. The blue line show the characteristics of the sensor A, the red line is the characteristic for the sensor B and the green line is the characteristic for the sensor C.

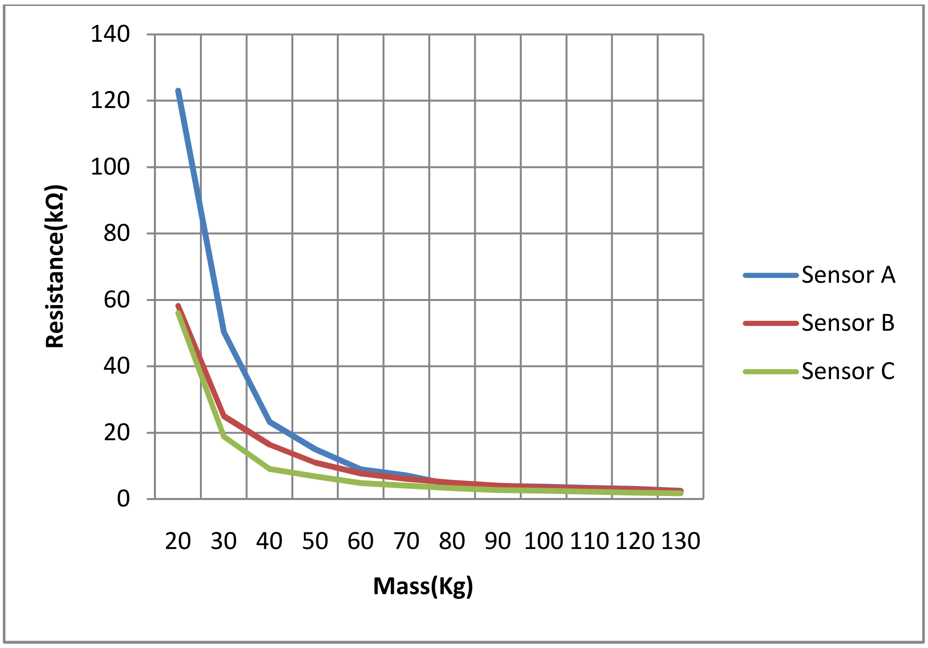

Figure 25: Resistance vs Mass

From the graph, the resistance decrease when the mass is increase and prove the sensor has ability to detect changes in force applied to the foot. The resulting resistance from this experiment indicates the force sensor uses in this project are within the range of 1 kΩ to 100 kΩ. The resistances characteristic for the all sensors are not identical since the sensors are customized.

4.2 Sensor circuit simulation

The result of the force sensor experiment indicates that the sensor will provide the resistance within the range of the 1 kΩ to 100 kΩ. The procedure of this simulation is explained in part 3.3. The input of the sensor will be fed to the sensor circuits and the reference resistance used is 1 kΩ. The equation $V_{out} = - V_1 * (R_F/R_{in})$ will determine the output voltage [4]. The full resistance characteristic over voltage is shown in table 3, table 4 and table 5. The mass chose in this experiment is ranging from 10kg to 100kg and the V_1 is -5 V. The data from the table 3, 4 and 5 are plotted as shown in figure 26, 27 and 28.

4.2.1 Sensor circuit simulation for sensor A

Table 3: Voltage for difference resistance (Sensor A)

Mass (Kg)	Resistance (Ω)	Output Voltage (V)
10	0.73 M	6.85m
20	123.0 K	40.6m
30	50.3 K	0.10
40	23.2 K	0.22
50	15.02 K	0.33
60	8.93K	0.56
70	7.06 K	0.71
80	4.2 K	1.19
90	3.95 K	1.27
100	3.70 K	1.35
110	3.33 K	1.50
120	3.07 K	1.63

130	2.47 K	2.02

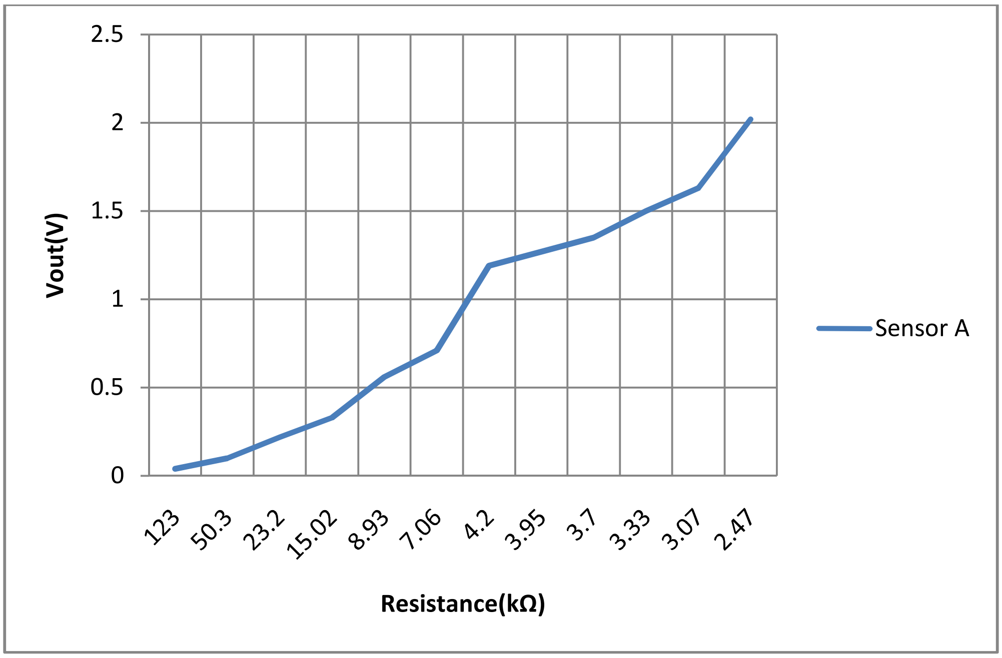

Figure 26: V_{out} vs Resistance for Sensor A

Table 3 and figure 26 show the characteristics for sensor circuit simulation (sensor A). The resistance in this graph is between 0.73 MΩ to 2.47 kΩ and the output voltage value is range between 6.85 mV to 2.02 V.

4.2.2 Sensor circuit simulation for sensor B

Table 4: Voltage for difference resistance (Sensor B)

Mass (Kg)	Resistance (Ω)	Output Voltage (V)
10	0.545 M	9.17m
20	58.2 K	0.09
30	25.0 K	0.20
40	16.4 K	0.30
50	11.0 K	0.45
60	7.7 K	0.65

70	6.08 K	0.82
80	5.0 K	1.00
90	4.04 K	1.24
100	3.65 K	1.37
110	3.34 K	1.50
120	2.98 K	1.68
130	2.45 K	2.04

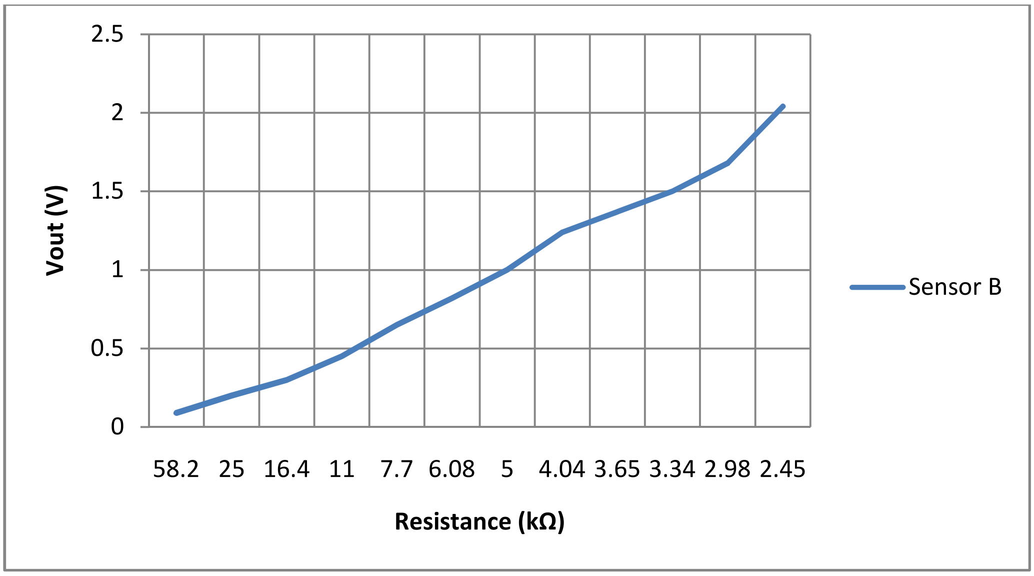

Figure 27: V_{out} vs Resistance for Sensor B

Table 4 and Figure 27 show the characteristics for sensor circuit simulation (sensor A). The resistance in this graph is between 0.545 MΩ to 2.45 kΩ and the output voltage value is range between 9.17 mV to 2.04 V.

4.2.3 Sensor circuit simulation for sensor C

Table 5: Voltage for difference resistance (Sensor C)

Mass (Kg)	Resistance (Ω)	Output Voltage (V)
10	0.404 M	12.3 m
20	56.0 k	0.09
30	18.8 k	0.27
40	9.07 k	0.55
50	6.8 k	0.74
60	4.8 k	1.04
70	4.0 k	1.25
80	3.26 k	1.53
90	2.7 k	1.85
100	2.47 k	2.02
110	2.22 k	2.25
120	1.9 k	2.63
130	1.73 k	2.89

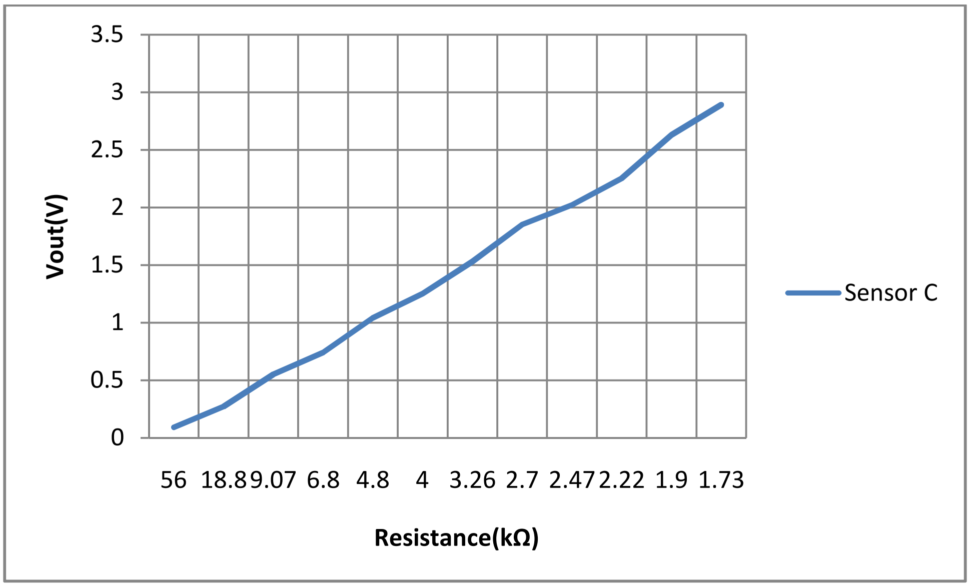

Figure 28: V_{out} vs Resistance for Sensor C

Table 5 and Figure 28 show the characteristics for sensor circuit simulation (sensor A). The resistance in this graph is between 0.404 MΩ to 1.73 kΩ and the output voltage value is range between 12.3 mV to 2.89 V.

4.2.4 Sensor circuit simulation analysis

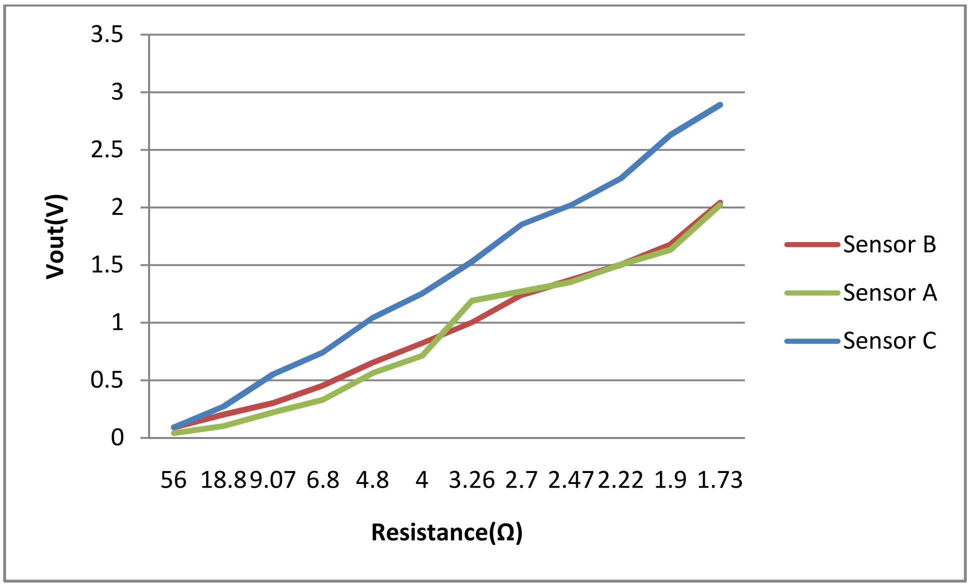

Figure 29: V_{out} vs. Resistance for Sensor A, B and C

The sensor graphs are plotted together in Figure 29 to determine the characteristic of all the sensors. From the graph, sensor A and sensor B have the almost the same voltage resistance relationship but the sensor C has different characteristics but all three sensors have linear relationship with the output voltage, the output can be used in analog to digital conversion (ADC) process. Since the sensors in this project have different characteristic, the mass voltage equation for all sensor will be difference

4.3 Sensor circuit testing

The sensor circuit is tested to verify the result of the simulation. 100 kΩ variable resistance is used to replace the sensor to obtain more accurate resistance value. The procedure for this testing is explained in 3.4. The range of the resistance is 92.9 kΩ to 2 kΩ based on the sensor analysis. The result of output voltage of the sensor circuit is shown in Table 6 and the value of the resistance is plotted in figure 30 for data analysis.

Table 6: Output voltage for sensor circuit testing

Resistance(kΩ)	V_{out}(V)
92.9	0.054
90	0.055
80	0.062
70	0.071
60	0.082
50	0.098
40	0.123
30	0.164
20	0.247
10	0.492
9	0.548

8	0.615
7	0.701
6	0.823
5	0.969
4	1.23
3	1.59
2	2.5
1.5	3.23
1	4.77

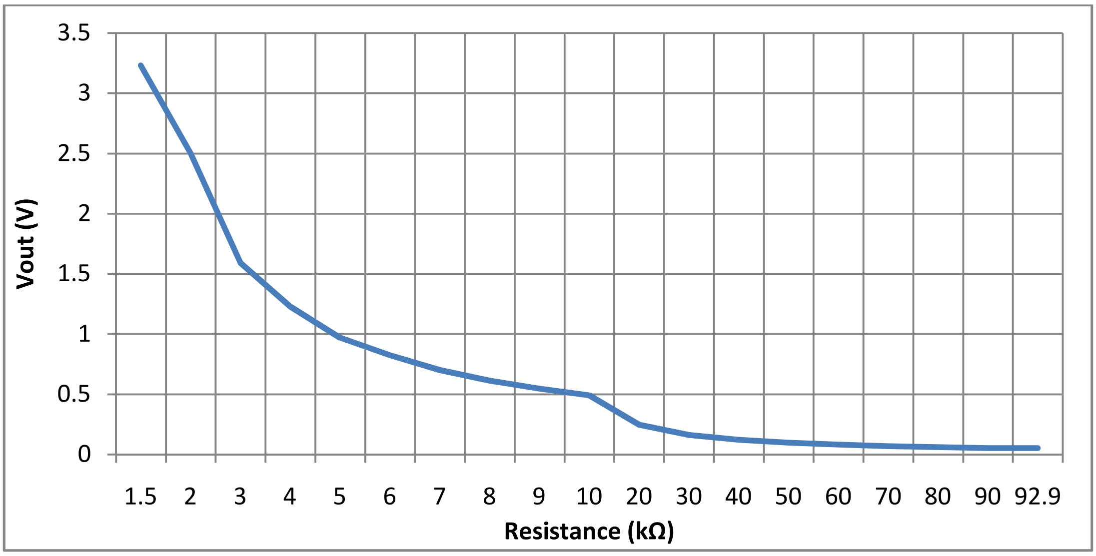

Figure 30: V_{out} vs Resistance

The graph for the circuit testing is shown in figure 30. The resulting graph is exponential which is not favorable for the analog to digital conversion. Since the minimum resistance for sensors in this experiment is 1.47kΩ, the output from 1.5kΩ will be used. The graph for output voltage from 1.5kΩ to 92.9kΩ is plotted as shown in figure 31.

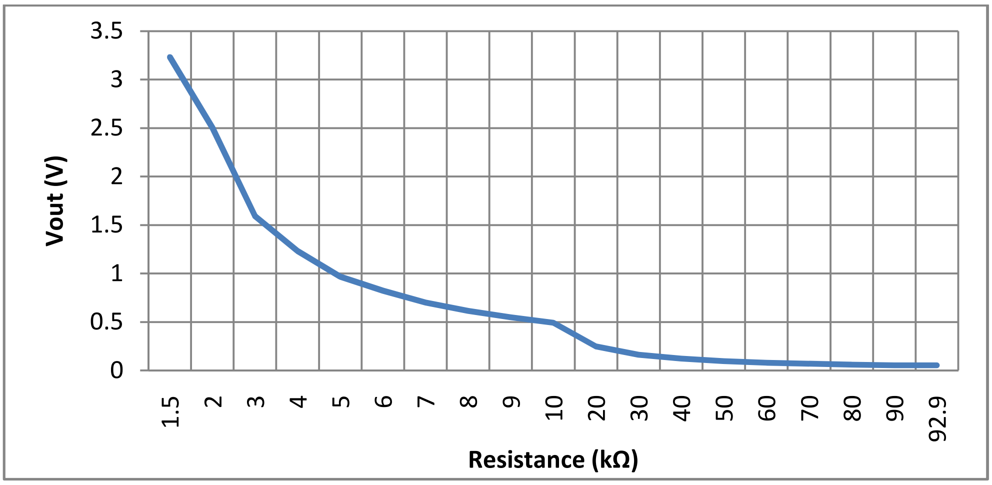

Figure 31: V_{out} vs Resistance for 1.5kΩ to 92.9kΩ

The graph in figure 31 shows a linear relationship between the resistance and the output voltage and the data can be used for analog to digital conversion.

4.4 Transmitter circuit

The transmitter circuit is designed to transmit the signal from the sensor under the shoe sole using the printed circuit board (PCB) designer. The receiver circuit is shown in Figure 32 and Figure 33:

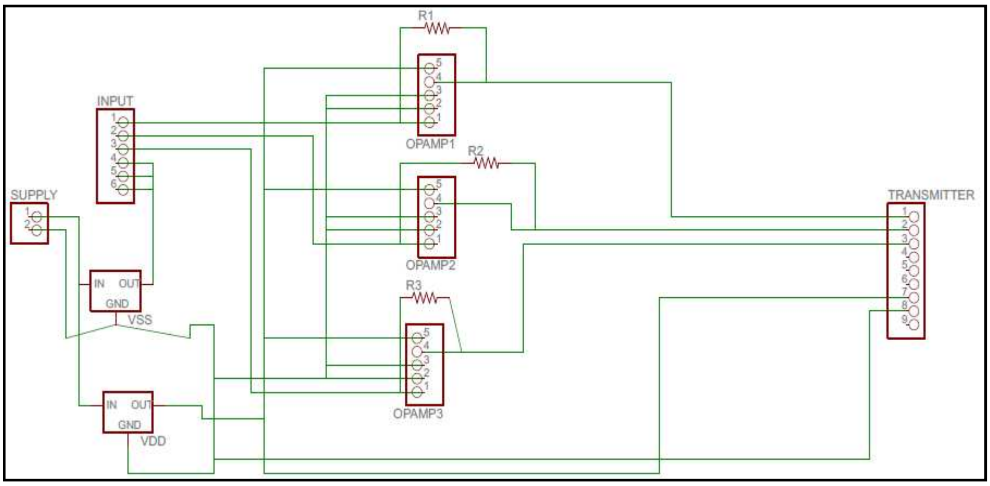

Figure 32: Schematic transmitter circuit

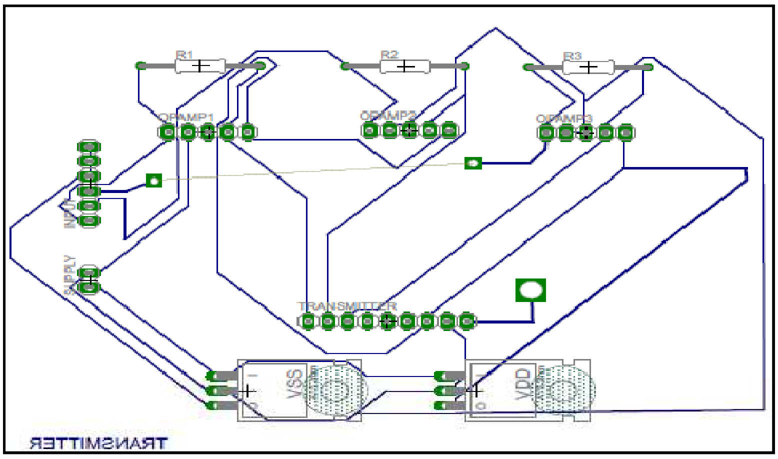

Figure 33: Transmitter board layout design

The transmitter circuit board consists of pinheads (linkage between the sensor and the transmitter, power supply (voltage regulator), operational amplifier (negative feedback operation) and the transmitter module. The connection of the circuit is based on the schematic shown in Figure 32 and the finished printed circuit board(PCB) is shown in Figure 33.

4.5 Receiver circuit

The receiver circuit will receive the signal from the transmitter and it converts the voltage into the pressure value. The design of the receiver circuit is shown Figure 34 and Figure 35:

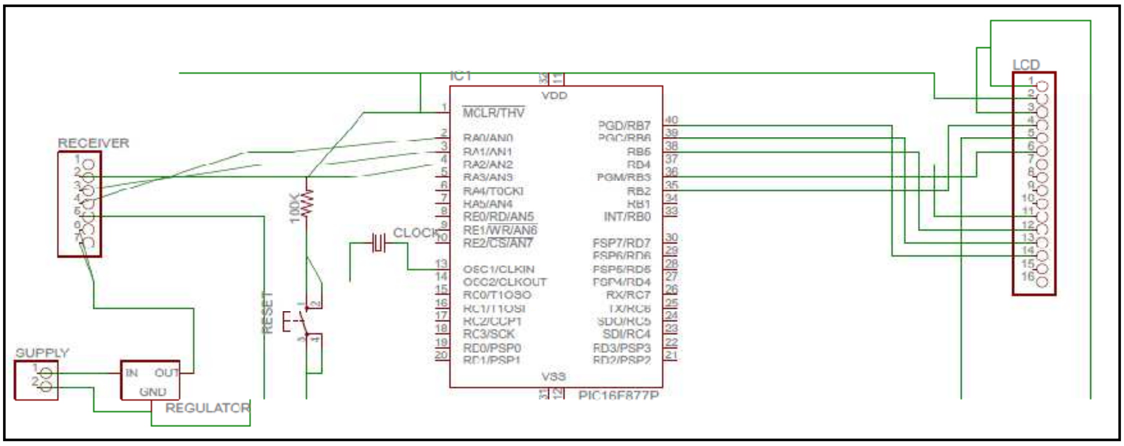

Figure 34: Schematic of the receiver circuit

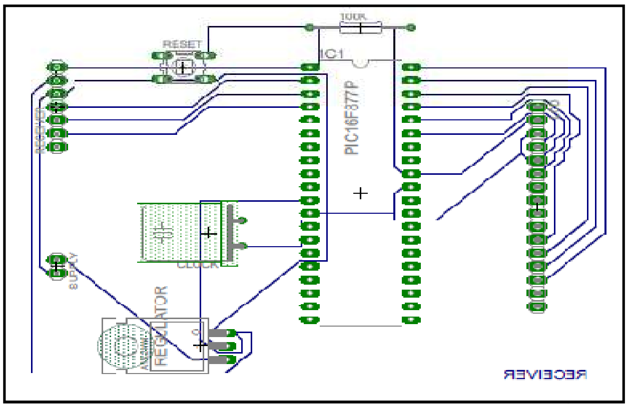

Figure 35: Receiver board layout design

The receiver circuit consists of 40-pin microcontroller, crystal clock oscillator, power supply (voltage regulator) and pinhead. The schematic of the receiver circuit is shown in Figure 34 and the board for the receiver circuit is shown in Figure 35.

4.6 Data acquisition design

The data acquisition in this project is consisted of the force sensor. The sole of the shoe is fitted with pressure sensor to obtain the force applied to the specific area on foot. The placements of the sensors are based on the Figure 36 [2,3]. The red areas are the proposed site for sensor placement.

Figure 36: Site for sensor placement [13]

The implementation of the sensors on the shoe sole is shown in Figure 37.

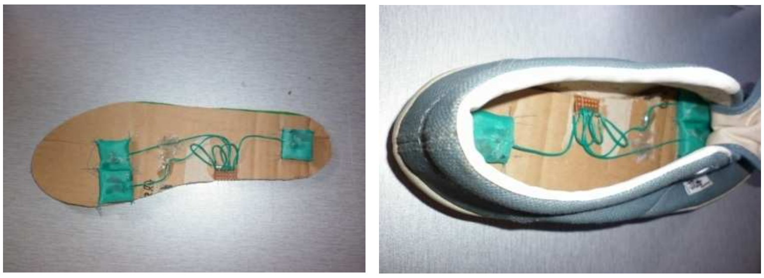

Figure 37: Sensor placement on shoe sole and in the shoe

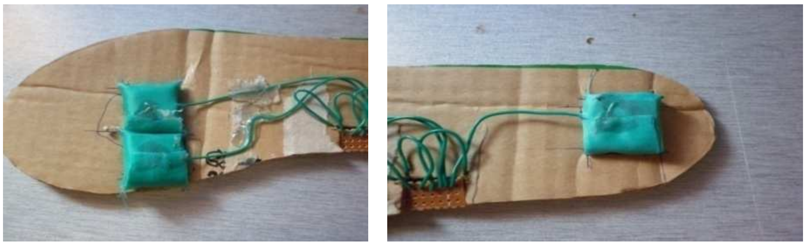

Figure 38: Sensor placement on 1st and 2nd metatarsals and heel

These placements are according to high pressure area on normal foot and diabetic foot. For normal foot pressure, the high force area is at heel and for the diabetic foot; the high force area is converted to the metatarsal area especially on 1st and 2nd metatarsal head. The resistance from foot is send to the sensor circuit.

4.7 Source code

The source code for data interpretation the analog input from port A to convert the output voltage from the receiver into the real value using the microprocessor [1,11].

The program in the figure 37 will convert analog data receive from either port AN0, AN1 or AN2 and convert to the digital data [11]. The data will be converted to the value of the mass based on voltage. The character is converted to the string in to enable the character display on the liquid crystal display (LCD).

In this program PORTC is defined as output and PORTA and PORTB as input by using the command below [11]:

```
TRISC = 0x00;
TRISB = 0xFF;
TRISA = 0xFF;
```

The selection button is initialized using the command below [11]:

```
#define switch1 portb.f0
#define switch2 portb.f1
#define switch3 portb.f2
```

Then the LCD is configured and the text “Diabetic Foot Detector” is displayed on the LCD for two seconds. The A/D is then configured by setting register ADCON1 to 0x80 so the A/D result is right-justified, Vref voltage is set to VDD (+5 V), and all PORTA pins are configured as analog inputs. The complete programming source code is on Appendix A.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The aim this project is to construct monitoring device to monitor foot pressure in the real time. The foot pressure data is collected using data acquisition module. The data acquisition achieves by interface the force sensor and the microcontroller. The wireless communication between the data acquisition and the microcontroller is done using the Radio Frequency (RF) transmission. The user interface is developed to enable the medical practitioner to monitor any abnormality and take early measurement.

5.2 Recommendation

There are some recommendations for this project. The first recommendation is to replace the force sensor with more accurate and smaller in size sensor. There are two types of the sensor that can be used in this project, the first is the monofilament force sensor and the second one is the piezoelectric accelerometer. Both are small in size and the output of the sensor is more accurate and precise compare to the force sensor uses in this project. The next recommendation is to replace the radio frequency transmission module with more robust system for example Zigbee®. This enhancement will decrease usage of the electronic component and the size as well. The advantage of replacing the radio transmission also is the user can log the data into the computer without using the external microcontroller.

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APPENDICES

Appendix A

Programming Source Code

```
sbit LCD_RS at RC2_bit;
sbit LCD_EN at RC3_bit;
sbit LCD_D7 at RC7_bit;
sbit LCD_D6 at RC6_bit;
sbit LCD_D5 at RC5_bit;
sbit LCD_D4 at RC4_bit;

// Pin direction
sbit LCD_RS_Direction at TRISC2_bit;
sbit LCD_EN_Direction at TRISC3_bit;
sbit LCD_D7_Direction at TRISC7_bit;
sbit LCD_D6_Direction at TRISC6_bit;
sbit LCD_D5_Direction at TRISC5_bit;
sbit LCD_D4_Direction at TRISC4_bit;

#define switch1 portb.f0
#define switch2 portb.f1
#define switch3 portb.f2
#define pressed 0
```

Appendix A

Programming Source Code

```
void main()
{
unsigned long vin,mv,vdec,vfrac;      //assign the variable
unsigned char op[12];             //assign the variable
unsigned char i,j,lcd[5],ch1,ch2,m;   //assign the variable
trisc=0x00;      //set port c as output
trisb=0xff;      //set port b as inout
lcd_init();       //lcd initial
lcd_cmd(_LCD_CLEAR);    //clear lcd memory
lcd_out(1,1,"diabetic foot");    //print out the character on first column and
row
lcd_out(2,1,"detector");    // print out the character on second column and first
row
delay_ms(2000);  //delay 2 second
adcon1=0x80;  //enable ADC and set 5v as voltage reference
for(;;)  //forever loop
{
if(switch1==pressed)    //switch 1 is pressed
{
lcd_cmd(_lcd_clear);
vin=adc_read(0);  //read from channel 0(AN0)
lcd_out(1,1,"SENSOR A");
lcd_out(2,1,"kg= ");
vin=488*vin;
vin=vin/100;
m=108*vin-99;   //convert voltage to mass
longtostr(m,op); //convert to string
j=0;
```

Appendix A

Programming Source Code

```
for(i=0;i<=11;i++)
 {
 if(op[i]!=' ')
 { lcd[j]=op[i];
   j++;
   }
   }
   lcd_out(2,6,lcd);
   delay_ms(1000);
   }

 if(switch2==pressed)
 {
  lcd_cmd(_lcd_clear);
 vin=adc_read(1);  //read from channel 1(AN1)
 lcd_out(1,1,"SENSOR B");
 lcd_out(2,1,"kg= ");
 vin=488*vin;
 vin=vin/100;
 m=108*vin-99;  //convert voltage to mass

 longtostr(m,op);
 j=0;
 for(i=0;i<=11;i++)
 {
```

```
}
  }
  lcd_out(2,6,lcd);
  delay_ms(1000);
  }
  else
  {
  lcd_cmd(_lcd_clear);
  lcd_out(1,1,"Please Choose");
  lcd_out(2,1,"Sensor");
  delay_ms(1000);
  }
  }}
```

Appendix B

Analog Digital (A/D) Module

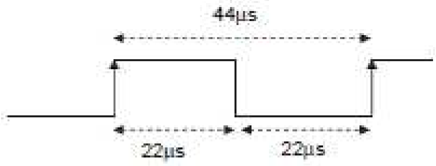

Figure 2.39: Generated PWM waveform

2.1.11 Analog-to-Digital Converter (A/D) Module

An analog-to-digital converter (A/D) is another important peripheral component of a microcontroller. The A/D converts an analog input voltage into a digital number so it can be processed by a microcontroller or any other digital system. There are many analog-to-digital converter chips available on the market, and an embedded systems designer should understand the characteristics of such chips so they can be used efficiently.

As far as the input and output voltage are concerned A/D converters can be classified as either unipolar and bipolar. Unipolar A/D converters accept unipolar input voltages in the range 0 to +0V, and bipolar A/D converters accept bipolar input voltages in the range ±V. Bipolar converters are frequently used in signal processing applications, where the signals by nature are bipolar. Unipolar converters are usually cheaper, and they are used in many control and instrumentation applications.

Figure 2.40 shows the typical steps involved in reading and converting an analog signal into digital form, a process also known as signal conditioning. Signals received from sensors usually need to be processed before being fed to an A/D converter. This

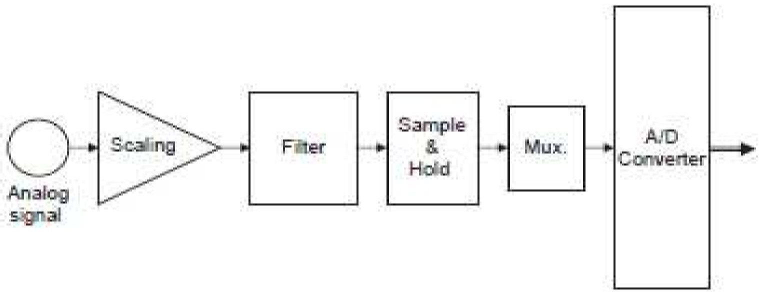

Figure 2.40: Signal conditioning and A/D conversion process

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Analog Digital (A/D) Module

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processing usually begins with scaling the signal to the correct value. Unwanted signal components are then removed by filtering the signal using classical filters (e.g., a low-pass filter). Finally, before feeding the signal to an A/D converter, the signal is passed through a sample-and-hold device. This is particularly important with fast real-time signals whose value may be changing between the sampling instants. A sample-and-hold device ensures that the signal stays at a constant value during the actual conversion process. Many applications required more than one A/D, which normally involves using an analog multiplexer at the input of the A/D. The multiplexer selects only one signal at any time and presents this signal to the A/D converter. An A/D converter usually has a single analog input and a digital parallel output. The conversion process is as follows:

- Apply the processed signal to the A/D input
- Start the conversion
- Wait until conversion is complete
- Read the converted digital data

The A/D conversion starts by triggering the converter. Depending on the speed of the converter, the conversion process itself can take several microseconds. At the end of the conversion, the converter either raises a flag or generates an interrupt to indicate that the conversion is complete. The converted parallel output data can then be read by the digital device connected to the A/D converter.

Most members of the PIC18F family contain a 10-bit A/D converter. If the chosen voltage reference is +5V, the voltage step value is:

$$\left(\frac{5V}{1023}\right) = 0.00489V \text{ or } 4.89mV$$

Therefore, for example, if the input voltage is 1.0V, the converter will generate a digital output of 1.0/0.00489 = 205 decimal. Similarly, if the input voltage is 3.0V, the converter will generate 3.0/0.00489 = 613.

The A/D converter used by the PIC18F452 microcontroller has eight channels, named AN0–AN7, which are shared by the PORTA and PORTE pins. Figure 2.41 shows the block diagram of the A/D converter.

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Appendix B

Analog Digital (A/D) Module

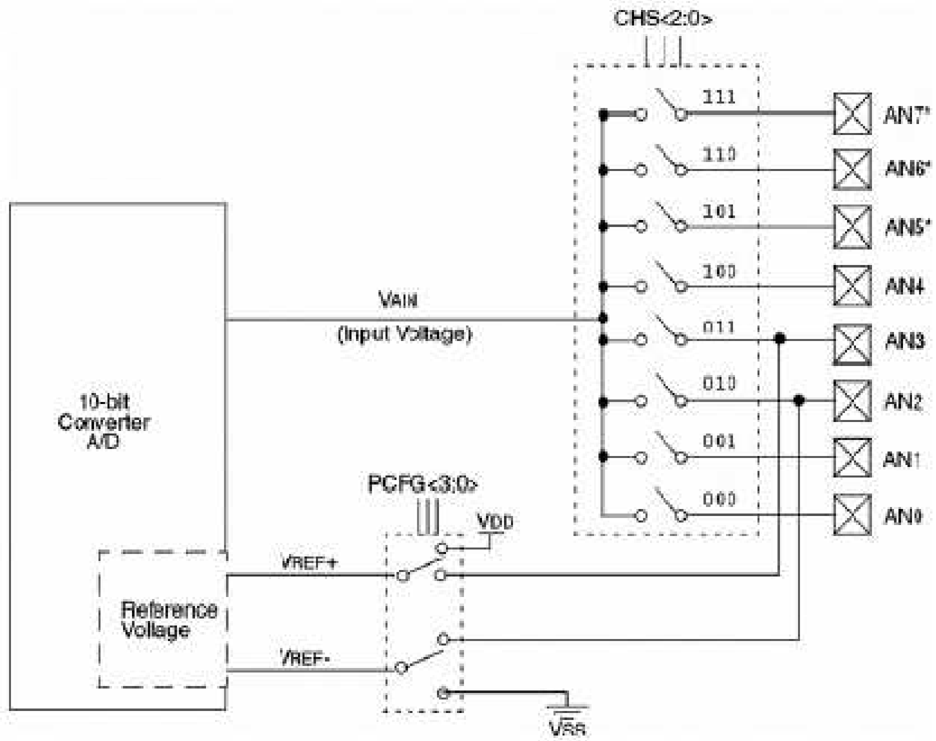

Figure 2.41: Block diagram of the PIC18F452 A/D converter

The A/D converter has four registers. Registers ADRESH and ADRESL store the higher and lower results of the conversion respectively. Register ADCON0, shown in Figure 2.42, controls the operation of the A/D module, such as selecting the conversion clock together with register ADCON1, selecting an input channel, starting a conversion, and powering up and shutting down the A/D converter.

Register ADCON1 (see Figure 2.43) is used for selecting the conversion format, configuring the A/D channels for analog input, selecting the reference voltage, and selecting the conversion clock together with register ADCON0.

A/D conversion starts by setting the GO/DONE bit of ADCON0. When the conversion is complete, the 2 bits of the converted data is written into register ADRESH, and the remaining 8 bits are written into register ADRESL. At the same time the GO/DONE bit is cleared to indicate the end of conversion. If required, interrupts can be enabled so that a software interrupt is generated when the conversion is complete.

Appendix B

Analog Digital (A/D) Module

R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	U-0	R/W-0
ADCS1	ADCS0	CHS2	CHS1	CHS0	GO/$\overline{DONE}$	—	ADON

bit 7 bit 0

bit 7-6 **ADCS1:ADCS0:** A/D Conversion Clock Select bits (ADCON0 bits in bold)

ADCON1 <ADCS2>	ADCON0 <ADCS1:ADCS0>	Clock Conversion
0	00	FOSC/2
0	01	FOSC/8
0	10	FOSC/32
0	11	FRC (clock derived from the internal A/D RC oscillator)
1	00	FOSC/4
1	01	FOSC/16
1	10	FOSC/64
1	11	FRC (clock derived from the internal A/D RC oscillator)

bit 5-3 **CHS2:CHS0:** Analog Channel Select bits

000 = channel 0, (AN0)
001 = channel 1, (AN1)
010 = channel 2, (AN2)
011 = channel 3, (AN3)
100 = channel 4, (AN4)
101 = channel 5, (AN5)
110 = channel 6, (AN6)
111 = channel 7, (AN7)

Note: The PIC18F2X2 devices do not implement the full 8 A/D channels; the unimplemented selections are reserved. Do not select any unimplemented channel.

bit 2 **GO/$\overline{DONE}$:** A/D Conversion Status bit

When ADON = 1:

1 = A/D conversion in progress (setting this bit starts the A/D conversion which is automatically cleared by hardware when the A/D conversion is complete)

0 = A/D conversion not in progress

bit 1 **Unimplemented:** Read as '0'

bit 0 **ADON:** A/D On bit

1 = A/D converter module is powered up

0 = A/D converter module is shut-off and consumes no operating current

Figure 2.42: ADCON0 register

Appendix B

Analog Digital (A/D) Module

R/W-0	R/W-0	U-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0
ADFM	ADCS2	—	—	PCFG3	PCFG2	PCFG1	PCFG0
bit 7							bit 0

bit 7 **ADFM:** A/D Result Format Select bit
1 = Right justified. Six (6) Most Significant bits of ADRESH are read as '0'.
0 = Left justified. Six (6) Least Significant bits of ADRESL are read as '0'.

bit 6 **ADCS2:** A/D Conversion Clock Select bit (ADCON1 bits in bold)

ADCON1 <ADCS2>	ADCON0 <ADCS1:ADCS0>	Clock Conversion
0	00	FOSC/2
0	01	FOSC/8
0	10	FOSC/32
0	11	FRC (clock derived from the internal A/D RC oscillator)
1	00	FOSC/4
1	01	FOSC/16
1	10	FOSC/64
1	11	FRC (clock derived from the internal A/D RC oscillator)

bit 5-4 **Unimplemented:** Read as '0'

bit 3-0 **PCFG3:PCFG0:** A/D Port Configuration Control bits

PCFG <3:0>	AN7	AN6	AN5	AN4	AN3	AN2	AN1	AN0	VREF+	VREF-	C / R
0000	A	A	A	A	A	A	A	A	VDD	VSS	8 / 0
0001	A	A	A	A	VREF+	A	A	A	AN3	VSS	7 / 1
0010	D	D	D	A	A	A	A	A	VDD	VSS	5 / 0
0011	D	D	D	A	VREF+	A	A	A	AN3	VSS	4 / 1
0100	D	D	D	D	A	D	A	A	VDD	VSS	3 / 0
0101	D	D	D	D	VREF+	D	A	A	AN3	VSS	2 / 1
011x	D	D	D	D	D	D	D	D	—	—	0 / 0
1000	A	A	A	A	VREF+	VREF-	A	A	AN3	AN2	6 / 2
1001	D	D	A	A	A	A	A	A	VDD	VSS	6 / 0
1010	D	D	A	A	VREF+	A	A	A	AN3	VSS	5 / 1
1011	D	D	A	A	VREF+	VREF-	A	A	AN3	AN2	4 / 2
1100	D	D	D	A	VREF+	VREF-	A	A	AN3	AN2	3 / 2
1101	D	D	D	D	VREF+	VREF-	A	A	AN3	AN2	2 / 2
1110	D	D	D	D	D	D	D	A	VDD	VSS	1 / 0
1111	D	D	D	D	VREF+	VREF-	D	A	AN3	AN2	1 / 2

A = Analog input   D = Digital I/O

Figure 2.43: ADCON1 register

Appendix B

Analog Digital (A/D) Module

The steps in carrying out an A/D conversion are as follows:

- Use ADCON1 to configure required channels as analog and configure the reference voltage.
- Set the TRISA or TRISE bits so the required channel is an input port.
- Use ADCON0 to select the required analog input channel.
- Use ADCON0 and ADCON1 to select the conversion clock.
- Use ADCON0 to turn on the A/D module.
- Configure the A/D interrupt (if desired).
- Set the GO/DONE bit to start conversion.
- Wait until the GO/DONE bit is cleared, or until a conversion complete interrupt is generated.
- Read the converted data from ADRESH and ADRESL.
- Repeat these steps as required.

For correct A/D conversion, the A/D conversion clock must be selected to ensure a minimum bit conversion time of 1.6μs. Table 2.11 gives the recommended A/D clock sources for various microcontroller operating frequencies. For example, if the

Table 2.11: A/D conversion clock selection

A/D clock source		
Operation	ADCS2:ADCS0	Maximum microcontroller frequency
2 T_{OSC}	000	1.25 MHz
4 T_{OSC}	100	2.50 MHz
8 T_{OSC}	001	5.0 MHz
16 T_{OSC}	101	10.0 MHz
32 T_{OSC}	010	20.0 MHz
64 T_{OSC}	110	40.0 MHz
RC	011	–

Appendix B

Analog Digital (A/D) Module

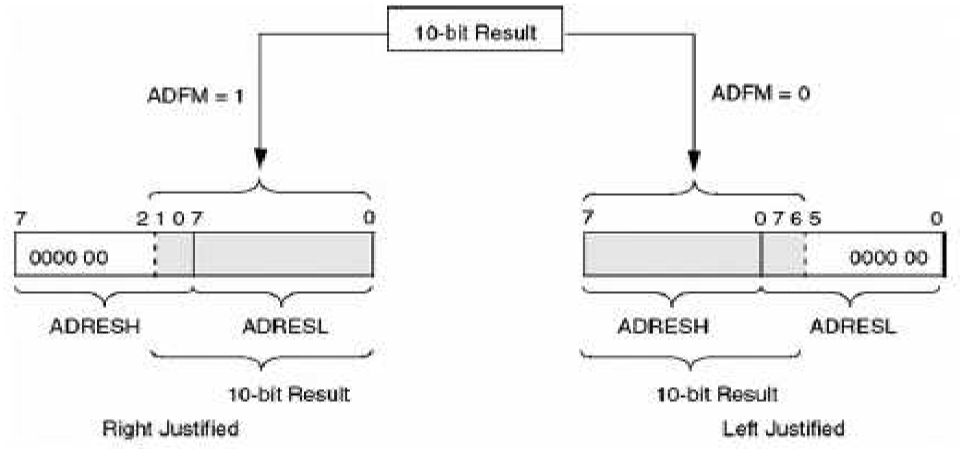

Figure 2.44: Formatting the A/D conversion result

microcontroller is operated from a 10MHz clock, the A/D clock source should be $F_{OSC/16}$ or higher (e.g., $F_{OSC/32}$).

Bit ADFM of register ADCON1 controls the format of a conversion. When ADFM is cleared, the 10-bit result is left justified (see Figure 2.44) and lower 6 bits of ADRESL are cleared to 0. When ADFM is set to 1 the result is right justified and the upper 6 bits of ADRESH are cleared to 0. This is the mode most commonly used, in which ADRESL contains the lower 8 bits, and bits 0 and 1 of ADRESH contain the upper 2 bits of the 10-bit result.

Analog Input Model and Acquisition Time

An understanding of the A/D analog input model is necessary to interface the A/D to external devices. Figure 2.45 shows the analog input model of the A/D. The analog input voltage V_{AIN} and the source resistance R_S are shown on the left side of the diagram. It is recommended that the source resistance be no greater than 2.5K. The analog signal is applied to the pin labeled ANx. There is a small capacitance (5pF) and a leakage current to the ground of approximately 500nA. R_{IC} is the interconnect resistance, which has a value of less than 1K. The sampling process is shown with switch SS having a resistance R_{SS} whose value depends on the voltage as shown in the

Appendix B

Analog Digital (A/D) Module

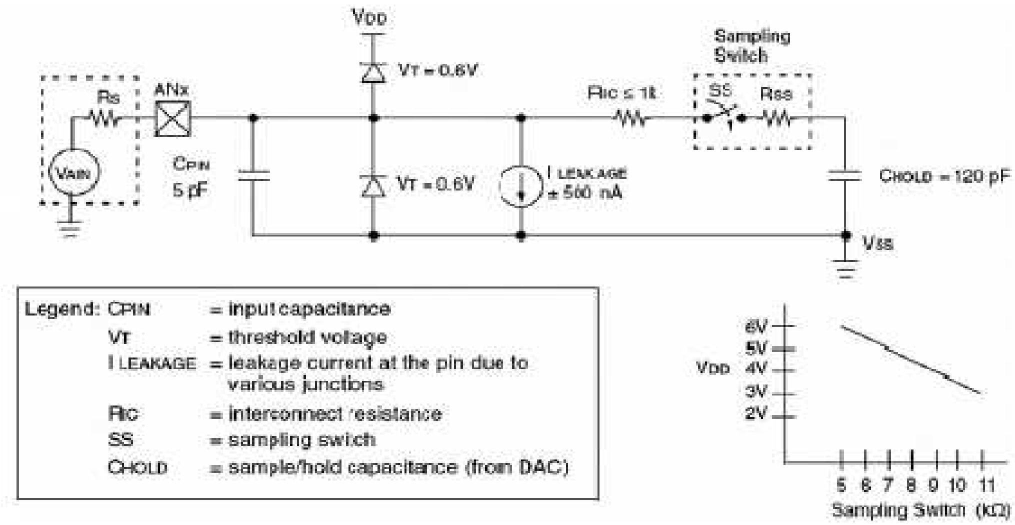

Figure 2.45: Analog input model of the A/D converter

small graph at the bottom of Figure 2.45. The value of R_{SS} is approximately 7K at 5V supply voltage.

The A/D converter is based on a switched capacitor principle, and capacitor C_{HOLD} shown in Figure 2.45 must be charged fully before the start of a conversion. This is a 120pF capacitor which is disconnected from the input pin once the conversion is started.

The acquisition time can be calculated by using Equation (2.7), provided by Microchip Inc:

$$T_{ACQ} = \text{Amplifier settling time} + \text{Holding capacitor charging time} + \text{temperature coefficient} \quad (2.7)$$

The amplifier settling time is specified as a fixed 2μs. The temperature coefficient, which is only applicable if the temperature is above 25°C, is specified as:

$$\text{Temperature coefficient} = (\text{Temperature} - 25°C)(0.05\mu s/°C) \quad (2.8)$$

Equation (2.8) shows that the effect of the temperature is very small, creating about 0.5μs delay for every 10°C above 25°C. Thus, assuming a working environment

Appendix B

Analog Digital (A/D) Module

between 25°C and 35°C, the maximum delay due to temperature will be 0.5µs, which can be ignored for most practical applications.

The holding capacitor charging time as specified by Microchip Inc is:

$$\text{Holding capacitor charging time} = -(120\text{pF})(1\text{K} + R_{SS} + R_S)\text{Ln}(1/2048) \qquad (2.9)$$

Assuming that $R_{SS} = 7\text{K}$, $R_S = 2.5\text{K}$, Equation (2.9) gives the holding capacitor charging time as 9.6µs.

The acquisition time is then calculated as:

$$T_{ACQ} = 2 + 9.6 + 0.5 = 12.1\mu s$$

A full 10-bit conversion takes 12 A/D cycles, and each A/D cycle is specified at a minimum of 1.6µs. Thus, the fastest conversion time is 19.2µs. Adding this to the best possible acquisition time gives a total time to complete a conversion of 19.2 + 12.1 = 31.3µs.

When a conversion is complete, it is specified that the converter should wait for two conversion periods before starting a new conversion. This corresponds to $2 \times 1.6 = 3.2\mu s$. Adding this to the best possible conversion time of 31.3µs gives a complete conversion time of 34.5µs. Assuming the A/D converter is used successively, and ignoring the software overheads, this implies a maximum sampling frequency of about 29KHz.

2.1.12 Interrupts

An interrupt is an event that requires the CPU to stop normal program execution and then execute a program code related to the event causing the interrupt. Interrupts can be generated internally (by some event inside the chip) or externally (by some external event). An example of an internal interrupt is a timer overflowing or the A/D completing a conversion. An example of an external interrupt is an I/O pin changing state.

Interrupts can be useful in many applications such as:

- *Time critical applications.* Applications which require the immediate attention of the CPU can use interrupts. For example, in an emergency such as a power failure or fire in a plant the CPU may have to shut down the system immediately in an orderly manner. In such applications an external interrupt can force the CPU to stop whatever it is doing and take immediate action.