Implementation of Bone Strain Measurement System using FPGA

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***Abstract*-- In this paper, the design is proposed for implementing the measurement of bone strain using FPGA. Normally embedded system is used for bone strain measurement system to calculate the bone strain. However the system is designed using embedded system but has to increase the efficiency of the result, the system need to be design using accurate value. In this case the value from the sensor output is in the form of voltage and this value is based on change in the resistance value of the sensor. The voltage signal is processed to enhance the output through filters and amplifiers. Then the analog signal is converted to digital signal through analog to digital converters. Eight channels are used to receive an eight sensor output and single strain sensor output data is received at a parallel to serial converter. Once all the strains are calculated, it can predict the strain levels and their exercise impact for bone formation. Thus the output of the parallel to serial converter is compared with the predicted strain levels for the convenient of patients to know their bone mass structure. The whole system to measure the bone strain which can be implemented using FPGA. This system shows that it is easy to measure the bone strain when compared to conventional methods.**

***Index terms*:** Bone Strain Measurement System, Analog to Digital Converters, Strain Sensor Output Data, UART Design, FPGA.

I. INTRODUCTION

Bones are the vital organs of the body. It supports different functions of the body. Bones are the rigid and hardest structures. It provides mobility, protection to internal soft tissues, mechanical support and shape to the body. It acts as a calcium reservoir. Bones are attached to the muscle to make contraction and relaxation. Bones are not static, that is they change their structure constantly according to the biological needs. But how the structural properties of bone are changed when varying loads are applied to the bones is not entirely understood. The biological study based on the structural variation of bone is very important to analyze the mechanism of bones. The healthy bone should possess good bone mass. Generally the bone mass gradually increases from birth and the bone mass acquisition becomes slower as a person gets older. Due to some reasons it may be biological factor or heavy mechanical loading, this bone loss becomes severe which leads to osteopenia and osteoporosis. Osteoporosis is the weakening of bone which occurs due to ageing and also further makes the bone to break. To reduce these types of illness several procedures are available. But not all the methods are 100% efficient to find the bone density accurately. To understand the mechanisms of bone clearly, it is the need to understand how the various load level have their effect on the bone. This type of learning leads to the advancement in the treatment of bone diseases like osteopenia and osteoporosis. By taking the X-ray images for diagnosis, only the calculus growth is visible.

In order to analysis the bone formation and deformation, bone strain measurement is important in addition to the understanding of bone mechanism. It is necessary to identify the range of load which makes variation in the structure of load. Bone strain measurement gives the range of the loads for which the bone can withstand. The monitoring of strain upto some extend is useful in rehabilitation exercises. The unit to measure the bone strain consists of sensor unit, amplifier, filter, analog to digital converter as basic components [1]. Initially to measure the bone strain, human bones are not directly used at this level. Phantom tissues or scaffolds are used in place of the bone. These scaffolds are used for load bearing applications.

They are fabricated by fused deposition model process uses a small chamber, extrusion system. Scaffolds are made from composite materials such as biopolymers and bioceramics which possess their chemical properties as it changes their shape as days passes [2]. Bone loss occurs due to different reasons. It may be due to ageing, drug treatments, estrogen deficiency, mechanical unloading or disuse of bones. Bone loss due to mechanical unloading has greater impact when compared to estrogen deficiency. This leads to the precaution measures to protect from osteoporosis. The bone modeling and remodeling are the two important mechanisms of the bone tissues. Some of the factors include activation frequency and threshold of bone multicellular units, refilling rate and strain are the significant parameters for determining the status of bone [3].

Currently the attachable clothing sensor system is employed to measure the knee motion of the orthopedic patient outside the laboratory. This leads to the ease of the monitoring and assessment of patients regularly by the clinicians in the absence of patient because the usage of instruments such as inertia measurement units and electro goniometers are reduced due to their bulky nature. Sensors play a vital role in all the measures of bone and the composed carbon nano material is base material for sensor [4]. Fiber Bragg Grating (FBG) based sensor networks are used in wide range of high speed applications. This sensor has a property of increased reliability, high speed and reduced crosstalk. The application areas of FBG include strain measurement in the field of measurement of rails, health monitoring, turbine blades, etc. The rate of measurement is limited and improved by the advanced chips [5].

Also microbend sensors are used to measure the strain which are very sensitive able to measure strain even at a minimum level [8]. During Magnetic Resonance Imaging (MRI) scan the patients cardiac and respiratory activities are monitored with the help of FBG based optical strain sensor, which is a safe and non-invasive method. This type of sensor is specially designed to obtain the ballistocardiographic signal of the patient who is radiated to the electromagnetic waves. The quality of the image acquired by the MRI scan does not destructed by the sensor activity [6]. A small unit on the moving subject is monitored by the system. The unit collects and sends information about the moving subject with the help of magnetic sensors [7].

The strain measurement of bones can be achieved through sensors by means of wireless communication with the help of bioimplantable metamaterial sensors [9]. The normalized cross correlation computation using graphics processing unit is employed to estimate the deformation of bone with reduced computation time when compared to 2-dimensional normalized cross correlation based algorithm [10]. Strains occur due to force, pressure, acceleration and sound are measured with the help of microscale strain gauges in Micro Electro-Mechanical Systems (MEMS) [11].

II. SYSTEM DESIGN

Nowadays several people suffer due to bone loss and this happens due to different reasons. This leads to bone diseases like osteoporosis. However several diagnoses are available, still it requires some more advancement in the treatment. Hence strain measurement of bone emerges in the bone formation and deformation phenomenon. While designing the system, the requirements of the system are the most significant thing. In this system, two main things are focused. First thing is the measurement of strain with the help of sensors. In this case, the strain should not be measured from humans because this is the starting analysis and measurement of the bone strain. So the testing and measurement directly with the human bone is not possible. So currently the setup

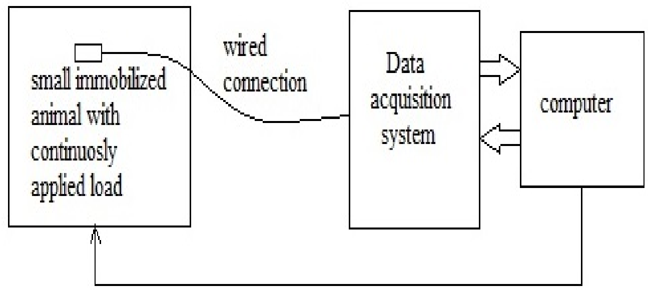

Figure.1 Block diagram for strain measurement when the subject is immobilized.

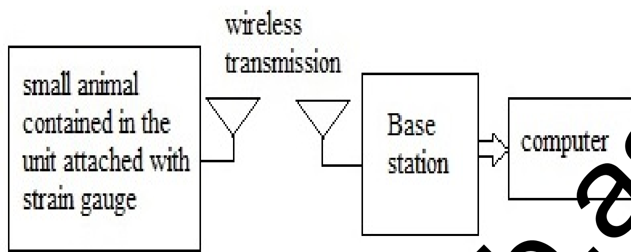

Figure.2 Block diagram for strain measurement when the subject is moving freely.

starts work on the small animals to measure bone strain. This can be achieved by continuously applying load on the animal bone. In earlier cases, the animals are completely immobilized. This uses data acquisition system as shown in figure 1. Then in another case they are allowed to move in the small limited environment and the unit is attached to the bone of the animal. In all the cases sensors are used to measure the strain data of the bone which varies with loading. After which the collected strain data is transmitted for analysis. If this transmission is a wireless means of communication, then the system operates with some more advantages. The block diagram for this type of transmission is shown in figure 2. Also the system is designed with help of microcontrollers to measure the bone strain and analysis purpose.

In the first case, it is employed only for further analysis of the bone mechanisms by the researchers. But in the normal living of human, most of the people suffer due to bone diseases. Currently for the diagnosis purpose X-rays are used, but it shows only the calculus growth of the bone. Anyway the patients treated after checking with the scan reports still some of they suffer with some burden to get recover from the pain. So the bone strain needs to be calculated. So, in the second case during the normal diagnosis if the bone strain is calculated then it is helpful in the treatment process with some more improvement. This is because once the bone formation and deformation mechanisms are measured as strain, they are stored in the database for the future purpose. This database values are predicted the bone strain as normal, abnormal and average values.

2.1. Requirements for System Design

To measure the bone strain sensors are required to find the small changes in the bone mass. Strain is the measure of change in the length of the bone or deformation rate of the bone structure when any force is applied. It may be positive or negative based on the expansion or compression respectively. The value of strain is very small hence it is expressed as microstrain. This small variation is sensed with the help of strain gauge sensors. Sensors are needed to be attached to the bone. Experiments with the living organisms are difficult. So the structure which should be act as a bone needs to be determined. The composite mixture of copolymers and carbon materials can be act as a bone. This is because of the chemical properties of the composite materials that react to the loading and unloading phenomena. In the initial analysis stage, it takes long time to determine all the possibilities i.e.

- The time taken by the normal person to return back to its original position after subjected to any load (accidents).
- The time taken by the abnormal person (i.e. they affected already increased bone loss) to get back to its normal condition after subjected to any load.
- The time taken by the normal and abnormal person to return back to its original position after some small mechanical work.
- The time taken by the women to get back to its normal condition after subjected to any load under various conditions.

This type of determination is very much helpful while treating the patients with bone loss in future. This is because once the strain values are determined; all the details are stored and compared with the patients present details of bone structure. This leads to the better improvement in the physiotherapeutic treatment for the patients. The sensors are utilized for the implanted applications so it should be very small. During the initial stage of analysis it takes long time to measure the bone strain. So the sensor needs to be attached to the bone for long duration. The battery should be connected to the bone for their non-breaking performance. To reduce the cost, size, design time and manufacturing time, the system should be designed with the available components of Field Programmable Gate Array (FPGA). FPGA works with CMOS technology hence it is employed wide range of applications for their low power and high speed performance. In order to process the strain obtained from the sensors, amplifiers, Analog to Digital Converters (ADC), processing unit are required.

III. METHODOLOGY

While measuring the strain for the localized single bone, six sensors are attached around the bone. This makes complete measure of the localized bone effectively. To provide power to the sensor, battery is connected to the sensors. The bone contracts and expands due to the mechanism of formation and deformation creates resistance in the bone which produces voltage difference. The measured voltage signal from the sensor output is transmitted to the receiver side for processing. The voltage signal is the very smaller value and cannot be further processed for analysis or to obtain the information. So the amplifier is used to enhance the signal level hence it can maintain the same information throughout the transmission without any degradation. The transmitted signal contains some of the noise along with the information. The block diagram for the measurement of strain is shown in figure 3. The flow for the processing of obtained signal is shown in figure 4.

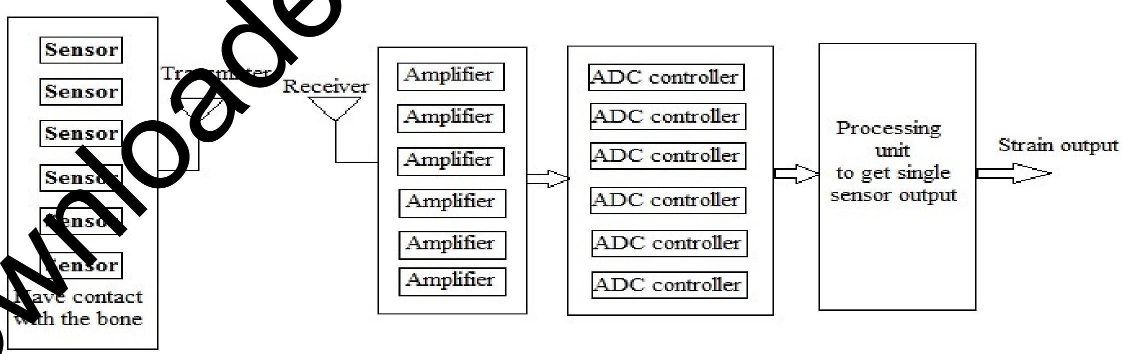

Figure.3 Block diagram for bone strain measurement

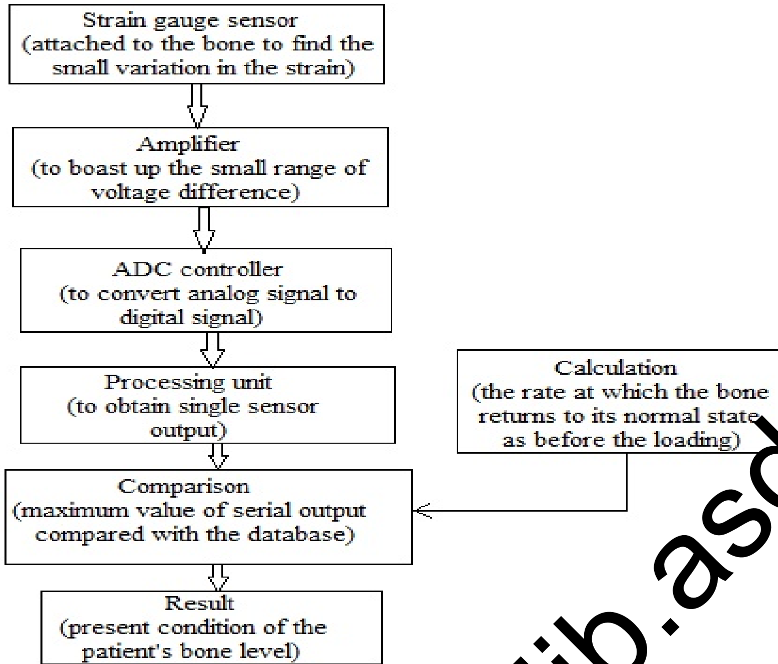

Figure.4 Flow diagram for measuring and processing the strain

In order to design the system to measure the strain with low power and high speed, the system is simulated using Xilinx and implemented on FPGA. FPGA uses CMOS technology and generally works under low power. FPGA processes and produces only the digital value. But the sensor produces the output as analog signal. To make the output fit for the digital processing, Analog to Digital Converter (ADC) is employed to convert the analog sensor output into digital value. All the sensor outputs and measure of strain are obtained in parallel manner at the receiving end of the ADC. To obtain a particular sensor value, the processing unit is used.

IV. SIMULATION RESULTS

4.1. ADC Controller

When converting the analog signal into digital signal, the continuous value is discretized at each instant. This includes the process of sampling and quantization. At every interval of time, the analog value is hold for some time and produces the digital value. The digital value at specific time of analog signal exists and extends continuously. To limit the digital value upto some extend ADC controller is used. In ADC controller, whenever the clock signal is given at that instant the sample produces a digital value and based on that digital value is limited. The simulation result and the RTL model for ADC controller using Xilinx is shown in figure 5 and 6.

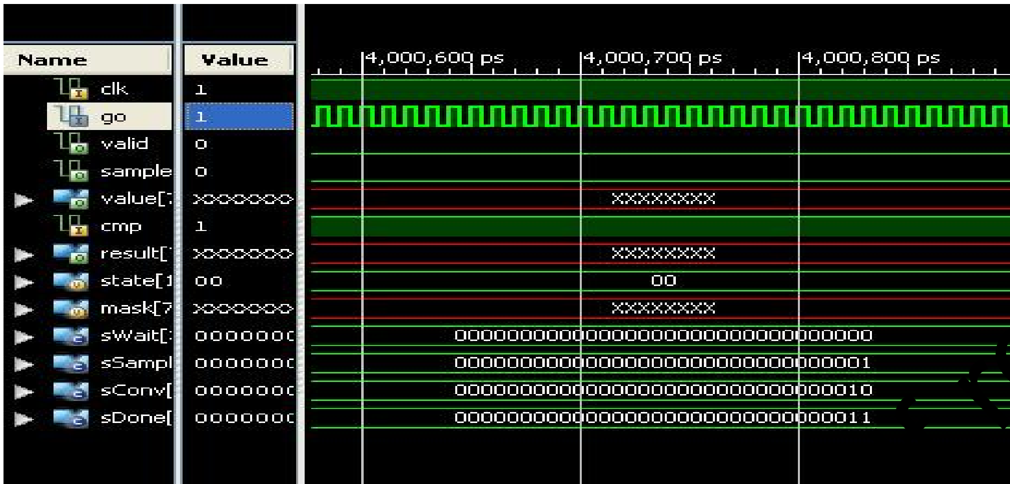

Figure.5 Simulation result for ADC controller

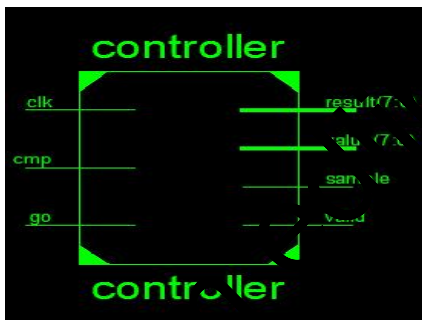

Figure.6 RTL model of ADC controller

4.2. Processing Unit

The processing unit helps in obtaining the strain value of one sensor serially at the output. The maximum digital output of the processing unit compared with the database and report about the condition of the patient. This comparison helps in the treatment process. Also gives the detail about the duration and depth of physiotherapeutic exercise intake.

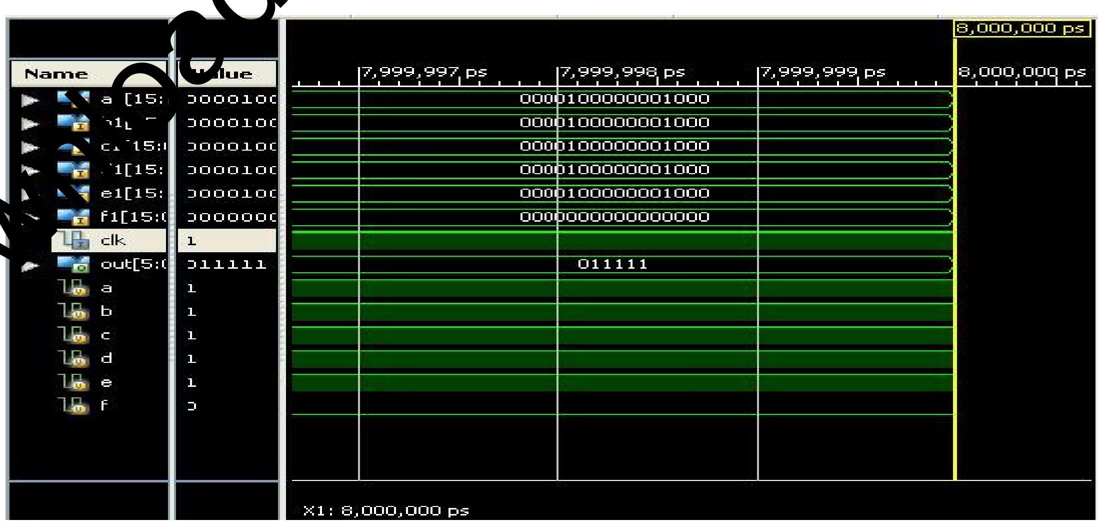

Figure.7 Simulation result for processing unit

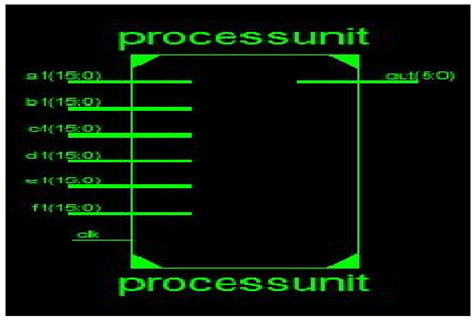

Figure.8 RTL model of processing unit

D. *Synthesis Report*

Device utilization summary:

Number of Slices:	31	out of	4656	0%
Number of Slice Flip Flops:	18	out of	9312	0%
Number of 4 input LUTs:	66	out of	9312	0%
Number of IOs:	124			
Number of bonded IOBs:	123	out of	232	53%
Number of GCLKs:	1	out of	24	4%

Speed Grade: -4

Minimum period: 3.077ns (Maximum Frequency: 324.992MHz)
Minimum input arrival time before clock: 4.351ns
Maximum output required time after clock: 6.264ns
Maximum combinational path delay: 8.374ns

V. DISCUSSION AND CONCLUSION

The system to measure the bone strain has been designed. This system design was completed with the help components such as sensor, amplifier, Analog to Digital Converter, processing unit. Hence it reduces the design time and cost of the system. It consumes low power because it is implemented on FPGA. Sensor is used as implanted device and transmission occurs through wireless communication so it should be charged with a battery through minimum power. This system design along with the X-ray was very useful in the normal diagnosis procedure patient bone loss and further improvement in the treatment of orthopedics. Comparison of bone strain details of the patient with the database makes the easier when compared to conventional methods.

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