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Simulation of Knee-Joint Angle Measurement for Accelerometer-Based Human Body Motion Monitoring System Using Quartus II

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Abstract: Knee angle measurement is important for investigating complex gait disorder, monitoring the progress of rehabilitation and provide the range of motion (ROM) during flexion or extension. The research presents an implementation of knee angle measurement in simulation by using Quartus II software. Verilog HDL is used to develop the modules of the knee angle measurement. There are ten groups of value have been used in this study. The result of the simulation is verified through the EDA tool. The knee angle measurement is compared with the value calculated by calculator. In the finding, the knee joint angle measurement in simulation has a ±17° difference as compared to the value calculated by the calculator. Thus, there is some improvement is needed to make the algorithm well suit with the healthcare applications. The benefit of this project is it can help the physiotherapists to measure the range of motion during stance and swing for treatment to regain the full function of range of motion.

Keywords: Knee Angle Measurement, Quartus II, Verilog HDL

1. Introduction

The knee is one of the weight-bearing joints that consists of bones, meniscus, ligaments and tendons. Knee is a complex structure and the most complex joints in the body. The knee flexion range of motion (ROM) of a normal person during stance is 18.0°±4.0°, while during the swing is 61.2°±6.1°. Loss of full ROM of the knee joint can be detrimental to the function of the lower extremity and treatment is needed to regain the full function of ROM. So, there is needed to measure the ROM [1].

Knee pain is caused by injuries, sprains and strains, overuse of the knee, infection, bad posture, improper stretching the muscles, and the age of the person and others [2]. Knee pain is a common medical problem in the community. Osteoarthritis is a common chronic condition of the joint and the main cause of knee pain, it occurs most often in the knees, hips, lower back and neck, small joints of the finger and the bases of the thumb, hand and big toe. There is cartilage cover the end of each bone

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in a normal joint and it acts as a cushion between the bones. The osteoarthritis causes pain, swelling and problems moving the joint.

From the global burden disease study in 2010 [3], hip and knee osteoarthritis were ranked 11th highest contributor to global disability. The knee and hip osteoarthritis rates are increasing continuously with age and gender. The risks to have osteoarthritis are higher for those with the knee injury and the increased of BMI [4]. The result shown by the study stated that 16.7% among the adult aged more than 45 having osteoarthritis as compared to 4.9% among the adult more than 26 years old. In Malaysia, the research of knee pain and functional disability of Knee Osteoarthritis patient in Malaysian government hospitals shows most of the patient were aged above 45 years old, and affected woman the most [5].

1.1 Problem statement

From the previous research[1][6][7][8], there is a lot of research on the knee angle measurement. The knee flexion/extension angle parameter is important for investigating complex gait disorders, monitoring the progress of rehabilitation and provide the required information for treatment plan to measure the range of motion during flexion or extension.

For measurement systems normally, the researcher will combine the measurement of knee and ankle for a research. For example, in [9], the researcher used Inertial Measurement Unit (IMU) to measure the flexion of knee of patient for a doctor or physiotherapist to adjust the therapy to suit the patient individually. Researcher [9] used ATmega328 microcontroller as a processing device. The advantages of microcontroller are the microcontroller has a very small and flexibility of processor chips and it is easier to use [10]. But, the disadvantages of microcontroller are the higher power device cannot interface the microcontroller directly and the number of executions can perform simultaneously are limited [10].

There is another processor device can be considered in the knee angle measurement that is field-programmable gate array (FPGA). The FPGA has many advantages in processing the program compared to the microcontroller. Firstly, FPGA able to be reprogrammed again to do any logic task [11]. Another advantage is the FPGA able process and execute the instruction in parallel [12]. Thus, FPGA is chosen as processor device for knee angle measurement. Hence, the preliminary stage for the implementation on FPGA is needed.

1.2 Objectives

The objectives of this project are:

- To design and develop a module that able to compute knee angle measurement using Verilog HDL.
- To verify the result from the developed module using electronic design automation (EDA) tools software.

2. Materials and Methods

In this section, the methodology of the project is discussed and explained to achieve the objectives. The software and coding used to design the functional block also stated in this section.

2.1 Block diagram of knee angle measurement

Figure 1 shows the block diagram of knee angle measurement. There are two sensors have been used to measure the knee angle: accelerometer 1 and accelerometer 2. The output of x and z are taken from the accelerometer. The value of alpha and beta is calculated by using the formula $\tan^{-1}\frac{x_1}{z_1}$.. After the value of alpha and beta has been calculated, both the value of alpha and beta are added together. Lastly, the knee angle has computed using the formula 180°-(α+β). In short, there are three modules have been designed, that are arctangent to the result of x-axis and z-axis, summation of angle of thigh and shank and performing the subtraction between 180 and summation of thigh and shank angle.

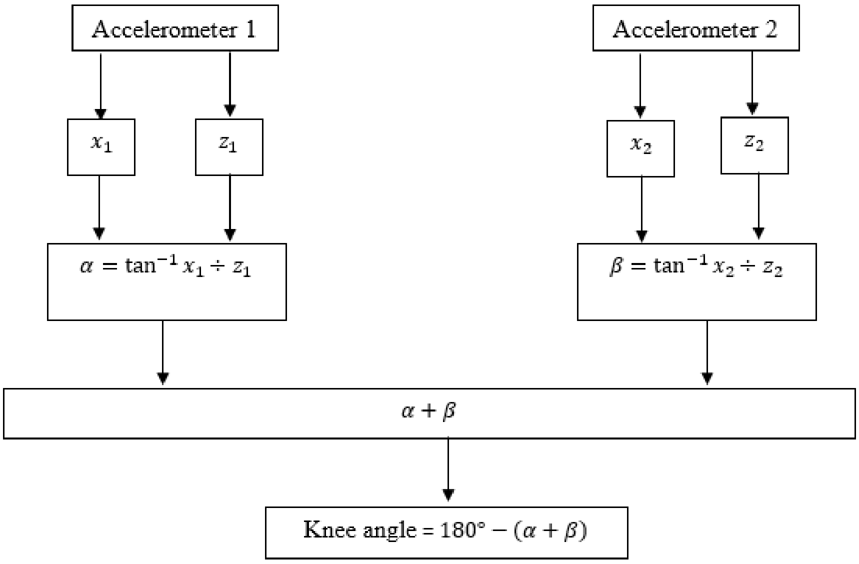

Figure 1: Block diagram of knee angle measurement

2.2 Software and hardware description language (HDL) coding

The software used to design the module of knee angle measurement is Quartus II version 13.0 Web Edition. The designed modules can be compiled and verifying by using the Quartus software. The built modules are integrated into the FPGA device by using the Quartus programmer tool. For this project, family device that selected to implement to DE-1 SoC board is 5CSEMA5F3C6 in Cyclone V. It is focusing on the design of the knee angle measurement. Quartus II can do the simulation of the coding and the coding is verified through EDA tool in the software. The result will be shown in a waveform. The HDL coding used is Verilog code.

3. Results and Discussion

The functional block diagram of the overall system is discussed in this section. Furthermore, comparison between the result in software and the result calculated by the calculator also describes and written.

3.1 Functional block diagram of knee angle measurement

The functional block diagram are made up of three modules, that are alpha_atan module, beta_atan module and arithmetic module. Alpha_atan module and beta_atan module were applying the same coding to build both modules. Thus, both modules shared one clock, one reset and one start node as their input. The input of alpha_atan module was 32 bits of x and y, whereas the input of beta_atan module was 32 bits of a and b. The output of alpha_atan was 32 bits of atan_alpha and 1 bit of finished. The same output goes to beta_atan which output were 32 bits of atan_beta and 1 bit of finished_1.

After that, the output of both alpha_atan and beta_atan modules was set as the input of arithmetic module. So, the inputs of the arithmetic module were atan_alpha, beta_atan, finished and finished_1. The output of the arithmetic module was 32 bits knee angle and 3 bits of q. This module will do the addition between the angle of atan_alpha and atan_beta. After the addition, the constant of 180° is minus with the addition of both angles to produce 32 bits of knee angle. The addition between finished and finished_1 to form the value of q is used to shows the workable of arctangent calculation.

3.2 Result of knee angle measurement

Figure 2 shows the result of knee angle measurement using Quartus II simulation when b is equal to 2, a is equal to 3, y is equal to 3 and x is equal to 1.

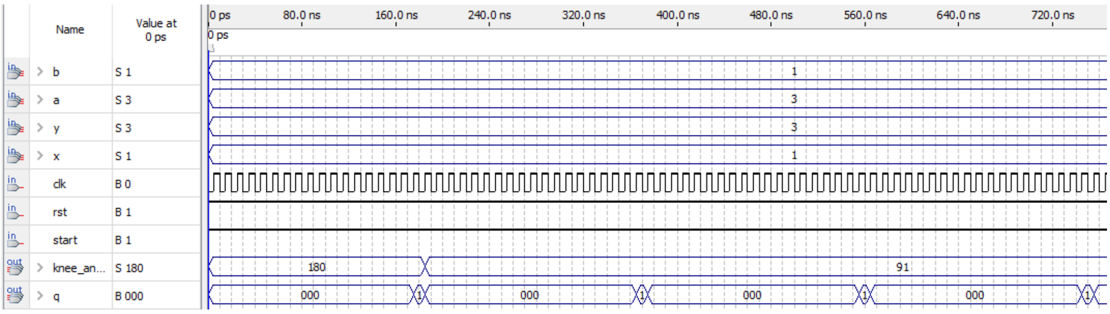

Figure 2: Simulation result when b=1. a=3, y=3 and x=1

When b is equal to 2, a is equal to 3, y is equal to 3 and x is equal to 1, the result of knee angle was equal to 91° and the value of q was equal to 010 to show there is a result of both arctangent angles in this calculation. All the result of knee angle measurement is tabulate in Table 1.

Table 1: Result of knee angle measurement

No	b	a	y	x	Knee angle (°)
1	1	3	3	1	91
2	3	2	3	5	77
3	8	3	7	1	24
4	1	7	3	5	144
5	3	8	2	3	116
6	7	3	1	1	66
7	7	5	8	3	52
8	1	7	8	3	105
9	8	6	6	7	84
10	1	3	3	3	119

3.3 Comparison result of knee angle measurement

Comparison of knee angle calculated by Quartus and calculator are shown in Table 2. The reset and start values were set to be 1 which enable the calculation of knee angle in Quartus. There were 10 results shown in the Table 2. By comparing the result calculated by using software and calculator, the greatest error between the 10 results is ±17°.

When the value of b is equal to 3, the value of a is equal to 2, the value y is equal to 3 and the value of x is equal to 5, the knee angle in Quartus is 77° but the value of knee angle calculated by the calculator is equal to 94°. The result of knee angle in Quartus has the greatest difference to the result of knee angle calculated in calculator, that is 36°. There is no error between the knee angle calculated by Quartus and calculator when b is equal to 1, s is equal to 3, y is equal to 1 and x is equal to 1, which angle is equal to 91°. The observed error between the result in Quartus and calculator might be explained by lack of fixed-point in the input and output. When the input and output is set as fixed-point, the accuracy of the knee angle result will be increased.

Table 2: Comparison of knee angle calculated by quartus and calculator

b	a	y	x	Knee angle calculated by Quartus (°)	Knee angle calculated by calculator (°)	|Error| (°)
1	3	3	1	91	91	0

3	2	3	5	77	94	17
8	3	7	1	24	30	6
1	7	3	5	144	142	2
3	8	2	3	116	127	11
7	3	1	1	66	71	5
7	5	8	3	52	57	5
1	7	8	3	105	103	2
8	6	6	7	84	87	3
1	3	3	3	119	117	2

4. Conclusions

A module to compute knee angle measurement is successfully designed and developed in this project. The designed module able to compute knee angle value when the input start and reset is equal to 1. And, the result is similar to the expected result.

After the module is developed, the result of each module has been verified using the Simulation Waveform Editor tool in software Quartus II. Furthermore, the result of each module has been compared with the result from the calculator, which show ±36° in difference. The other results such as addition and subtraction have no significant difference. The result of knee angle has the average difference of ±7.3°.

In a nutshell, all the objectives stated is successfully achieved. The aim of the project also reached as this research is aimed to develop as a preliminary stage for implementation of knee angle measurement on FPGA..

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