Design of a Stress Monitor Based on Breathing Signals Using a Smart Textile Shirt

Master of Science Thesis in the Master Degree Programme,

Biomedical Engineering

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Göteborg, Sweden, 2012

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Abstract

Long term exposure to stress is related to health problems, for example, exhaustion syndrome, cardiovascular and metabolic disturbances. Respiratory rate, heart rate, and the variability in heart rate are considered as direct measures that contribute information on whether a person is stressed. Long term monitoring of respiratory rate and respiratory pattern and heart rate (HR) is of interest to monitor and then evaluate stress over time. Recent development in wearable technologies has presented smart shirts that incorporate textile based sensors which enable monitoring of physiological signals such as respiration and ECG in daily activities.

The aim of the thesis is to design a stress monitor based on respiratory signals measured by a smart textile shirt. The smart textile shirt consists of two coated elastic conductive straps that can measure changes in resistance to monitor respiratory related movements at the chest and the abdomen. The smart textile shirt has been developed by the Swedish School of Textiles (THS), at the University of Borås. The designed system is a further development of a laboratory prototype developed in the THS to arrive at a wearable and ambulatory stress monitor system.

The functionality of the existing laboratory prototype was analyzed to find issues which needed to be improved. Some solutions were proposed and a prototype system was implemented to demonstrate key aspects. A new portable interface unit was implemented for data acquisition and to interface the smart textile shirt with a laptop. A LabVIEW program was used as the user interface on the laptop. This implemented prototype system was evaluated to prove its operation. The results showed that using the smart textile shirt with the implemented portable interface unit, respiratory signals can be measured and sent to the remote laptop via Bluetooth. The acquired breathing signals can be displayed in real-time, and recorded on a local storage for further analysis. The breathing rate can be calculated and displayed in real-time.

Keywords : respiratory, wearable, Arduino, Bluetooth, LabVIEW

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Suchawadee Ratnarathorn

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Abbreviation list

ADC	Analog-to-Digital Converter
Arduino BT	Arduino Bluetooth
DAQ	Data Acquisition Device
ECG	Electrocardiography
GUI	Graphical User Interface
HR	Heart rate
HRV	Heart rate variability
IC	Integrated circuit
IDE	Integrated Development Environment
LIFA	LabVIEW interface for Arduino
NI	National Instruments
PDA	Personal Digital Assistant
SPSS	Statistical Package for the Social Sciences
THS	The Swedish School of Textiles (TextilHögSkolan), University of Borås, Sweden

1. Introduction

Exposure to long periods of stress is associated to health problems like exhaustion syndrome, cardiovascular and metabolic disturbances, as well as neck and shoulder problems. Taken together these health problems represent large costs to society and not seldom both social and economical consequences for the individual. Current information on stress prevalence is typically based on self-reports and only to some extent direct measurement of physiological response as e.g. stress hormones from blood, saliva or urine samples. Respiratory rate, heart rate, and the variability in heart rate are other direct measures that contribute information about to what extent a person is stressed or not. Today, long term monitoring of heart rate (HR) can be considered a standard procedure and is extensively used in cardiology (Holter system) [1] and sports medicine (Polar system) [2]. Evaluation of heart rate variability (HRV) is less common as it requires a high quality ECG signal and a more demanding analysis. Finally, long term monitoring of respiratory patterns, especially the division between abdominal or diaphragmic (deep breathing) and chest (shallow) breathing is of interest to monitor or evaluate stress over time [3].

Recent development in textile technologies has presented smart textile shirts that incorporate textile based sensors. The smart textile shirt has been developed and applied for medical and healthcare purposes to monitor physiological parameters such as ECG, temperature, and respiration because of the key properties of textiles; flexibility to comfort to the body, soft, and washable. People feel comfortable using the shirts and also the shirts look nice and attractive [4]. These textile properties together with current available technology enable ambulatory and remote health monitoring systems to achieve user requirements of a wearable monitoring system which are washable, wearable, portable and mobile [5]. As a result, users can monitor their own health status in normal daily activities to enhance their quality of life [6].

There are several projects developing smart textiles and clothes in health ambulatory monitoring. Lifeshirt system by Vivometrics Inc. is a continuous ambulatory monitoring system using textile sensors sewn under a garment. It can provide information in real time and continuously record and analyze cardiopulmonary information and can also measure, for example, blood pressure, blood oxygen saturation and temperature with added peripheral devices [**7**]. Another similar product is SmartLife HealthVest® [8] which is a totally textile based sensor monitoring ECG, heart rate, respiratory rate, temperature and so on. It can monitor, record, and transfer data in real time using Bluetooth to a remote computer or PDA [8]. HealthGear [9] is a real-time wearable system for monitoring and analyzing physiological signals developed by Microsoft Research Corporation. It contains physiological sensors wirelessly connected via Bluetooth to a mobile phone which can record, send, display and analyze the data [9]. Wealthy or Wearable Health Monitoring system [10] is a research project which develop smart textile for personal health monitoring. Its prototype has sensors for temperature and heart monitoring. A small portable electronic device transfers data in real-time over a GPRS link to the remote medical center which would analyze and monitor the received data [10].

“*Disappearing sensor-Textile Based Sensor for Monitoring Breathing*” [11] is one of the projects in smart textile developed by the Swedish School of Textiles (THS), at the University of Borås, Sweden. The project has designed and developed a shirt using the benefits of new textile technology which is the electrically conductive textile structure or functional coating hidden in a normal shirt to sense respiration associated with the movement of the thorax and abdomen. It was adapted from traditional respiration monitoring technique such as strain gauge, or plethysmograph, but employ coated textile sensors integrated in a shirt to enable personal respiratory monitoring in daily life [11].

1.1 The THS laboratory prototype

This section describes the THS laboratory prototype to provide background for the current thesis. An overview of the THS laboratory prototype is shown in figure 1.The prototype consists of a smart shirt based textile breathing sensors, a data acquisition device (DAQ), and a laptop.

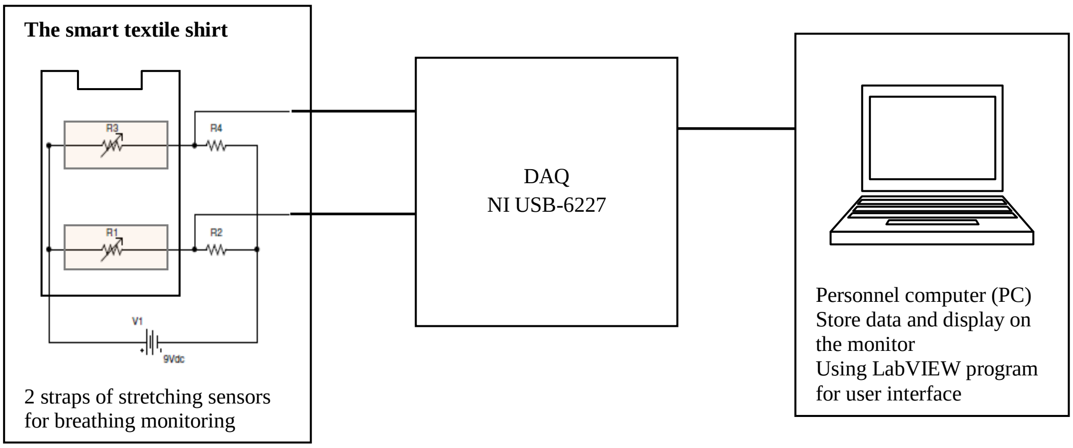


***Figure 1*. An overview of the breathing monitoring laboratory prototype developed in the THS. The THS laboratory prototype consists of a smart textile shirt, a DAQ device by National Instruments and a laptop using LabVIEW for the user interface.**

In the THS’s project [11], they have developed a smart textile shirt sensing changes in the thoracic circumference corresponding with respiration. A prototype garment consisted of two coated elastic conductive textile straps and conductive threads as illustrated in figure 2. The two coated elastic conductive textile straps are textile sensors that show a change in resistance associated with movement of the thorax and abdomen during respiration. Li Guo, *et al.* described [11] that two sensor straps on the prototype garment were made by conductive coating which consisted of a conductive silicone and the textile substrate, PA/Lycra woven fabric which has good elasticity and recoverability. Furthermore, conductive threads act as electrical conductive wires integrated on the smart textile shirt.

Figure 2. **The prototype garment developed by the THS. It consists of two textile sensors coated with the garment at the chest and the abdomen, and it has conductive threads acted as electrical conductive wires** [**11**].

The functionality of this smart textile shirt can be described that the coated straps function as strain gauges which are sensitive to the change in diameters of the thorax and abdomen when breathing. For example, during inhalation, the length of the coated straps are extended, which make the impedance of the straps increasing. Each coated strap is connected with a fix resistor which its value equals to the initial impedance of the strap, and connected to a 9 volt battery and acts as a voltage divider circuit to transfer changes in resistance to changes in voltage to enable measurement in electrical signals. The schematic circuit of the smart textile shirt with voltage divider circuits is shown in figure 3. Each coated strap is shown as a variable resistor symbol. The textile straps are deformed when the chest and the abdomen are moved associated with respiration, which make the strap resistance changes. As a result, the output voltage of the resistor circuit is changed.

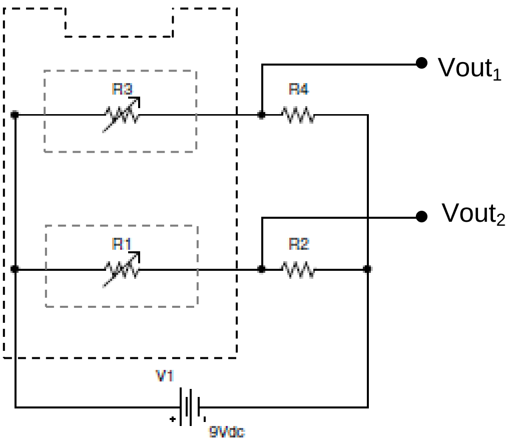


Figure 3. **A schematic circuit of the smart shirt and voltage divider circuit. Each textile sensor act as a variable resistor connected to a fix resistor to build a voltage divider circuit.**

In addition, conductive threads are used to conduct electrical signals on the shirt connected to the strap sensors. The 9 volt battery is the power source for the breathing shirt circuit. Since this prototype is used in a laboratory setting, crocodile clips with electrical wires are used to connect the battery to the smart textile shirt. Moreover, crocodile clips with electrical wires are used to connect and transfer output electrical signals from the shirt to the DAQ (NI USB-6277) from National Instruments (NI).The

DAQ device collects the output voltage signals from the voltage divider circuit, converts analog signals to digital signals so that the signals can be stored and processed in the laptop. The DAQ transfers data to the laptop via an USB connection. LabVIEW has been used to develop a graphical user interface to control the DAQ, display the acquired signals in graphical waveform charts, and record the signals on the hard disk for future analysis.

1.2 The purpose of the thesis

The purpose of this thesis is to design of a stress monitor based on breathing signals using a smart textile shirt. The designed system would be a further development of the existing THS laboratory prototype to be a wearable monitoring system, in order to enable monitoring of personal stress in normal daily activity.

2. Methods

This thesis is based on a literature review for the principle of smart textiles for medical and healthcare systems, user requirements in wearable systems, and recent smart textile application in healthcare to clarify the design concept of the monitor system using the smart textile shirt and possible solutions for development. The journals and articles were searched through digital libraries and the internet. Moreover, medical instrumentation books provide essential principles regarding medical instrumentation systems as well as methods and techniques for measurement of the respiratory system.

The information about the smart textile shirt and the laboratory prototype for respiratory monitoring developed by THS were provided by Li Guo. She is a PhD student in the Swedish School of Textiles (THS) who has been working with the smart textile shirt and the THS laboratory prototype for breathing monitoring. Analysis of the THS laboratory prototype was made by interviewing Li Guo and by observations in the THS laboratory. The THS laboratory prototype was analyzed to devise improvements to design a wearable stress monitoring system.

In this thesis, for demonstration of some key aspects, a stress monitoring system was implemented. Research studies were made to find possible solutions using current available technology in the implemented system.

Finally, the implemented stress monitoring system was evaluated to verify the functionality of the implemented system. Methods for the evaluation are as follows.

1. Using generated sinusoid signals to test the implemented software.
2. Using a machine test to simulate breathing.
3. When applied to a real person, monitoring real breathing signals

Each method for the evaluation is described in more detail.

2.1 Method in the implemented software testing

In the implemented software, LabVIEW graphical programming was used to create a graphical user interface (GUI) for controlling and monitoring of the implemented system. The Arduino Bluetooth (BT) is the main microcontroller platform used in the implemented system. To verify the function of the Arduino BT board with the implemented LabVIEW interface, a test was set up. The aim of this test is to prove that the Arduino BT board could obtain analog signals, and transmit them to the laptop wirelessly. Then, the measured signals could be displayed on the monitor, and recorded in a measurement file (.lvm). In addition, the breathing rate should be displayed in real-time correctly after a smoothing filter was applied. A sinusoidal test signal with a known amplitude and frequency was used to be the analog input signal to the Arduino BT. The sinusoidal signal was chosen because it is a simple analog signal and can function as a model of a respiratory signal. The sinusoidal signal was generated by a function generator (GFG-8216A, GW inSTEK®) and was connected to two analog input pins of the Arduino BT board. The amplitude of the generated sinusoidal signal was set to a similar value as the real amplitude of the output signal from actual measurements. Due to the limitation of the function generator and the Arduino board, the amplitude of the sinusoidal signal generated by the function generator was set to 0.2V with off-set because actual signals provided by the smart textile shirt is small in the amplitude [11] and the Arduino can receive signals only above zero [12]. Since the typical normal breathing rate is about 12 breaths/min in a healthy adult [13], the frequency of the generated sinusoidal signals was set to 200 mHz (12 cycles/min).

2.2 Methods in machine simulation testing

Machine simulation testing is to use a cyclic tester connected with a coated strap of the same type used in the smart textile shirt in order to apply a cyclic force to the textile sensor and make it repeat deformations to simulate breathing signals [11]. The machine can be set to different speed and elongation to simulate different types of respiratory signals applied to the system for measurement.

The cyclic tester was set to generate signals of 20 cycles/minute. It was connected to the implemented system and the THS laboratory prototype. The measured data were displayed on the laptop and recorded in the local hard disk of the laptop. The SPSS program was used to present the results from both the implemented system and the THS laboratory prototype in a graphical form.

2.3 Methods in actual breathing signal testing

Actual breathing signals testing is that real breathing was tested with the implemented system to verify the function of the implemented system with actual respiratory movements. The implemented prototype system and test setup is shown in figure 4.

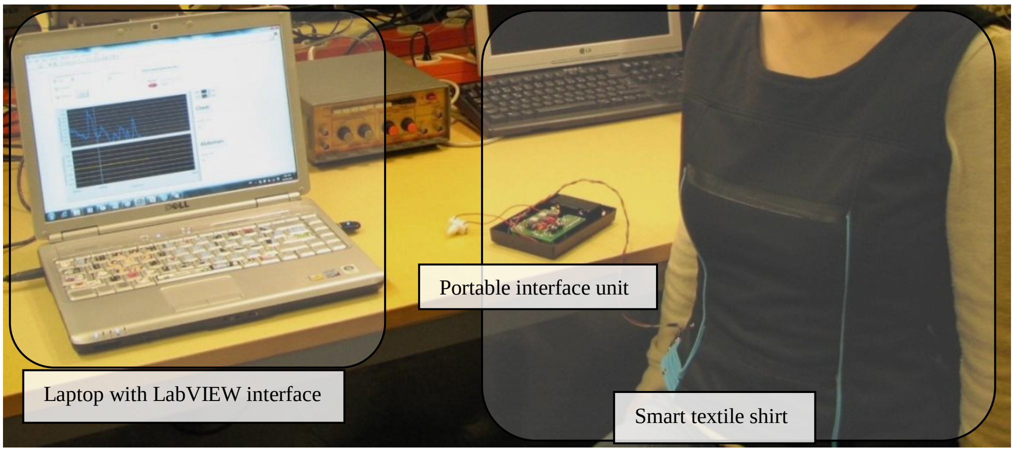


***Figure 4*. The test setup for the evaluation of the implemented system.**

It has to be mentioned that this preliminary examination was under testing conditions to receive verifiable results. A test subject was a certain person in a certain position. The smart textile shirt was worn by the test subject who sat steadily on a chair to minimize movement artifacts and in front of a desk. The portable interface unit was connected with the smart shirt and placed on the desk. The position of the tested subject with the portable interface unit was not far from the laptop which was placed on the desk also. In an initial test, the respiration was controlled. The test subject breathed normally and slowly which made the chest and the abdomen move synchronously. The respiration should not be shallow or too deep, so the portable interface unit can receive respiratory related signals of good quality from both positions (the chest and the abdomen).

Calibration was needed to control the level of the acquired signals. The calibration was done by adjusting trimming potentiometers in the offset-nulling circuitry of the Wheatstone bridge circuits and in the amplifier circuit in the portable interface unit. The initial output signals of the bridge was set to be zero or nearly zero to keep the level of the amplified signals within the voltage range of the portable interface unit.

3. Results

3.1 Concept design of the target system

The aim of this thesis is to design a personal stress monitor system based on breathing signals using a smart textile shirt. The target system in this project would be developed from the laboratory prototype in the THS mentioned in the introduction to be a wearable, portable and mobile system for stress monitoring.

Figure 5 shows the concept design of the target monitor system in this project. The concept design is that using the possibilities of smart textiles combined with currently available technologies to build a portable unit to acquire data and to interface between the smart textile shirt and a mobile control and monitor unit using a wireless technology.

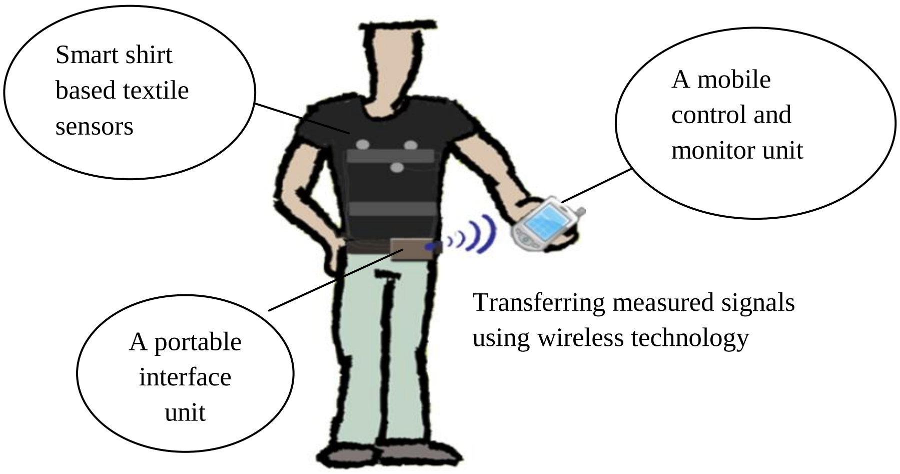


***Figure 5*. The concept design of the target monitoring system using smart shirt based textile sensors combined with a portable interface unit for data acquisition and connection between the smart textile shirt and a mobile control and monitor unit using wireless technology.**

The concept of the target system is that the system would consist of three parts: a smart textile shirt, a portable unit and a mobile control and monitoring unit. The principle of functional analysis of each part could be described as follows.

1. The smart textile shirt would consist of textile sensors which can measure respiratory related movements of the chest and the abdomen.
2. The portable interface unit should be a small, portable electronic unit used for acquisition and pre-processing of the measured signals. Moreover, it should transmit the signals to the mobile control and monitor unit wirelessly. It should be easy to carry by users such as holding on to a belt or putting it in a pocket.
3. The mobile control and monitor unit should be a small, mobile device which could receive signals from the portable interface unit wirelessly and then could process and analyze the obtained signals. Additionally, the control and monitor unit should have data storage to store the acquired signals for further analysis.

3.2 Analysis of the THS laboratory prototype

The THS laboratory prototype described in the introduction demonstrates that it is feasible to fabricate a shirt coated with conductive textile and combined with conductive threads which can be used as a smart shirt for respiratory monitoring. The THS garment integrated with textile sensors can be washable, wearable and comfortable as a normal shirt [11].

However, from the analysis of the THS laboratory prototype, there are some limitations which are;

1. The main issue is the data acquisition device (DAQ) used in the system. It is a stationary device which is big, heavy and difficult to carry.
2. Since the THS system has been set as a laboratory setting, many wires are used to link the system together. The wires connect the textile sensors with the voltage divider circuits, the circuit with the DAQ and the DAQ with the

computer which limit user’s activities. The DAQ unit is connected to the laptop by wires, so it is inconvenient for movements.

3. Moreover, crocodile clips are used to connect between the textile sensors and the electronic part. The crocodile clips are easy to use in a laboratory setting, but they are unsuitable to be used in practice. The clips are big, and they are not tight and flexible. They could easily lead to disconnections during movement.
4. In this system, A 9 Volt battery supplies power for the sensor circuits, while the DAQ unit is powered by an AC power line because of the stationary device. Therefore, the THS prototype is incompact and unportable.
5. Furthermore, the control and monitor unit is a laptop which is big and heavy. It is difficult to carry.

To improve the THS laboratory prototype to be as the target stress monitoring system as shown in figure 5, there are some requirements for improvements as follows.

1. The data acquisition device(DAQ) would be more compact and portable, which could be carried on a belt or put in the pocket of the shirt. However, it still can function as the DAQ device used in the THS laboratory prototype which is able to receive signals from sensors, convert analog signals to digital signals, and transmit signals wirelessly to a control and monitoring unit.
2. A control and monitor unit which is a laptop in the THS laboratory system should be changed to another mobile device, which is easy to carry and lightweight. However, the new mobile control and monitor unit should have the same functionality. It should monitor, present and analyze measured signals. Moreover, it could have large enough capacity of memory to keep data and support software for user interface. In addition, it should communicate with other devices using wireless technology.
3. To be a more mobile system, the connection between a new portable DAQ unit and a new mobile control and monitor unit would be changed from wire connection to wireless connection.
4. There would be only one power supply, which could provide power to the smart textile shirt circuit and also to a new portable DAQ unit. The power supply would be small and lightweight for mobile system, and it could supply power for continuous operation of both circuits (textile sensors and portable DAQ circuits) for at least 24 hours.
5. New connectors connecting between the smart textile shirt and the new portable DAQ unit are needed instead of crocodile clips. The connectors should be strong enough to frequent connection cycles, and allow being easily detached. Additionally, a part of the connector attached on the smart shirt should be washable.

3.3 Suggested solutions

To achieve the target system shown in figure 5 and the requirements described in the previous section, some solutions were suggested. It has to be mentioned that this thesis did not focus on development of the smart textile shirt because it has been developed in the THS. Therefore, development of the DAQ unit and the control and monitor unit were considered. Some possible solutions are proposed as follows.

3.3.1 A portable interface unit

A new portable interface unit should be designed to replace the DAQ device.
The portable interface unit will consist of hardware with essential circuitry to acquire signals from the smart textile shirt and to interface between the smart textile shirt and the mobile control and monitor unit. According to research studies [14], [15], [16], to meet the requirements, the portable interface unit should basically contain a signal conditioning circuit, a microcontroller or microprocessor with an analog-to-digital converter (ADC), and a wireless module. The hardware of the proposed portable interface unit is presented as a block diagram shown in figure 6.

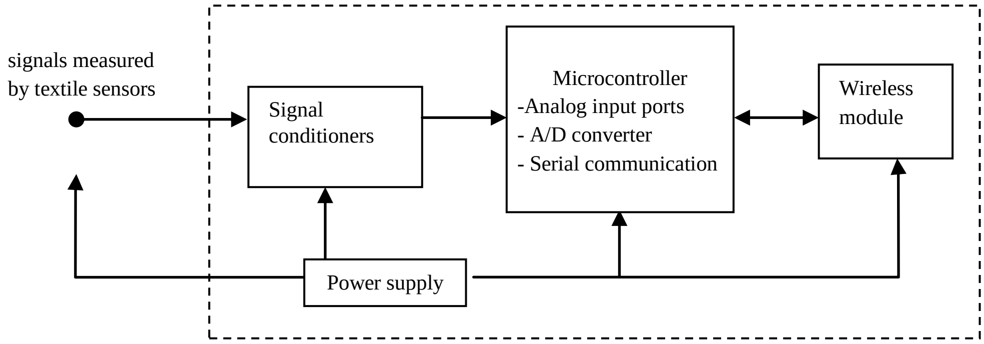


Figure 6. **Block diagrams presenting hardware of the proposed portable interface unit.**

Microcontroller

A microcontroller is the main device of the unit. It should have analog input ports to receive signals from multi- channel sensors and also contain an analog-to-digital converter (ADC). Moreover, the microcontroller should have a serial communication supporting signal transmission to other devices such as a computer and a wireless module.

Signal conditioners

Signal conditioning circuits would be needed to extract changes in resistance of the textile strap sensors to changes in voltages for measurement. It should also include amplifiers to amplify the small output voltage. In the THS prototype laboratory, a simple voltage divider circuit is used to translate changes in resistance into changes in voltage, so the signal can be monitored and analyzed. However, the signal provided by the voltage divider circuit has a very small amplitude. It makes it difficult for signal analysis when used with the new circuit design of the new portable interface unit. There are two methods proposed to convert changes in resistance of the textile strap sensors to changes in voltage. These methods could make the circuit smaller, give less power consumption and improve the signal-to-noise ratio. The suggested methods are described below.

One method is using a constant current source instead of a voltage source to drive the strap sensors on the smart textile shirt, as shown in figure 7, allowing the output voltage signals to be directly measured from the sensors. When the resistance of the straps changes related with movement of the chest and the abdomen during respiration, the output voltage is changed. This method could result in a more compact unit with low power consumption if using a small current to excite the circuit.

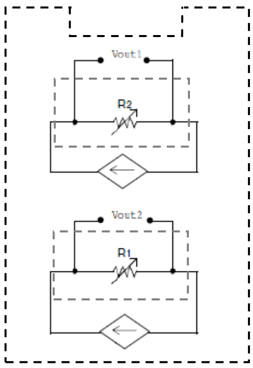


***Figure 7*. The smart shirt with excitation current source.**

Another signal conditioning for impedance respiratory sensor is a Wheatstone bridge circuit which is an ideal circuit to measure small changes in resistance [17]. In general, it almost always is applied with strain gages to measure small changes in resistance [18]. The conductive straps integrated in the shirt function as strain gauges, so the Wheatstone bridge with an excited dc voltage could be applied for converting change in resistance of the textile sensors to voltage signals. The general Wheatstone bridge circuit, shown in figure 8, consists of four resistive arms excited with dc voltage.

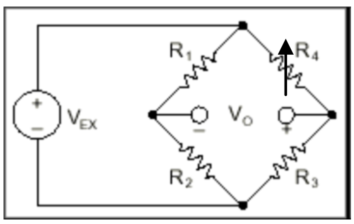


***Figure 8*.The general Wheatstone bridge circuit with an excitation dc voltage [18].**

Resistor R_4 functions as a resistive-type sensor. The output voltage V_o is the differential voltage between two voltage divider circuits, it can be calculated from equation 1 [18].

$$V_o = \left[\frac{R_3}{R_3 + R_4} - \frac{R_2}{R_1 + R_2} \right] \times V_{EX} \qquad (1)$$

When R_1/R_2 is equal R_3/R_4, V_o is zero and the bridge is called to be balanced. Changes in resistance of R_4 make the bridge unbalanced, which can be detected by measuring a nonzero output voltage. Since the output of the resistive sensors and bridges is relatively small, differential amplifiers are needed to boost signal level to be compatible with a microcontroller, improve signal-to-noise ratio and increase measurement resolution [18].

Wireless module

According to the requirements, wireless technology should be used to transfer data between the portable interface unit and the control and monitor unit instead of a wire connection. In this thesis, the monitoring system would be designed as a wireless personal area network (WPAN) which has a range of interconnection of information technology devices of typically 10 meters [19]. Currently, possible wireless sensor network technologies for low-power device are Zigbee, Bluetooth, and ANT [20]. Timo *et al.* [20] identified key properties of these wireless technologies to be considered for technology selection. The key properties are power consumption, the amount of software required, data rate and a range of connections. They pointed out that Bluetooth consumes more energy than the others, but it has a high data rate, which allows relatively low duty cycles, so the average energy consumption can be decreased. Nevertheless, Bluetooth requires a large quantity of program memory for a software stack [20]. However, there are a number of commercial Bluetooth modules which are easy to utilize with a microcontroller and many applications and devices support Bluetooth connections.

Power supply

Another device to be considered is the power supply for the portable interface unit and the smart shirt circuit. Since the interface unit would be a portable unit, power source should be small, lightweight and portable. A battery is chosen to provide energy for the interface unit and the textile sensor circuit. It is small and light weight to make the interface unit more compact and decrease the size and weight of the unit.
It should provide power for continuous monitoring for at least 24 hours. In addition, the battery should be rechargeable and has a long battery life.

All together, suggested solutions presented in this section would create the new portable interface unit to improve the THS laboratory prototype and meet the requirements of the target monitoring system.

3.3.2 A control and monitor unit

A handheld device should be used for a control and monitor unit which is easy to carry, for example, a Tablet PC, Smartphone or PDA. There are many various commercial handheld and portable devices available on the market today which can be used. They are now small and portable, and they have a display for monitoring. Moreover, they support wireless communication and have large data storage. There are several studies using handheld devices for healthcare monitoring, for example, using Smartphone for heart rate monitoring [21], a tablet PC for monitoring and processing vital signals of pregnant women [22], and a mobile phone for monitoring and analyzing physiological signals [9].

The previous description suggests some development of the THS laboratory prototype to be the envisioned wearable stress monitoring system. All together, an overview of the proposed system architecture is illustrated in figure 9.

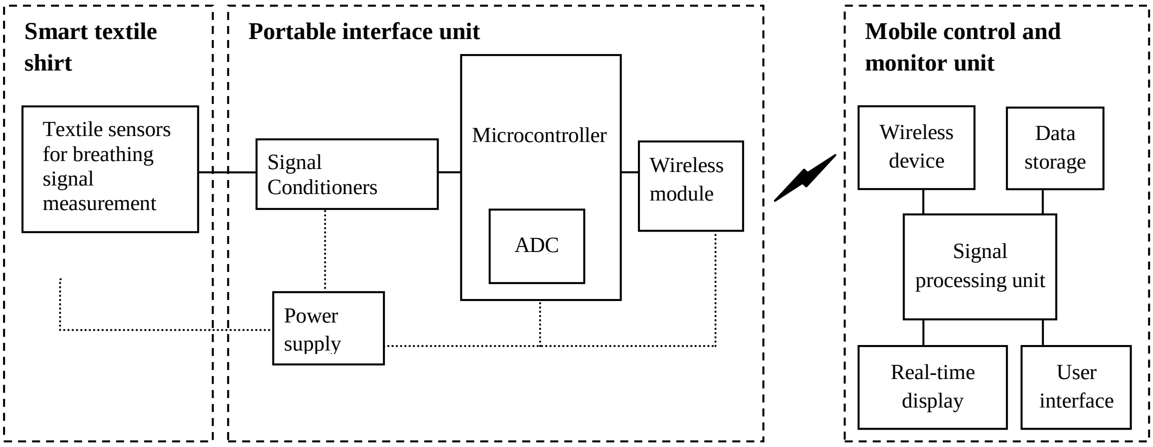


***Figure 9*. An overview of the designed system.**

3.4 Implementation

According to suggested solutions, a prototype of a portable interface unit was implemented for demonstration. A laptop was still used to be a control and monitor unit but new software was implemented relating to the new portable interface unit. However, during this study project, thanks to the THS, the smart textile shirt also had been developed to improve the smart garment to be more attractive, comfortable, and easy to use. Therefore, the implemented system is described in terms of an overview of the system first, and then each part of the system is explained in detail.

3.4.1 An overview of the system implementation

The stress monitoring system based on respiratory signals using the smart textile shirt was implemented. The overview of the implemented system is presented in figure 10. It consists of the smart shirt integrated with textile breathing sensors, the prototype portable interface unit and the laptop with a user interface using a LabVIEW program. The implemented system demonstrates that the smart textile shirt can sense respiratory related movements at the chest and the abdomen. Next, the portable interface unit acquires signals provided by the smart textile shirt for data acquisition and then transmits acquired signals via Bluetooth to the laptop where the acquired signals can be displayed in real-time and recorded on the hard disk for further off-line analysis.

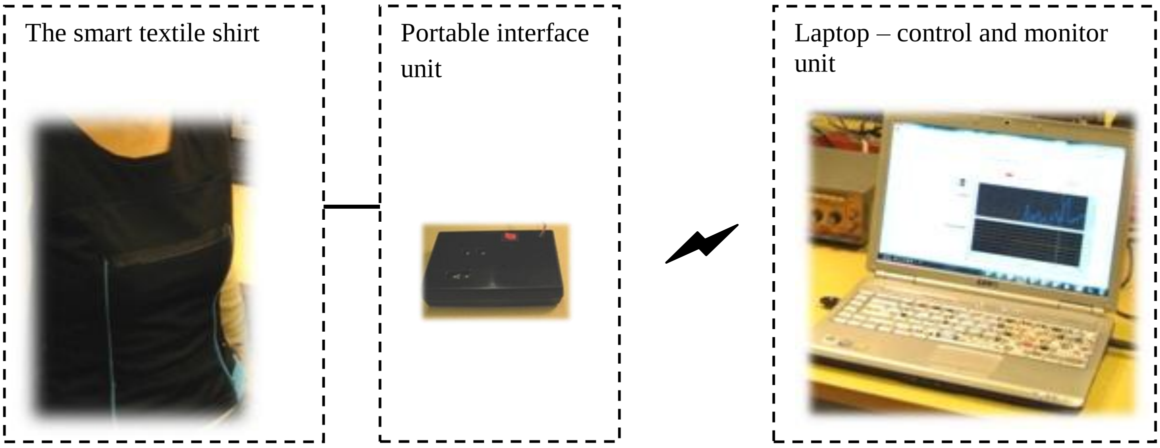


***Figure 10*. An overview of the implemented system in this project. The system consists of the smart textile shirt, the prototype portable interface unit, the laptop with a user interface for control and monitor using LabVIEW.**

Each part of the implemented system is described in more detail.

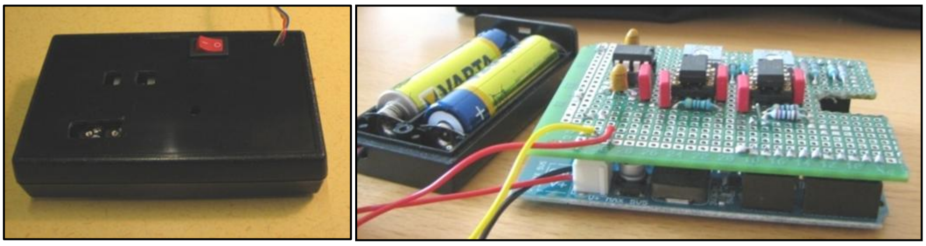
3.4.2 The smart textile shirt

During this thesis work, the smart textile shirt had been further developed by the THS focusing on improved appeal, comfort and ease of use. Two-piece gripper snaps are used to act as connectors to link textile circuit on the smart shirt with a portable interface unit. One side of the snap is attached to the smart shirt, and another side is attached to the electrical device. The snap can be attached and removed easily, and it can be washed [23]. The developed smart textile shirt is shown in figure 11.

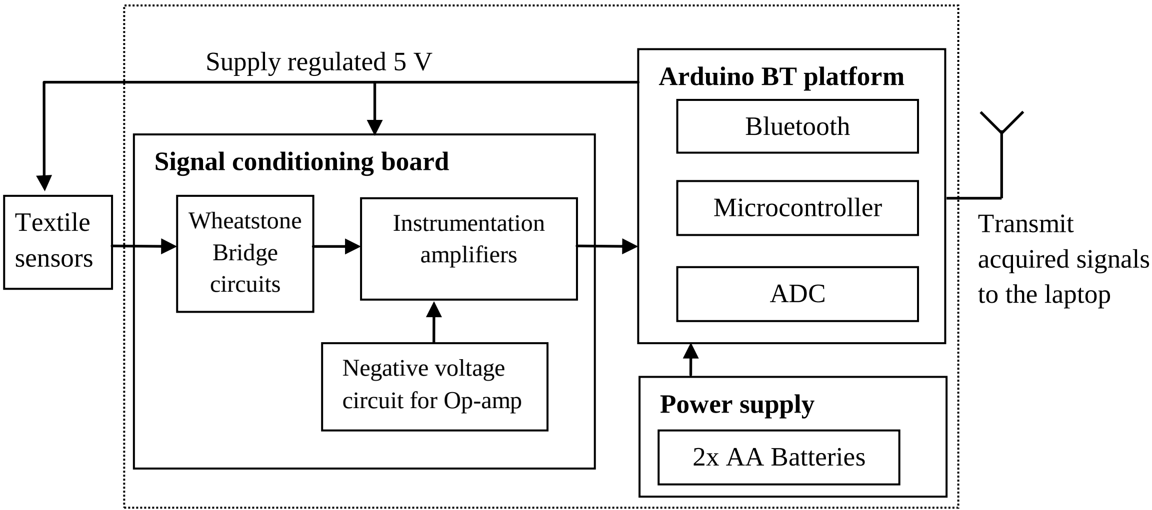
***Figure 11*. The smart shirt contains of two textile sensors placed at the chest and the abdomen for respiratory measurement, conductive thread and snap buttons developed by the THS.**

3.4.3 The portable interface unit

A prototype of the portable interface unit was built. It is an electrical unit to interface the smart textile shirt with the laptop. The interface unit consists of an Arduino Bluetooth (BT) board, a signal conditioning board, and a power supply. Figure 12 shows the prototype of the portable interface unit and its hardware as a block diagram.



(a) **(b)**



(c)

***Figure 12*. The prototype of a new portable interface unit implemented in this project.**
a) The portable interface unit. b) The portable interface unit before assembled in the box.
c) Hardware of the portable interface unit presented as block diagrams.

The Arduino BT platform is the main microcontroller board of the prototype interface unit. The signal conditioning board consists of the Wheatstone bridge circuits, integrated amplifier circuits and also negative voltage circuits for the amplifier IC. The signal conditioning board is plugged on top of the Arduino BT board to make the interface unit more compact. Two AA rechargeable batteries are used to provide power supply 2.4 V to the Arduino BT and the voltage convertor on the Arduino BT convert 2.4 to 5 V used to supply the circuits on the signal conditioning board and the smart textile shirt. Each part of the implemented interface unit is described in more detail.

Arduino Bluetooth (BT)

Arduino is "*an open-source physical computing platform based on a simple microcontroller board and a development environment for writing software for the board"* as presented on the website [24]. The Arduino Bluetooth (BT) was selected to be the main board of the prototype interface unit because it is a small platform containing a low power microcontroller (ATmega168) with low power supply voltage; 1.2-5.5V. It has 6 analog inputs which can receive analog signals, an analog-to-digital converter (ADC) and a Bluetooth module (BlueGiga-WT11) to allow wireless communication with other devices [12]. The microcontroller on the Arduino board can be programmed by the Arduino programming language and the Arduino development environment (IDE) which can be downloaded from the Arduino website [24]. The Arduino BT hardware platform is already set up and ready to work with the microcontroller and the serial communication over Bluetooth. In addition, there are many supporting tools provided such as tutorials, source code, and examples, which allow an easy and fast prototyping.

The Arduino BT, shown in figure 13 [12], is the main board of the prototype of the portable interface unit which should receive signals provided by the textile sensors via analog input pins of the microcontroller, then converts analog signals to digital signals and sends acquired signals to a computer using Bluetooth.

***Figure 13*.The Arduino Bluetooth (BT) board [12].**

Signal conditioning board

The signal conditioning board consists of Wheatstone bridge circuits, instrumentation amplifiers and negative voltage supply circuits for the amplifier ICs.

In general, a Wheatstone bridge circuit is applied with strain gauges to measure small changes in resistance and convert to small changes in voltage signals [18]. Since the textile strap sensors on the shirt acted as strain gages, thus the Wheatstone bridge circuit was used in the prototype. Figure 14 shows two Wheatstone bridge circuits used in the implemented interface unit.

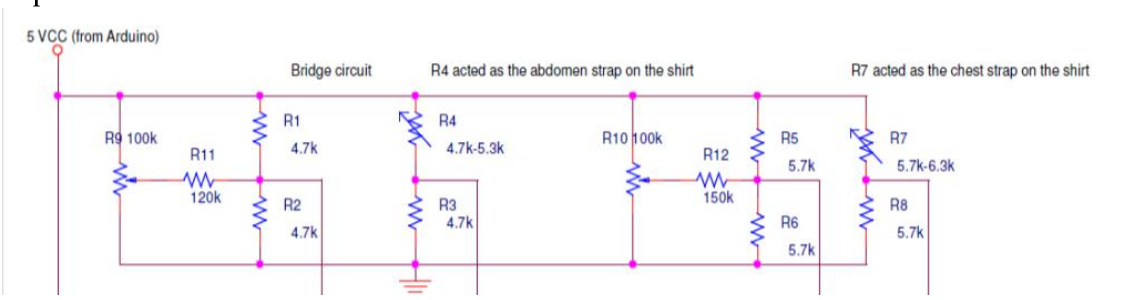


***Figure 14*.Two Wheatstone bridge circuits.**

A quarter-Wheatstone bridge circuit is used with each strap sensor. The resistance of the strap at abdomen, *R4*, is around 4.7 kΩ and the resistance of the strap at the chest, *R7*, is around 5.7 kΩ. Other arm resistors of each bridge were chosen following the strap resistance to make the bridges balanced, thus when there is no change in the length of the strap sensors, the output voltage of the bridges is zero. When breathing, the resistance of each strap is changed, which make the bridge unbalanced, as the result, the output voltage is nonzero. Moreover, resistors *R11, R12* and variable resistors *R9, R10* were added for initial resistance adjustment which enables the balance of the bridge to be adjusted.

Amplifiers are needed because the amplitude of the output voltage signals from the bridge circuit is very small. It would be less than 10mV/V (10 mV of output per volt of excitation voltage) [18]. The excitation voltage in our bridge circuit is 5 Volts, thus, the output signal would be 50mV. Amplifiers would amplify the level of the output signals to be seen more clearly and be measured. INA218, a small low power instrumentation amplifier integrated circuit (IC), was chosen to amplify the differential voltage signals from the bridge circuit because it is small and has high input impedance, high common mode rejection (CMRR), low power consumption, and an adjustable gain by means of a single external resistor. The gain of the amplifier is set by an external resistor (R_G). According to the INA218 datasheet [25], R_G can be calculated from equation 2.

$$Gain = 1 + \frac{50k\Omega}{R_G} \qquad (2)$$

where the 50 $k\Omega$ is the sum of the two internal feedback resistors of the two first op-amps of the instrumentation amplifier INA128 [25].

In the prototype, a variable resistor of 5 kΩ is used to be a gain setting resistor (R_G) (which is R_{13} and R_{14} shown in the schematic circuit, appendix A), so the gain can be adjusted for each bridge circuit between 11 to 10000 (V/V) . However, the amplitude of the output voltage signal is limited by the value of supply voltage of the amplifiers which is 5 V. Therefore, the gain of the amplifiers was moderately adjusted.

Additionally, on the signal conditioning board, there is a chip, MAX1044, used for supply negative voltage to INA128 amplifiers. It converts positive 5 V (+5 V) to negative 5V (- 5 V).

All in all, the whole schematic circuit of the signal conditioning board is presented in appendix A.

Power supply

In the implemented system, the smart textile shirt and the prototype interface unit are powered by two AA rechargeable batteries. The two AA batteries can supply voltage 2.4 V to the Arduino board, and then the voltage converter circuitry on the Arduino provides 5 V to excite the circuits on the signal conditioning board and the smart textile shirt.

To consider energy consumption of the implemented interface unit, the current consumption of active components chosen for the prototype interface unit was calculated. Total current consumption from the calculation is 62 mA in stand-by mode, and 177 mA when in active mode (transferring data between the microcontroller board and laptop via wireless) approximately. The Bluetooth module is the highest power consuming component in the circuits. Table 1 shows the main active components chosen for the interface unit and their current consumption specification. Moreover, current consumption was measured directly from the circuit also. The current consumption from measurement was 60 mA in stand-by mode and 170 mA when in active mode.

***Table 1*.The main active components chosen for the interface unit and their current consumption specification**

Components	Description	Current consumption Stand-by mode (mA)	Current consumption Active mode (mA)	Note
Arduino BT board				
ATmega168	Microcontroller	0.001	0.25	
BlueGiga WT11	Bluetooth Module	54.6	170	Active mode =transmitting data
MAX1676	Step-Up DC-DC Converters	0.16		
MC33269D	Voltage regulator	5.5		
Signal conditioning board				
INA128	Instrumentation amplifiers	1.4		(0.7 mA x 2)
MAX1044	switch-capacitor voltage converters	0.03		
Total current consumption from calculation		**61.7**	**177.34**	

According to the requirements for the design system, the capacity of the battery should be 4256 mAh approximately, so the portable interface unit can operate continuously for 24 hours. However, due to the limitation in size and weight of the portable interface unit in the implementation, two AA rechargeable batteries with a capacity of 2100 mAh was used for the prototype testing.

3.4.4 The control and monitor unit with software implementation

Due to the limit of time of this thesis work, the laptop was still used to be a control and monitor unit in the implemented system. A Bluetooth USB adapter (Belkin®) is plugged in the laptop to enable wireless communication with the Arduino BT board. LabVIEW graphical programming is used to create a graphical user interface (GUI) operating on the laptop with, in this case, the Windows 7 operating system (OS). In this project, LabVIEW interface for Arduino (LIFA) toolkit is used because it allows users to easily interface the Arduino board using LabVIEW. The LIFA toolkit helps users to easily apply the Arduino board and LabVIEW with their prototype projects in a short period of time. The toolkit can be downloaded from the LabVIEW interface for Arduino community website [26]. The procedures of setting LabVIEW interface for Arduino are described in Appendix C.

Figure 15 illustrates the concept of coding strategy for the software implementation using LabVIEW on the laptop. The basic concept is that the laptop can communicate with the Arduino BT board, receive signals wirelessly, display them in real-time graphical waveforms and compute respiratory rate. Moreover, the acquired signals can be recorded in a hard disk of the laptop.

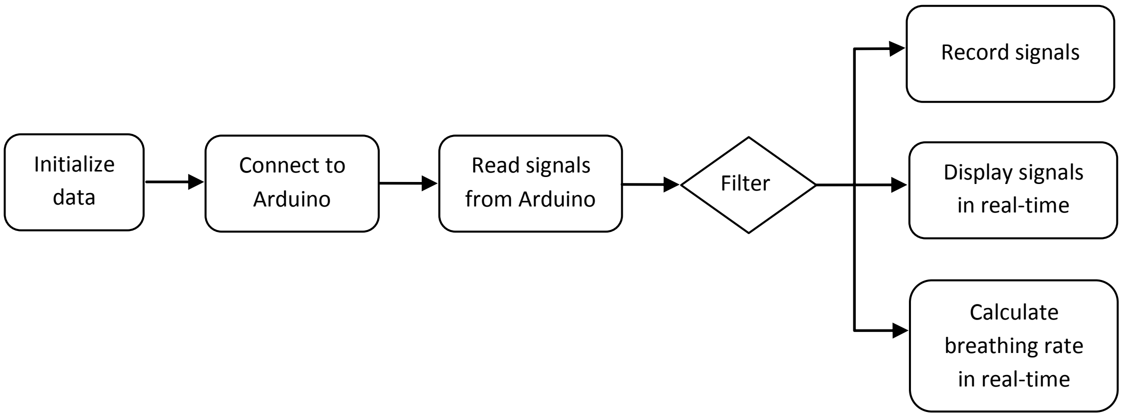


Figure 15. **Coding diagram for the software implementation using LabVIEW.**

The coding diagram was implemented as the LabVIEW block diagram presented in appendix B. The implemented LabVIEW user interface is shown in figure 16. There are two graphical waveform charts to display respiratory signals related movement of the chest and the abdomen as a function of time. The user interface allows the users to choose which serial COM port to connect to the Arduino BT board. The user interface offers the user the option to choose channels of the input signals and the option to smooth measured signals. The user can record signal data to a measurement file (.lvm) and there is a numerical display to show elapsed time of the recording. Moreover, there are also two numerical displays to show the breathing rate. The software can be run by the running button of the LabVIEW window, and it can be stopped by the stop button on the user interface. In addition, there is an initial setting before running the program which is explained in appendix D.

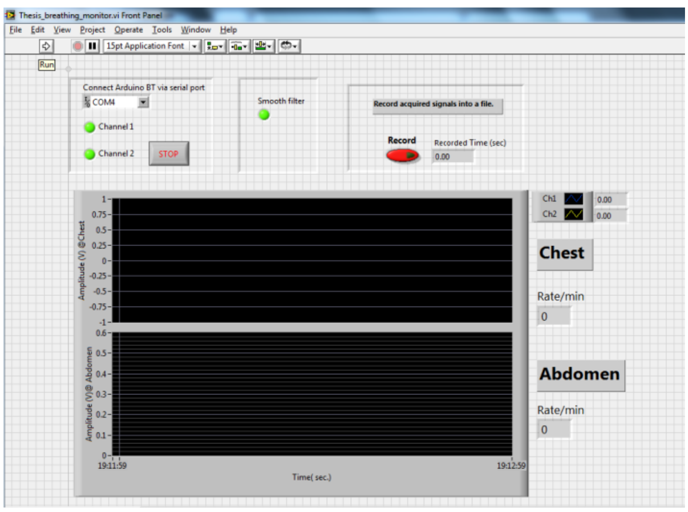


Figure 16. **User interface using LabVIEW.**

In the implemented system, a digital filter provided by LabVIEW was used because it was easy to apply and test for the prototype. A smoothing filter with a half-width rectangular moving average was chosen. Since raw measurement data can be recorded in the local storage, the respiratory signals can be studied and analyzed off-line more in-depth. The smoothing filter can reduce noises and provide smoother signals, which allow visual observation of respiratory pattern and peaks of the signals. After signals are smoothed, the peaks of signals are clear and can then be analyzed with a LabVIEW function called “peak detection function” used for breathing rate calculation.

In the LabVIEW coding diagram, the breathing rate is calculated by the number of samples between the two latest peaks of the received signals and divided by the sample rate in Hz to obtain the time (in second) of a cycle of the breathing signal. Then, it is multiplied by 60 to get the rate as breaths per minute. This can be written in equation 3.

$$\text{Breathing rate (bpm)} = \frac{\text{sample rate}}{(\text{peak - peak interval})} \times 60 \tag{3}$$

In this thesis, the sample rate is 10 Hz in the implemented software.

3.5 Evaluation of the implemented system

Some tests were performed to evaluate the implemented stress monitoring system. The purpose of evaluation is to verify the function of the portable interface unit and the implemented software. The methods of the evaluations were described in the methods section. This section shows the results of the evaluation of the implemented system.

3.5.1 Results of the implemented software testing

This section shows the results of using generated sinusoid signals to test LabVIEW interfacing with the Arduino BT board. In the verification, the sinusoidal signals were measured continuously, so the graphs shown in the results were a snap shot of the test in one minute. The result of the sinusoid signals with frequency 200 mHz displayed on the user interface is shown in figure 17.

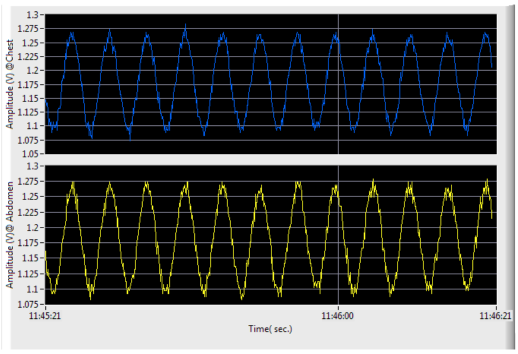


***Figure 17*. The result of sinusoidal signals on the monitor testing LabView interface with the Arduino board. There is no filter applied.**

The result in figure 17 shows that the Arduino BT with the implemented LabVIEW user interface can connect and operate together. The laptop can receive sinusoid signals wirelessly from the Arduino BT and can display acquired sine signals on the monitor. However, it can be seen that the sinusoidal signals were corrupted by noise, so a digital smoothing filter was applied to remove noise and to smooth signals. The result is shown in figure 18.

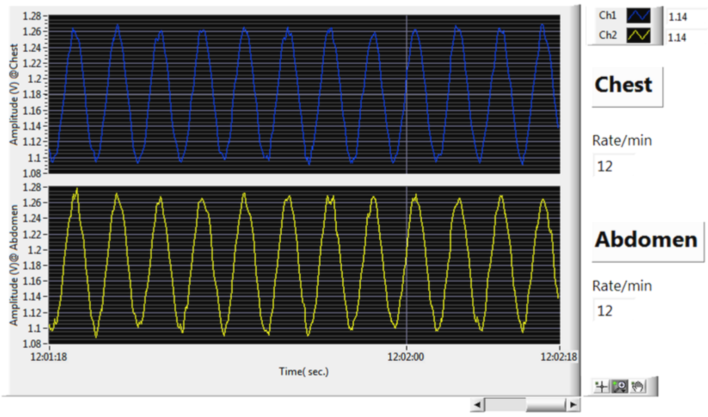


***Figure 18*. The result of sinusoidal signals on the monitor testing LabView interface with the Arduino board. There is the smoothing filter applied and frequency rate of signals was calculated (cycles per minute).**

In figure 18, it can be noticed that after applied digital smoothing filter, the sinusoidal signals are clearer and the peaks of the signals are more significant. Although, the peaks of the sine signals are attenuated by noise and the smoothing filter, the signals can be seen as sinusoidal signals with correct frequency. In figure 18, the signal rate was displayed correctly as 12 cycles per minute.

3.5.2 Results of machine simulation testing

This section shows the results of using the cyclic tester to simulate signals as the breathing signals. Figure 19 shows the result of the simulated signals on the LabVIEW user interface measured by the implemented system.

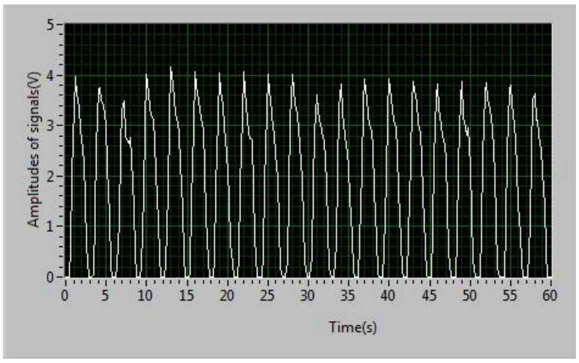


***Figure 19*.The results of the simulated signals measured by the implemented system. The frequency of signals was 20 cycles/min.**

The evaluation result shown in figure 19 presents that the implemented system can measure and monitor signals simulated by the cyclic tester. In figure 19, it can be seen when the textile strap was extended, the amplitude of signal was increased and decreased when it was released and going back to the initial state. The maximum amplitude of the signal was limited by positive voltage supply of amplifier IC which is 5 V but it is shown to be around 4.3 V in the graph.

Comparison with the THS laboratory prototype

The measurement results from the THS laboratory prototype and the implemented system were compared by the SPSS program to present the results in a graphical form. The result is shown in figure 20.

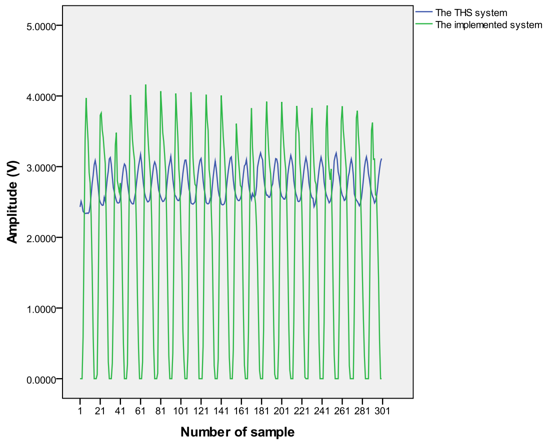


***Figure 20*. The graph presenting the simulated signals measured by both two systems; the THS laboratory prototype (blue) and the implemented system (green).**

Due to the different systems, measured signals provided by both systems are different in amplitude and phase, but the rate cycle of the signals is equivalent. Comparing with the THS laboratory prototype in figure 20, the signals measured by the implemented system is clearly visible which is easy for observation and for analysis.

3.5.3 Result of actual breathing signal testing

This section shows the results of using the smart textile shirt to measure breathing signals. The respiratory signals were measured by the implemented system continuously. The results shown in figure 21 and figure 22 are snapshots of the whole measurement.

Figure 21 shows the result of actual breathing measurement with no filter. Even though, the signals were disturbed by artifacts, the breathing pattern can be noticed. The amplitude of the signals increased during inhalation and, in contrast, the amplitude of the signals decreased during exhalation. Moreover, it can be seen in figure 21 that the signals were affected by noise and motion artifacts, especially the measured signals at the chest. One possible cause is that, in the area of the thorax, the sensor might be effected by motion artifacts from muscle contractions of the thorax and also from the cardiac activity.

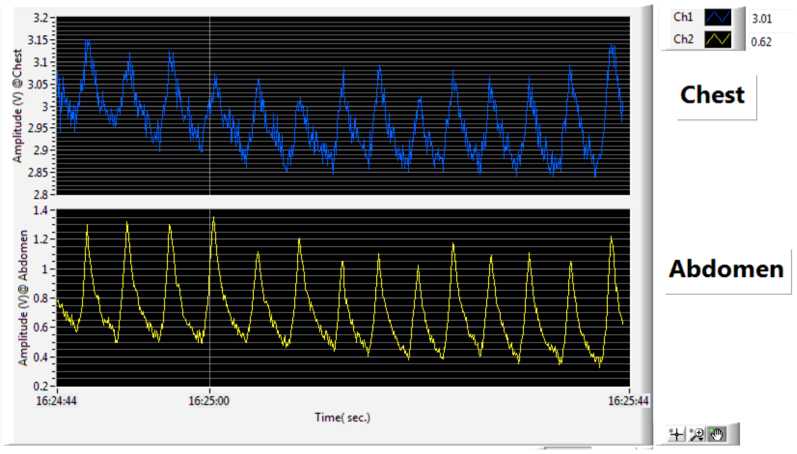


***Figure 21*. The result of measured normal breathing signals using the implemented system. There is no filter applied.**

The respiration was measured again with a smoothing filter applied. Additionally, the breathing rate was calculated by the software and displayed on the monitor in real-time. The result is shown in figure 22. It can be seen that noise was reduced and the upper peak of the breathing signals was more clearly visible which is good for breathing rate calculations using the peak detection function.

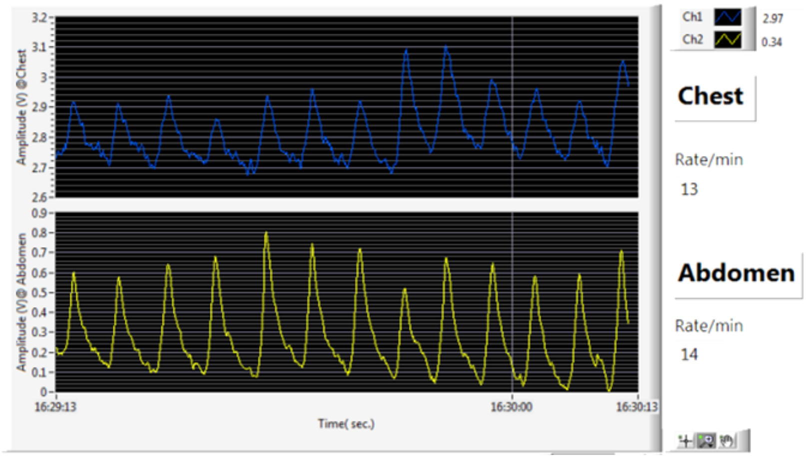


***Figure 22*. The result of measured normal breathing signals using the implemented system. The smoothing filter using LabVIEW was applied to reduce noise. The breathing rate was displayed in real-time.**

During this evaluation, the test subject also counted the amount of breaths in one minute to compare with the result shown on the display. The breathing rate was 13 breaths/minutes counted by the test person. In figure 22, the breathing rate shown on the display is 13 breaths/minute at the chest and 14 breaths/minute at the abdomen.
This discrepancy is caused by the peak-to-peak measurement used for the breathing rate estimation and the effect of rounding the value to the nearest integer which make the estimation less accurate.

4. Discussion

The aim of this thesis was to design a stress monitor based on respiratory signals using the smart textile shirt. The system has been a further development of the THS laboratory prototype to be a personal ambulatory stress monitoring system. Therefore, the design is limited by the user requirements of the wearable monitor systems. The smart textile shirt has been developed by THS and it can measure volume changes of the chest and the abdomen corresponding with respiration. In the design, a small and portable interface unit is connected to the smart textile shirt to acquire signals and to transfer the data to a handheld device wirelessly. The handheld device displays respiratory signals in real-time, records data in the local memory and analyzes the data. All these requirements could be feasible because of recent technology development.

In the improved prototype, a portable interface unit was implemented. It is a small and portable unit which the user can carry around. It is connected with the smart textile shirt which provides voltage power to the circuitry on the smart textile shirt and obtains measured signals from the smart textile shirt. It can also communicate with the remote laptop using Bluetooth, which allows the mobile ability.

Testing the function of the implemented portable interface unit and implemented software with the machine simulation showed that the simulated signals can be obtained by the interface unit and transmitted wirelessly to the remote laptop. On the laptop, the signals can be displayed in real-time and recorded in the local memory.
The result, shown in figure 18, indicates that the implemented software basically functions properly. However, the result demonstrates the limitation of the hardware and show that signals got affected by noise. In addition, there are some problems with the result when testing with low setting speed of the machine which needs more studies to figure out the causes of the problem.

It is a challenge dealing with signals from actual respiration because the textile strap sensors are deformed in any direction along muscle movements at the chest and the abdomen. It was mentioned before that testing with the actual respiration, however, was examined under test conditions. The evaluation was performed by a certain subject with a certain position and a normal breathing technique, so the signals can be readable from both measurement positions (at the chest and the abdomen). In preliminary tests with actual respiration, the result shows the feasibility of respiratory measurement using the smart textile shirt.

It can be seen in figure 21 and 22 that the breathing signals can be observed; although, the measured signals were effected by artifacts. Testing with other characteristics of breathing was performed, but the result was unstable and unreliable and requires further studies in depth. The signals were distorted by motion artifacts and noise and are difficult to analyze.

Moreover, it is more challenging with real-time analysis. In this thesis, I tried to display the breathing rate in real-time. From the evaluation, the derived breathing rate showed correct values when testing with generated signals. When testing during actual respiration, the breathing rate appeared correctly only during controlled and normal breathing. On the other hand, when breathing was uncontrolled, the derived breathing rate showed an inaccurate result.

According to the evaluation, the implemented system still has problems in terms of reliability and accuracy of the hardware and software operation in real-time, which need more experiments and further study for improvement. However, it has been shown that at least the respiratory signals can be measured and stored with the implemented system during normal breathing, so the signals can be analyzed off-line.

4.1 Issues and uncertainties in the implemented system

According to the evaluation of the implemented system, some issues and uncertainties can be summarized as follows.

4.1.1 The need for calibration in the portable interface unit

The portable interface unit always needs to be calibrated in the beginning of measurements because the resistance of textile sensor straps easily varies and depends on the strap positions, body size, posture and dynamic conditions, which leads to an undetermined initial value of the output signals of the Wheatstone bridge circuit. A slight change in resistance of a bridge arm (textile sensor strap) and a lead wire resistance can generate an offset voltage in the initial state of the bridge circuit. This offset voltage can lead the output signals to be saturated if they exceed the dynamic voltage range of the implemented system.

Thus, an offset-nulling circuit using a variable resistor is added in each bridge circuit to adjust the initial voltage of the bridge circuit to be nearly zero or zero and to control the voltage signal level. Also, a variable resistor is used to adjust the gain in each amplifier.

The calibration is accomplished by using a small screwdriver to adjust the variable resistors in the Wheatstone bridge circuits and in the amplifier circuits, so the output signal level is in the range of the measurement for readability. In order to make this calibration easier, an improvement would be to make use of digital variable resistors instead of manual adjustable variable resistors for easy adjustment and accuracy.

4.1.2 Limited dynamic range of the measurement

Due to limited values of the strap resistance variations and the resistance in the offset-nulling circuit, it is still possible for the signals to exceed the dynamic voltage range. Furthermore, the portable interface unit can measure the signals in the range of zero and 5V. It was limited by the power supply voltage of the amplifier IC which is 5 V and also by the limitation of input voltage range of the Arduino BT board, which is zero to 5 V.

4.1.3 Unstable connection between LabVIEW and the Arduino BT board.

In the implemented system, a verification of the Bluetooth connection between the laptop and the interface unit has to be done before any measurement to ensure the connection. As the initial procedure before the measurement mentioned in appendix D, the laptop needs to search the Bluetooth device on the Arduino BT and connect every time before the measurement starts. Then, LabVIEW also is needed to check the connection with the Bluetooth device on the Arduino BT. The serial COM port shown in Measurement & Automation Explorer of National instruments, and in the Arduino BT properties should be the same serial COM port.

Uncertainty in the Bluetooth connection between the LabVIEW program and the Arduino BT happened when I turned on and off the Arduino BT board or the LabVIEW program many times during the experiment. When the connection was lost, an error is shown that the LabVIEW program cannot find the Arduino BT board connection, although the laptop and the Arduino board were connected. Moreover, the connection between LabVIEW and the Arduino BT board will show "Unknown" in the device status in Measurement & Automation Explorer of National instruments. Normally, when the connection between them is right, the status shown is "The device is working properly."

In the LabVIEW troubleshooting, it explains that "the device is missing functionality, and the solution is to restart the computer again to clear the memory". Thus, the solution for this problem is restarting the laptop. One potential cause is that this version of LabVIEW (LabVIEW 2009) has programming errors, so using a new upgraded version of LabVIEW might solve this problem.

4.1.4 Inaccuracy of breathing rate calculation in real-time

The breathing rate can be calculated and displayed in real-time correctly when testing with simulated signals as the result shown in figure 18, but it still has an error when testing with actual respiration, especially during rapid breathing. It can be seen in figure 22 that there is discrepancy of the breathing rate shown on the display. This inaccuracy of the breathing rate can be caused by the effect of rounding the value to the nearest integer in the programming code. Also, one possible cause might be that the method used for breathing rate estimation might be too simple. Due to the peak-to-peak measurement used for breathing rate estimation and that small inaccuracy of the peak detection makes the estimation inaccurate. Using the average of peak-to-peak in one minute might improve the accuracy of the breathing rate estimations.

4.1.5 The implemented system cannot be operated for 24 hours

In the system implementation, it was decided that size and weight of the portable interface unit had higher priority; therefore, the two AA rechargeable batteries with its capacity of 2100 mAh were used, and they can supply power for the implemented system to operate continuously for 11 hours approximately.

However, according to the target design, the system should function continuously at least for 24 hours. An easy solution would be to use more AA batteries in parallel, so the capacity of power source would be increased and adequate for 24-hour system operation. Another solution is using another battery that has a high capacity adequately with consideration in its size and weight. Otherwise, the design of the interface unit needs an improvement to decrease the power consumption.

4.2 Future works

This thesis is considered to be a starting project, so several further improvements may be suggested. Future works could be listed as follows.

1. The portable interface unit needs improvement in dynamic range of measurement and dealing with noises and motion artifacts for measurement of respiration in real situations.
2. Usability in the portable interface unit should be improved. The need for calibration should be addressed.
3. Improvement in the model on how to estimate breathing rate and patterns.
4. The implemented system should be developed in terms of power consumption. It should operate for monitoring at least 24 hours continuously.
5. A Smart Phone or another handheld device should be used as the control and monitor unit. It could enhance real-time monitoring and the mobility of the system.
6. The system could be improved to enable measurement of other physiological signals such as ECG.

5. Conclusions

This thesis presented the design and a first implementation of a stress monitoring system based on respiratory signals measured by a smart textile shirt. This work is based on a laboratory prototype of a smart textile shirt for breathing monitoring developed by THS. The target design was to improve the THS laboratory prototype to become a wearable, portable and mobile system to allow users to monitor their stress during normal activities. The stress monitoring system was implemented as a portable unit which can easily be carried. The portable interface unit made the system more mobile and portable. The implemented system was evaluated in relation to its intended operation. The results demonstrated that the breathing signals can be measured by the smart textile shirt, and that these signals are converted and transmitted to a remote laptop wirelessly by the portable interface unit. The breathing pattern can be presented on the monitor in real-time and can also be recorded in the local storage for further analysis of stress monitoring. However, this study may be considered as a preliminary research. Further improvement in hardware and software of the system are required to improve stability, reliability and accuracy of the measurements, and also to fulfill all requirements of using a smart textile shirt for a personal stress monitor based on respiratory signals.

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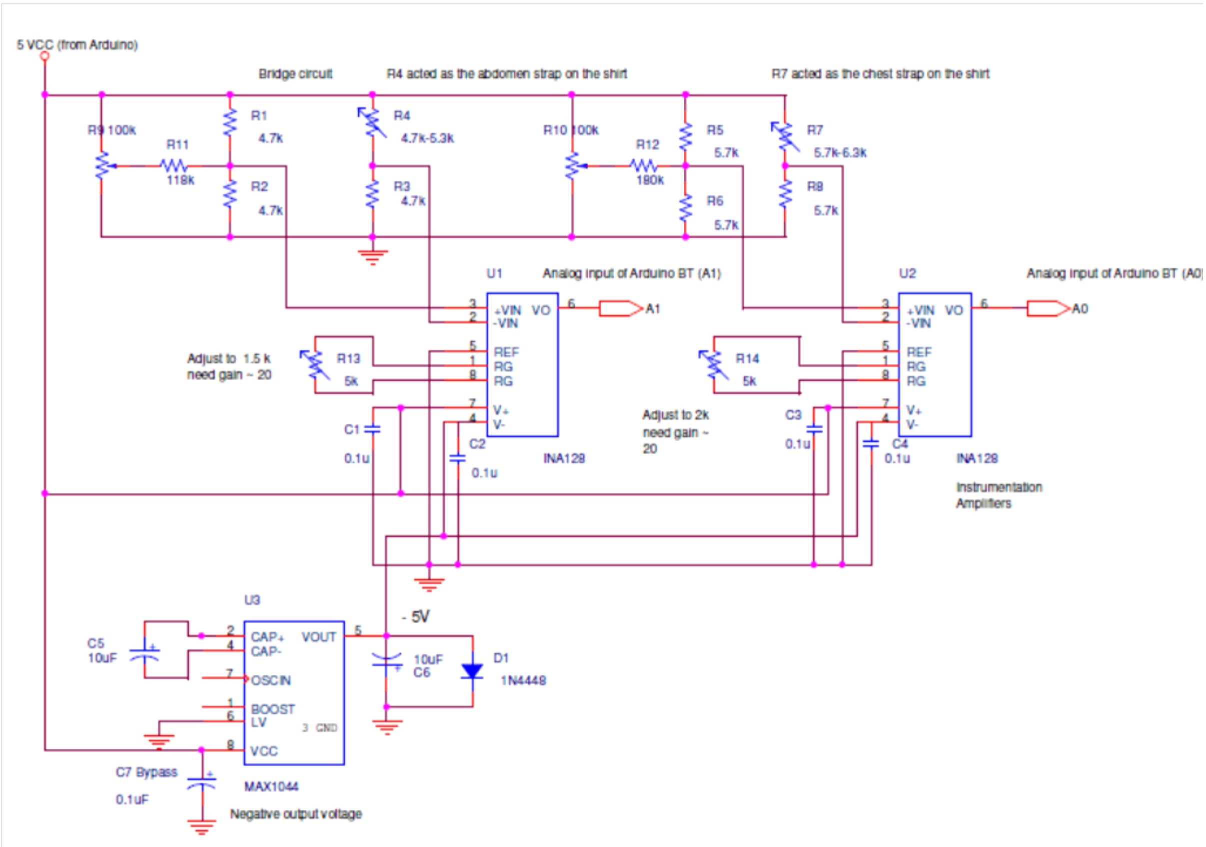
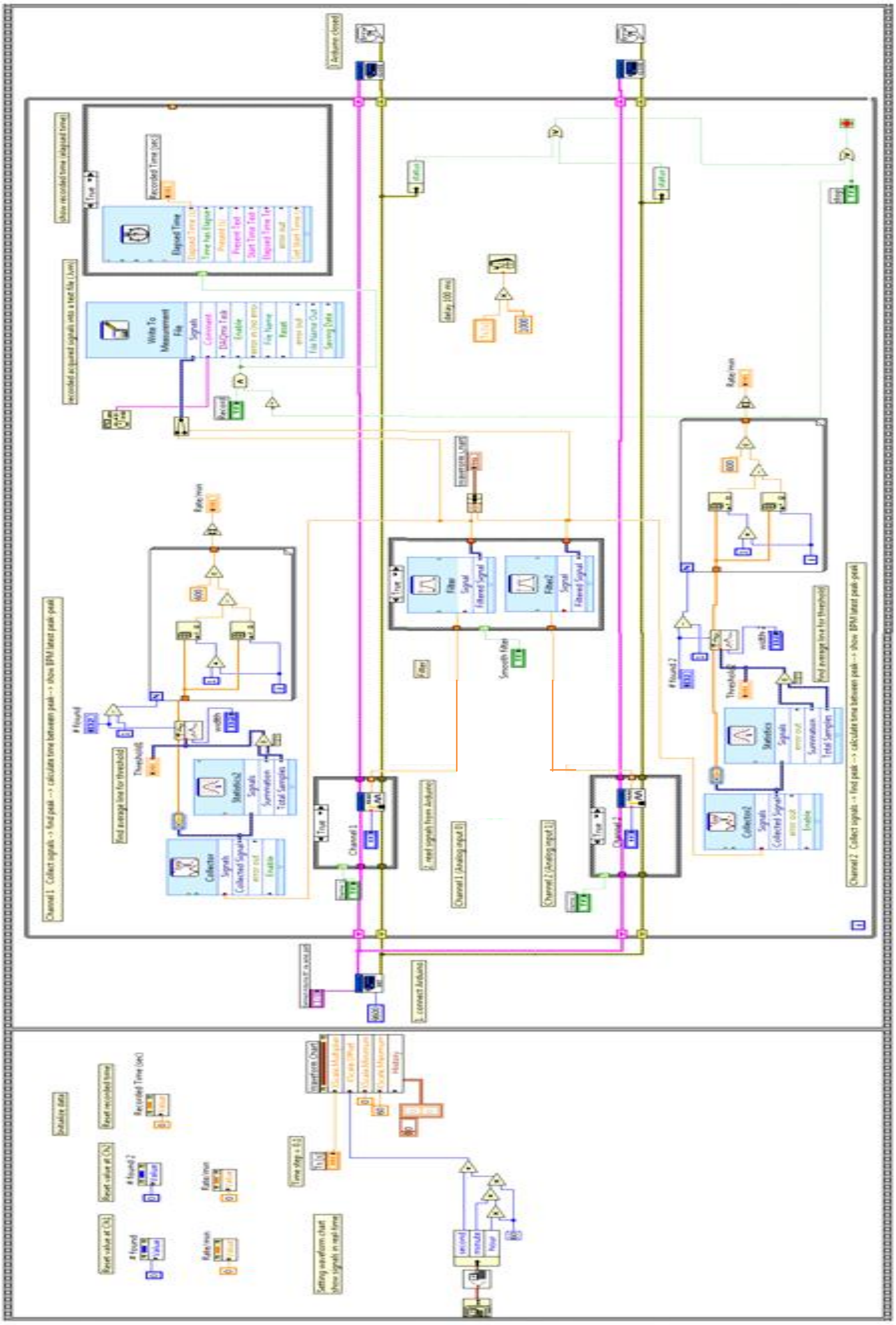
7. Appendices

Appendix A: The schematic of the prototype of the implemented portable interface unit.



Appendix B: LabVIEW block diagram of the implemented software.



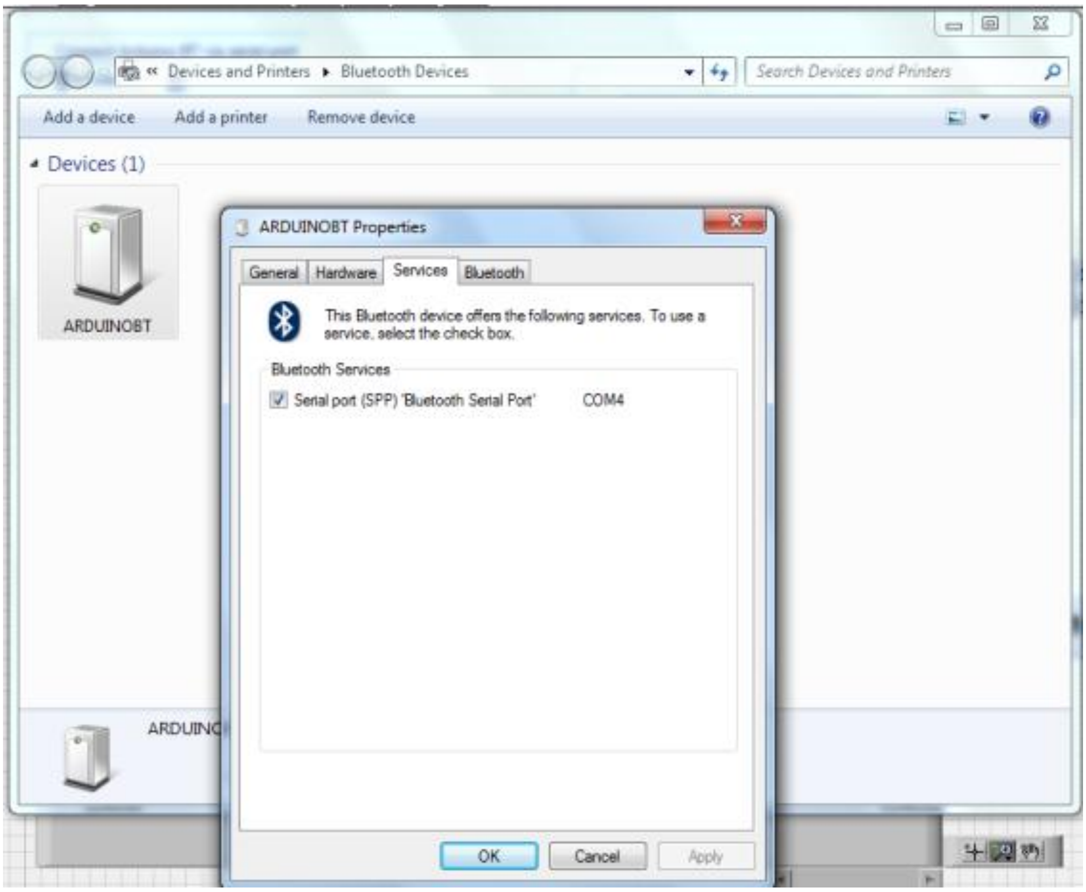
Appendix C: **The procedure of setting LabVIEW interface for Arduino.**

This step-by-step guide for setting LabVIEW interface for Arduino (LIFA) was mainly explained in VIShots website [27] and some explanations for setting the Arduino Bluetooth (BT) were added.

1. After get the Arduino BT board, install the Arduino software or the Arduino IDE and drivers for Windows into a computer. It can be downloaded in the Arduino website [24].
2. Pair the Arduino BT board with the computer and create a virtual serial port for it. Look for a Bluetooth device called ARDUINOBT and the pass code is 12345. [12]
3. Install LabVIEW 2009 or newer because the LabVIEW interface for Arduino toolkit is developed and saved in LabVIEW 2009.
4. Install latest version of NI-VISA Drivers for Windows. The Arduino appears as a serial instrument device for LabVIEW.NI-VISA driver is need for LabVIEW to communicate with serial instruments. It can be downloaded in National Instruments website [28].
5. Install the LabVIEW interface for Arduino toolkit. It is available as a VI package through the LabVIEW Tools Network, so VI Package Manager (VIPM) needs to be installed first. It can be downloaded at JKI website [29].When VIPM is installed, download NI LabVIEW Interface for Arduino Toolkit in this link https://lumen.ni.com/nicif/us/evaltlktlvardio/content.xhtml
6. A *sketch* is the name that Arduino uses for a program. It's the unit of code that is uploaded to and run on an Arduino board [24]. Upload the sketch name 'LIFA_Base.pde' to the Arduino. The LIFA comes with a sketch program that must be uploaded to the Arduino before you can use the VIs to communicate with it. The sketch is located at: C:\Program Files\National Instruments\LabVIEW 2010\vi.lib\LabVIEW Interface for Arduino\Firmware\LVIFA_Base\LVIFA_Base.pde
7. In the Arduino IDE environment, select Arduino BT from the Tools/ Board menu. When uploading to the Arduino BT, you need to press the reset button on the board shortly before clicking upload in the Arduino software.

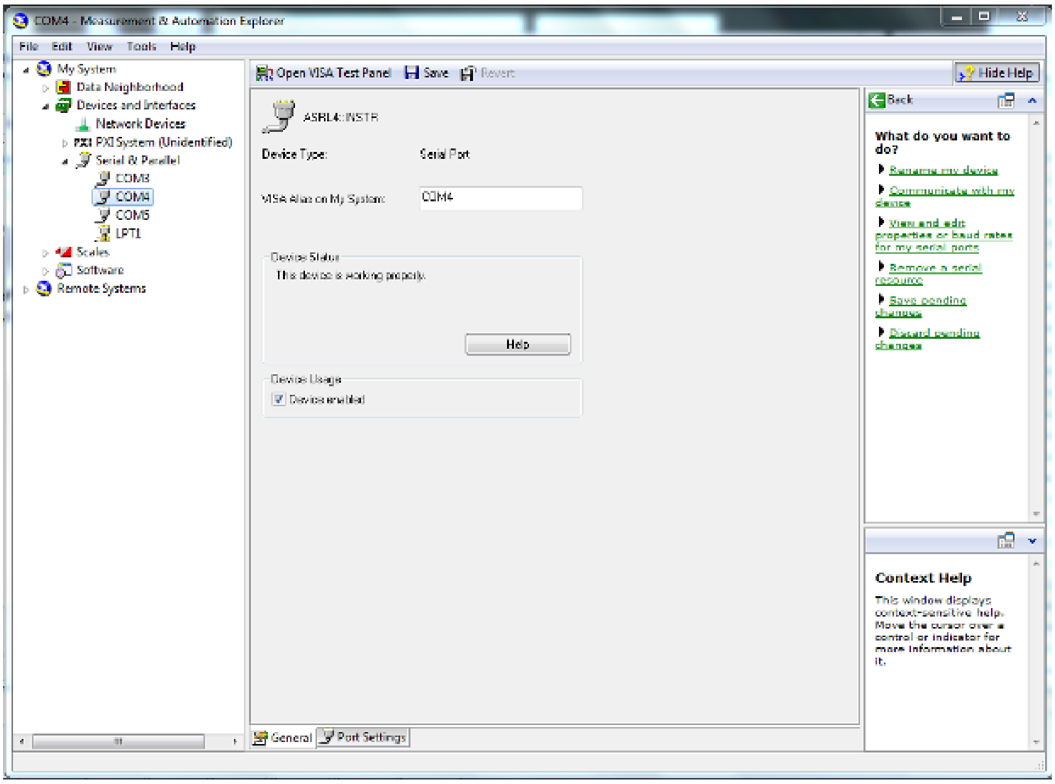
Appendix D: The initial procedures before running implemented software to connect and receive signals from the Arduino.

1. Turn on the Arduino BT board.
2. Check the Arduino BT connect with the computer correctly.



The Arduino BT shows as serial COM port. Go to device properties to connect and see which serial COM port is connected with the Arduino BT.

3. Open Measurement & Automation Explorer of National instruments. The same COM port connection should show in Devices and Interfaces/ Serial& Parallel.



4. After checking that the connection is proper, LabVIEW program can be run.