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PHYSIOLOGICAL USING FPGA IN HEALTH MONITORING SYSTEM

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ABSTRACT

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(Keywords: RISC, FPGA, Electromyography)

The reliability of health monitoring system always comprises its capability to perform accurate physiological data acquisition which is obtained from designated biosensors that are attached to a patient's body. Proper digital signal processing techniques need to be executed efficiently on various stages such as noise cancellation, auto-correlation and filtering to achieve better signal quality. In this project, digital signal controller (DSC) is developed to deliver the capability of on-board signal processing power while at the same time provides integrated control mechanism to the overall health monitoring system. The DSC design includes a single chip solution approach which integrates RISC processor and DSP cores on a reconfigurable platform. A modified instruction set design is structured to perform signal processing tasks during the signal acquisition stage. The processed signals are stored on common memory module to be utilized by either a RISC processor or a DSP core for the next stages. Overall, the DSC is functioning as a robust sensor-reading platform that ensures reliable data acquisition through its signal processing tasks. Implementation of the DSC as a single-chip solution also has reduced the overall surface area by minimizing the number of components on-board.

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CHAPTER 1

INTRODUCTION

Digital signal controller has been widely regards as the natural progression in microprocessor evolutions. Starting with the CPU itself, microprocessor has been evolved from basic computational functions to high-end, state-of-the-art architecture. The progression of microelectronic and IC fabrication make the microprocessors more popular as the ‘brain’ for various electronics gadgets and appliances. Since the last two decades, microcontroller has been introduced, which physically combine the microprocessor architecture with I/O peripheral and memory in a single integrated chip.

On the other hand, digital signal processing (DSP) has been adapted to a wide variety of applications because of demand in analog signal interfacing. As DSP could be realized easily in a simulator, implementing DSP algorithms in hardware platform is totally a different matter. The establishment of digital signal processor has helped this cause but the DSP alone could not satisfy the whole package in making a fully functional system. A hybrid of microcontroller and digital signal processor, also known as digital signal controller (DSC), has been introduced and implemented with several advantages (Bannatyne, 2003, Anant and Hutchings, 2005). Figure 1 shows the variations of processor in accordance to its control processing and signal processing capabilities.

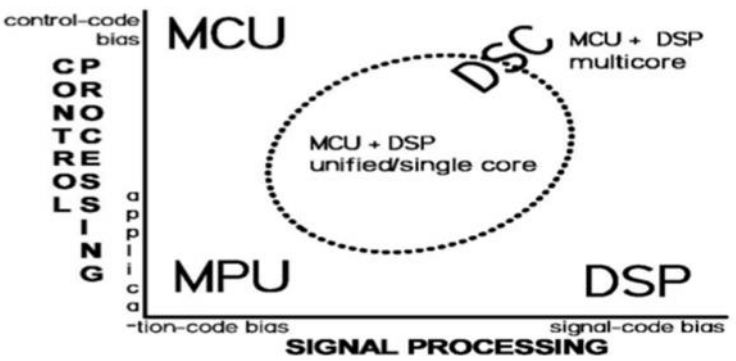

Figure 1 Processor Type Variations

Conventional health monitoring system still requires several apparatus in order to capture physiological signals from a human body to data logger. When attached to a human body, bio-signal sensors then are fed to amplifier and filters to provide a clean physiological signal. Then, analog-to-digital converter is needed in order to pass the signal to a data logger or a PC for analysis or further signal processing. During the whole data acquisition process, at least two devices are required to perform the operation and these devices necessitate different power requirement and cable connections. Therefore, there are rooms for improvement with regards to minimizing the total board area of a data acquisition module which include reducing the number of components without sacrificing the overall functionality and reliability of signal acquisition in the health monitoring system.

1.1 Objectives

The study embarks on the following objectives:

a) To design data acquisition modules in a single-chip digital signal controller to capture and log physiological signal data.
b) To assess the accuracy of the captured physiological signal to be comparable with commercially available signal acquisition devices.
c) To evaluate and analyze performance of data acquisition process in terms of error-rates and power consumptions.

1.2 Problem Statement

The key research question for this proposal is "How single-chip design with signal processing integration of digital signal controller would improve the accuracy in data acquisition process in a health monitoring system?"

Biosensors are the main devices that feed the physiological inputs to the monitoring system. Limitation due to its size and sensor positioning are factors that influence the reliability of the measurements (Pantelopoulos and Bourbakis, 2010). Although biosensors are integrated with amplifier and filter, signal filtering and conditioning could be improved greatly with proper signal processing tasks perform on-board by digital signal controller.

Human body is also susceptible to various anomalies that could affect the accuracy of the physiological data transmitted. Signal noise in the form of sudden rise in body temperature, moisture and humidity could disrupt the body signal and in turn will jeopardize the diagnosis of the patients. A reliable digital signal controller would provide the best mean in recognizing and filtering the unnecessary noise. Advanced on-board DSP would also be able to correlate acquired measurement to recognize an overall condition of the patient's health.

1.3 Project Scope

There are various stages involve in bio-signal processing flow and this project is mainly focusing on the feature extraction process after physiological signals are obtained from the biosensors. The entire project utilized electromyogram (EMG) signal as the physiological signal for future project expansion with regards to EMG signal processing and its related control application. On the other hand, the design and development of DSC is targeting on the integration of an 8-bit RISC processor core and DSP modules implemented in an FPGA platform. A signal processing task, i.e. FFT, is implemented in the DSP core to identify the signal parameter during the feature extraction stage.

1.4 Report Overview

This report consists of five chapters where all chapters are essential to describe the architecture and the functionality of the project.

Chapter 2 focused on the literature review of this project. It mainly explains the two methods in the implementation of a reconfigurable system. Overview of soft-core processors and instruction set customization are also addressed in this chapter.

Chapter 3 describes about the methodology of this project. All method to achieve the result including simulation process is explained in details. Data verification process is also clarified in this section.

Chapter 4 describes the result and discussion of the project. It covers all analysis results of the project from simulation and hardware implementation.

Chapter 5 concludes about the knowledge that had been achieved during the development of the project. Also the recommendation for future upgrades and improvement upon the UTeMRISC02 processor are explained in this chapter.

CHAPTER 2

LITERATURE REVIEW

As we advance to the next millennium, the world faces a new challenge, which is the ageing society. With life expectancy is increased due to better lifestyle and healthcare, the world population will be shared with higher percentage of senior citizens. While the healthcare technology is constantly being developed to assist senior citizens in continuing with their daily lives, it could not be the same with the available healthcare infrastructure. The higher cost in setting up hospitals and the rising prices of medication and prescription could lead to difficulties for the community in having better treatment and healthcare services.

In view of this issue, health monitoring system is proposed to assist the doctors by monitoring vital signs without the need for the patient to be there at the hospital. The system will be attached to the patient body, continuously or at certain period of time, to check the related physiological signal such as heart rate, ECG, etc., and early sign or warning of illness could be detected on the spot. Continuous monitoring on the doctor’s behalf could easily be done using teleconference or by internet connection. On some cases such as physiotherapy, treatment could also be done to the patient remotely through what it is called as telemedicine. In the long run, health monitoring system have only one purposes which is to provide a better healthcare and support for community without the need to leave their homes.

2.1 General Health Monitoring System

In general, health monitoring may comprise various types of miniature sensors, wearable or even implantable. These biosensors are capable of measuring significant physiological parameters like heart rate, blood pressure, body and skin temperature, oxygen saturation, respiration rate and electrocardiogram (Pantelopoulos and Bourbakis, 2010). Designing wearable systems involve numerous parameters to satisfy with, including low power consumption, small size, and ergonomic and also limited hardware specifications. Biosensors, on its own, only provide limited analog-to-digital converter (A/D), filtering and amplifying due to its size and resource limitation. While all the mentioned constraints make the system more complex, health monitoring system still gaining a lot of attention from research community for the past decade due to its cost saving and potential development of miniature biosensors, IC design technology and reliable data transmission.

Basically, health monitoring system involved heavy signal processing on physiological signal such as electrocardiography (ECG), blood pressure and oxygen saturation. In certain cases, complex physiological signals such as electroencephalography (EEG) and electromyography (EMG) signal is measured from the patient body. For example, ECG signal monitoring is very critical for heart disease patients in order to be able to detect early sign of heart failure. For rehabilitation patient that require physiotherapy, EMG signal monitoring will ensure all related muscle contraction, strain and fatigue could be identified by the patients themselves or by their physiotherapist in real-time.

All physiological signals are obtained by the biosensors which are positioned in conjunction with the source of the signals. To make the health monitoring system ubiquitous and unobtrusive, the biosensors are manufactured in tiny packages to minimize the circuit size. Advance MEMS technology has the capability to produce miniature biosensors for various physiological signals. However, with little board space and physical constraint on the circuit size, there are issues on the biosensor accuracy and also its capability in doing more than data acquisition. Normally, the accuracy of biosensors is related to the performance of the amplifier, filters and A/D converter which all are integrated in the same board. To minimize the size of the biosensor, some performance trade-off is inevitable in order to cramp all circuit modules, plus wireless transmission module in the same board. Therefore, having the single-chip system-on-chip (SoC) solution on the biosensors development is recommended to balance the minimal size requirement of biosensors while maintaining reliable measurement of physiological signal acquisition. Figure 2 shows the block diagram of a general health monitoring system.

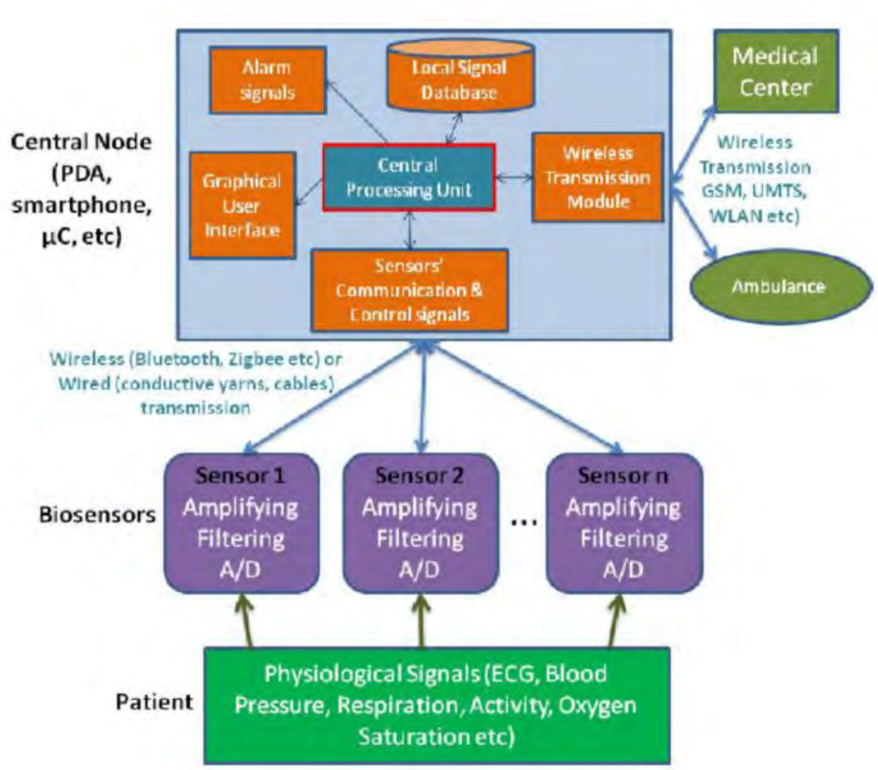

Figure 2 General Health Monitoring System

The biosensor itself is only responsible for the data acquisition process for the health monitoring system. Resource-intensive operation such as signal processing, feature extraction and signal classification could not be operated by biosensors alone as it requires additional microcontroller (MCU) or digital signal processor (DSP) unit. There is a variation of health monitoring system that utilize remote processing, where the biosensors acquire the physiological data, transmit it to central node for minor signal processing and then communicate with central server (located in hospitals or medical centre) for further data processing or immediate action. This method will put the burden of signal processing on to the powerful server and equipment ensuring accurate result and diagnosis. However, this system is heavily dependent on a reliable data transmission and data communication infrastructure. On the other hand, localized processing is implemented by several health monitoring systems where the signals are processed locally by the on-board DSP and communication with central server only occurred when certain alarm or warning signs are triggered that indicate the patient needed immediate attention. Localized processing provide a near real-time indication of patient's health condition although integrating the whole MCU, DSP and filters and A/D on the same board will result in a bulky biosensor with undesirably high power consumption. The development of biosensors on SoC platform has minimized the component requirement while providing adequate signal processing power to the biosensors.

2.2 Digital Signal Controller (DSC)

Single-chip solution for DSCs has been introduced by several big players in DSCs, namely Microchip Inc., Analog Devices and Freescale Semiconductor. However, most of the produced DSCs are the high-end processors (Salim et al., 2008). With regards to health monitoring system, the advantage of combining RISC processor core and DSP processor core provide a whole new opportunity in term of signal acquisition, features extraction and classification. Figure 3 shows the other type of controller that is based on CPU processing apart from DSC.

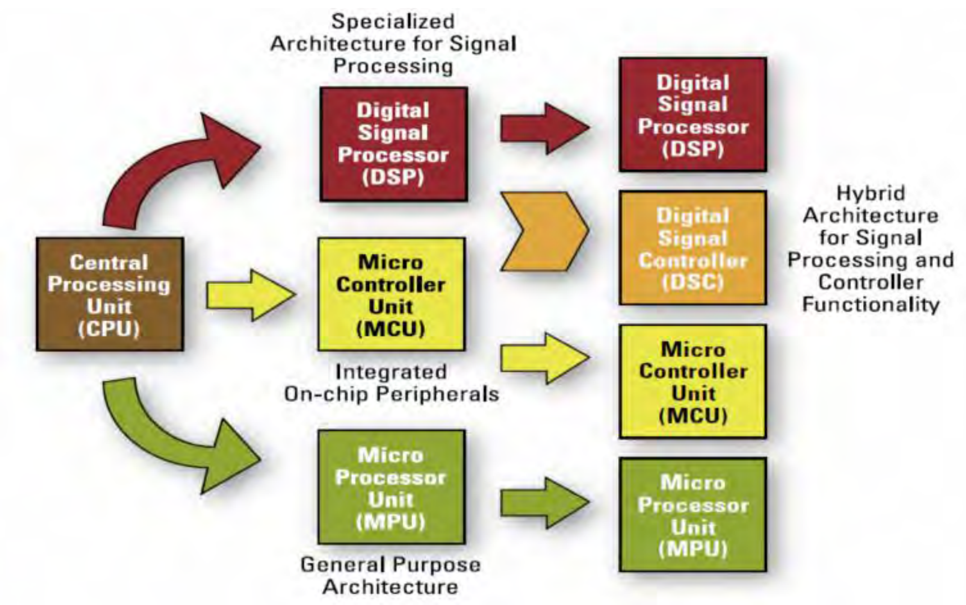

Figure 3 CPU-based System Variations

On-board signal processing also has been recognized as potential system improvement in lowering the power consumption, hence smaller footprint and reduce battery size and power requirement (Estrin et al., 2002, Celka et al., 2005). Embedding sensor with pre-processing unit as suggested in (Acharyya et al., 2008) has the potential in providing less surface area. However, normal signal processing techniques need to be modified to suite the requirement of the targeted DSP architecture.

Data reliability depends greatly on the capability of signal acquisition architecture embedded on the DSC chip. At the same time, advanced signal processing algorithm demands a lot of computational operation hence the requirement of a stable power design architecture. The linkage between data reliability and low power architecture need to be fully comprehended in order to provide satisfactory signal analysis while maintaining an acceptable power consumption (Acharyya et al., 2008).

2.3 EMG Signal Processing

Electromyography (EMG) is a technique for evaluating and recording the electrical activity produced by skeletal muscles (Konrad, 2005) EMG is performed using an instrument called an electromyograph, to produce a record called an electromyogram. An electromyograph detects the electrical potential generated by muscle cells (Perry, 1998) when these cells are electrically or neurologically activated. The signals can be analysed to detect medical abnormalities, activation level or to analyse the biomechanics of human. Figure 4 shows the effective frequency range of three main physiological signals.

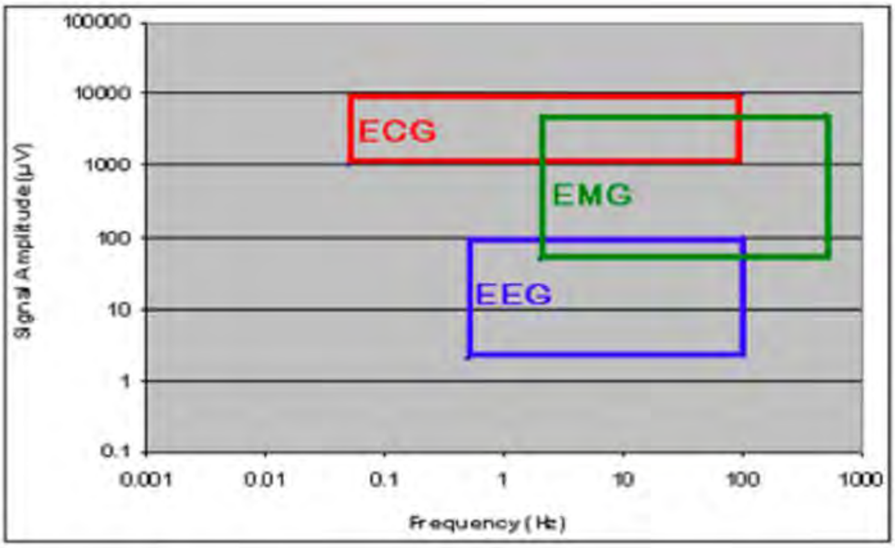

Figure 4 Physiological Signal Frequency Range

The EMG signal is the summation of the discharges of all the motor units within the pick-up range of the electrode. During a sustained weak contraction, a needle electrode might detect two motor units discharging independently at rates of about ten discharges per second. The EMG signal will consist of two distinct trains of motor unit action potentials (MUAPs). Most of the MUAPs will be clearly recognizable. Occasionally, the two motor units may discharge at nearly the same time, and the two MUAPs will overlap one another. This condition is called a superposition. The resultant waveform can be either larger or smaller than the individual MUAPs, depending on whether the overlap results in a constructive or destructive interference.

Focus is given to surface electromyography (sEMG) signal due to its potential end-user application in prosthesis or any control mechanism based on muscle signalling. sEMG in health monitoring system is responsible to determine health condition related to muscle activities, in particular musculoskeletal disorder problem. sEMG signal classification also involves muscle fatigue estimation and measurement of muscle recovery rate.

2.3.1 EMG Signal Processing Flow

Figure 5 shows the steps in EMG signal processing. Selection of feature subset with best discrimination ability is still an issue for classifying EMG signals.

The success of pattern classification system depends on the choice of features used to represent the raw signals (Han-Pang et al., 2003). Even though the raw EMG contains important information of the muscle contraction it needs to be further processed in order to extract its information (Konrad, 2005). The filtered raw signal will be further processed with feature extraction which is an essential pre-process step for pattern recognition. Two type of analysis will be performed for the feature extractions which are amplitude and frequency analysis.

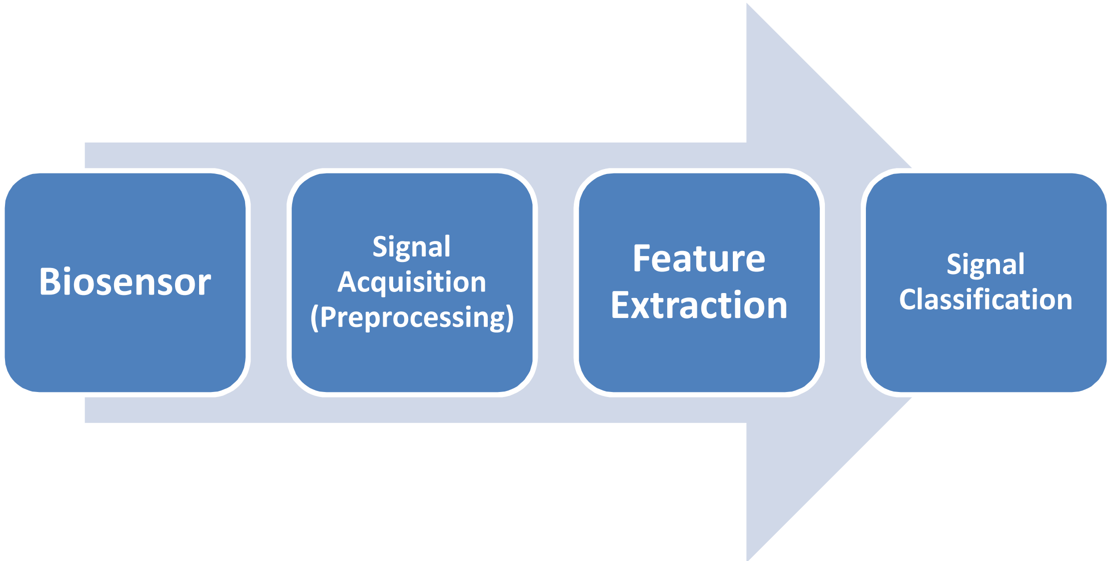

Figure 5 EMG Signal Processing Flow

The large amount of raw EMG data will be processed by performing FFT analysis to acquire the information on the signals because it is impractical to use the raw signal directly for classification as some information might be hidden in the sequence of raw data. It is not valid to directly compare the EMG output of a muscle across subjects because different subjects will have muscles with (Inman et al., 1952):

- different physiological cross-sections
- different lengths - geometry
- different ratios of slow- to fast-twitch fibers
- different recruitment patterns
- different firing frequencies

Voluntary muscle contraction is the results of communication between the individual muscle fibres of the musculoskeletal system and brain where a thought is transformed into electrical impulses that travels down motor neurons (in the peripheral and spine nerves) to the neuromuscular junctions that form a motor unit. Individual muscle fibres within each motor unit contract either with all or none response when stimulated which means that the muscle fibre is either contracting to its maximum potential or none at all. Whole muscle contraction strength is dependent on the number of individual fibres which are activated and capable of correlating with the electrical activity measured over the muscle with an EMG sensor.

2.3.2 sEMG Signal Acquisition

In EMG measurement, the three main categories of electrodes used to record EMG signals are needle electrodes, fine-wire electrodes, and surface electrodes. Needle electrodes have the advantage that they can be manipulated within the muscle to sample different parts of the muscle and to optimize signal characteristics. Fine-wire electrodes are typically inserted with a hypodermic needle. The ends of the wires remain in the muscle while the wires pass through the skin to connect to the amplifier. One advantage of fine-wire electrodes is that it tends to remain in place well throughout a long experiment.

Surface electrodes have the advantage that they are completely non-invasive, but the limitation that they can only sample superficial muscles. Since surface electrodes are far away from the muscle fibres, the MUAPs recorded are small in amplitude and tend to look alike. To overcome this issue, electrode arrays are often necessary in order to obtain decomposable signals.

2.3.3 Feature Extraction

In gesture recognition, feature extraction is a special form of dimensionality reduction. This also helps to extract important information from the EMG signals. When the input data to an algorithm is too large to be processed and it is suspected to be redundant, then the input data will be transformed into a reduced representation set of features. Transforming the input data into the set of features is called feature extraction. The process of feature extraction helps the machine to learn the algorithm quickly instead of just training the machine with bulky raw data which would have made it computationally expensive.

Fast Fourier Transform (FFT) is used to determine the frequency spectrum of the EMG signal. The frequency spectrum of the EMG signal is capable of detecting muscle fatigue force production (Bigland-Ritchie et al., 1981). Before performing the FFT, the raw signal will go through full wave rectification where all the negative amplitudes are converted to positive amplitudes by moving up the negative spike of the signal reflected by the baseline. Full wave rectified signals are easier to be read and offer capability of applying standard amplitude parameters such as mean and peak value to the signal curve (Konrad, 2005).

2.4 Processing Platform

DSP algorithms have been the heart of many sophisticated systems nowadays due to the requirement of having large chunk of data that are needed to be processed before any output could be produced. The most common DSP technique that is being applied in various fields is Fast Fourier Transform (FFT). FFT and its variance have been adopted especially in signal analysis in order to detect or identify certain features of the signal that can be used as a unique input for the system. FFT also has the capability to extract more information in frequency domain of a certain signals that could benefit the system processing unit in order to come out with accurate feedback and system's output. Although FFT algorithm is considered capable in performing adequate analysis during signal processing, further research and development has introduced a slew of other algorithms that are derived from the FFT methodology. For example the introduction of short-term FFT (STFT) is used to determine the sinusoidal frequency and phase content of local sections of a signal as it changes over time. In physiological signal analysis, wavelet transform is widely adopted as the transformed signal provides information about the time and the frequency. Incidentally, wavelet-transformation contains information similar to the short-time-Fourier-transformation, but with additional special properties of the wavelets, which show up at the resolution in time at higher analysis frequencies of the basis function.

Performance and accuracy of FFT-based transformation is dependant to many type of factors such as the algorithm used, the selected radix-n and the total sampling points. Different signals also required different type of FFT analysis and parameters to produce optimized and persistent system's output. Therefore, adopting suitable FFT algorithm with matching characteristic of the input signals is vital in order to develop an efficient DSP-based processing system.

The implementation of DSP-based system is divided into two types of processing, which is an online processing and an off-line processing. DSP-based system with an online processing basically performed all FFT algorithm and other processing tasks on-site by using the hardware processor as the processor platform. Usually, a processor that is capable in handling DSP algorithm is chosen to function as the central processing unit of the system. All input signals are captured, conditioned and directed to the processor to perform the necessary FFT tasks. Upon completion of the signal analysis, appropriate outputs or feedbacks are channelled to the associated output devices such as display monitors. In other perspective, DSP-based system with an online processing capability could also be comprised of a system that acted as the data collection or signal acquisition modules together with a host server that is located off-site from the module vicinity. The signal acquired from the module will be relayed to the host server for FFT computation, most likely through telecommunication network such as 3G GSM or the networking Ethernet. Once the server has completed the computation, the results will be relayed back to the system for subsequent operations. With this type of configuration, the FFT processing is executed in near real-time as certain delays are included during data transmission to and from the host server. As comparison to the processor based system, having a host server provided bigger performance advantage due to higher hardware specification of the host server although the transmission delay is unavoidable and it also very dependent towards the transmission network reliability.

An off-line processing is considered the conventional and low-cost method in implementing a DSP-based hardware. In an off-line processing system, the signals acquired from the signal acquisition modules are stored first in a designated memory bank or a removable media. Once the capacity is full or after a certain time period has passed, the data will be sent to a host server for FFT computation and analysis. This system is normally applied to non-critical applications such as a data monitoring system. The system implementation is simple and straight forward and the signal analysis could be done comprehensively to ensure robust and accurate outcomes.

CHAPTER 3

METHODOLOGY

The architecture of the proposed single-chip DSC includes a RISC processor core, a DSP processor core, two ROMs for the RISC control program and the DSP signal processing program and a common RAM for both RISC and DSP processor. All are designed in one integrated chip while providing I/O interface to accommodate all sensors and communication modules.

The RISC processor acts as the heart of the system where it controls and synchronizes the I/O data according to the programmed operations. Input data from sensors are put through the RISC processor first before being transferred to RAM device. Assembled program of the RISC processor is stored in the ROM. The RISC processor plays an essential part in the design as it permits analog-to-digital conversion feature of the DSC. The RISC processor with a reduced instruction command does make program development and code compilation more simplified.

The DSP processor core provides signal processing functionality, which is to identify, filter, correlate and isolate raw data signals from noises and disturbance. The capability to multiply and accumulate (MAC) in a normalized fixed-point arithmetic would assist in providing clean data signals before being transmitted to the end-server. The DSP core also has its own instruction commands and essentially is a form of a RISC processor as well. Therefore another ROM device is needed to store instruction command for the DSP processor.

With regards to single-chip solutions, the design of a RISC processor, a DSP processor, communication modules and peripheral logics are to be described in Verilog Hardware Description Language (HDL). These hardware blocks are to be integrated and implemented using Field Programmable Gate Array (FPGA) chip. In hardware design, logic synthesis and design verification process follows to determine the accurate outcome of the data acquisition techniques. For software part, a RISC processor program will be developed and debugged before being stored in ROM. Hardware and software design are integrated and implemented in the FPGA chip.

A benchmarking process will commence to validate all physiological data recorded by DSC with sample data obtained from commercially-of-the-shelf devices. This is done to ensure all data obtained is dependable and consistent with industrial-grade measurement equipment. Statistical analysis will be conducted to support the validation results for any disparity. In the first half of the project timelines, a lot of simulation is done in Xilinx Integrated Software Environment (ISE) to develop and test Verilog codes for the microcontroller chip. Several modules are developed including ALU, ROM, RAM, Special Function Registers, Stack and Instruction Decoder. The latter half of the timelines is devoted to the downloading of the processor design into Xilinx FPGA chip and testing it to perform as expected at higher frequencies.

3.1 Overall Block Diagram

UTeMRISC02 processor utilized Harvard architecture where the memory modules are separated into program memory and data memory as shown in Figure 6.