Development and Implementation of Instrumentation System for Diagnosing Bone Quality using Vibration Technique

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Abstract:

In this paper, the development of Instrumentation system for diagnosing the condition of bone quality is discussed. The conventionally available method for the assessment of bone mineral density and its related disease is through DEXA SCAN and cost of this machine is more for every scan which is not affordable for all people . This work is based on vibration analysis from impulse input on human leg bone. Two commercial MEMS accelerometers are attached on the shaft (long vertical leg bone) at appropriate locations where vibrations are predominant. The proposed system consists of a MEMS accelerometer sensor ADXL335 from Analog Devices is used as a detection sensor that measures vibrations in terms of acceleration produced by mild impulsive force applied on the diaphysis of left tibia and interfaced with Data Acquisition Card (DAQ) and displayed in the PC. The experiment was performed on human subjects by applying impulsive force using automated hammer in order to excite the bone with uniform force consistently in all trials. The time and the frequency domain analysis of the obtained output signals (analog voltages proportional to the accelerations from two sensors) gives the useful information about the BMD of the human subjects. The results have shown that the accelerations obtained in terms of voltages from the excitations of bone is different for men and women with different age groups .The information acquired and analyzed is used to evaluate the quality of the bone.

Key words: Micro Electro Mechanical System (MEMS), Bone Mineral Density (BMD),Personal Computer(PC),Impulsive force, Diagnosis

I.INTRODUCTION

BMD measurements in conjunction with information about the structure and elastic properties of bone will result in a good indication of its mechanical condition and susceptibility to fracture. Moreover, during accidental impact, our bones arc subjected to high strain rate loading. Since bone is a viscoelastic material [4], its response to this type of loading cannot be assumed to be the same as predicted by a static analysis. Therefore, it is important to study dynamic characteristics of bone under normal and diseased state in order to understand its response to more realistic loading condition [5]. The change in Peak acceleration magnitude with age is also evaluated. Osteoporosis is a disease of the bones. It happens when you lose too much bone, make too little bone or both. As a result, bones become weak and can break from a minor fall or, in serious cases, even from simple actions, like sneezing or bumping into furniture.

The risk of osteoporosis fractures can be reduced with lifestyle changes and in those with previous osteoporosis related fractures medications. Lifestyle change includes diet, exercise, and preventing falls. The utility of calcium and vitamin D is questionable in most. Bisphosphonates are useful in those with previous fractures from osteoporosis but are of minimal benefit in those who have osteoporosis but no previous fractures. The diagnosis of osteoporosis can be made using conventional radiography and by measuring the bone mineral density (BMD). The most popular method of measuring BMD is dual-energy x-ray absorptiometry (DEXA).

Bone quality is a composite of properties that make bone resist fracture such as its micro architecture accumulated microscopic damage the quality of collagen mineral crystal size and bone turnover. The most prevalent sequence is compression fractures of the vertebral bodies and fractures of the ribs, proximal femur (hip), humerus and distal radius. These fractures lead to deformity, loss of mobility, independence and even death. With increasing population of elderly women, the assessment and treatment of osteoporosis has become an important problem in clinical gynecology. Bone mineral loss occurs with aging, menopause, and disuse. The decrease in biomechanical strength of bone with age is much more pronounced than the loss of bone mass due to perforations during the remodelling process [3].

Therefore, it is important to study dynamic characteristics of bone under normal and diseased state in order to understand its response to more realistic loading condition [5]. The change in acceleration magnitude with age is also evaluated.

II.RELATED WORK

X-ray studies of the thoracic and lumbar spine can help to assess the extent of osteoporotic damage, but generally, x-ray films show bone loss only when it exceeds 40% or more.Risk factors play important role in helping to identify patients with possible low bone quality.Bone Mineral Density (BMD) testing has great clinical significance in the early detection and diagnosis of osteoporosis.Bone Mineral Content (BMC) is found by tracing the profiles along the edges

of the bone image.Bone Mineral Density (BMD) is the ratio of bone mineral content to projected bone area.Diagnosis of Osteoporosis: T-score above -1: NormalT-score between -1 to -2.5: Osteopenia (early stage of osteoporosis).T-score below -2.5: Osteoporosis. Change in bone mineral density with age in men and women show that there is a Bone Mineral Loss with age.6-7% per decade in premenopausal women.10-11% per decade in Postmenopausal women.6-7% per decade in men.

Ultrasound studies provide information about the medium (tissue) through which it is being propagated. Ultrasound wave is modified by bone's structure, composition, and mass (Kaufman and Einhorn, 1993).Two principal types of alteration can occur: The medium can alter the velocity of the wave (Speed of Sound-SOS).The medium can reduce the amount of energy transmitted and thereby attenuate the wave (Broadband Ultrasound Attenuation-BUA).

Measurement of SOS in the heel involves accurate determination of the transit time of a sound wave as it

passes through the healMeasurement of BUA involves sending a broadband ultrasound pulse through the bone and measuring the reduction of intensity at different frequencies.Stiffness Index combines BUA and SOS into a single clinical measure that has lower precision error than either variable alone.The resultant empirical formula is:

$SI = [(0.67 \times BUA)+(0.28 \times SOS)] - 420$

The SI is scaled in such a way to make the young adult value equal to 100 **.** Change in bone stiffness with age in men and women showed that there was a Decrease in Bone stiffness with age.7-8% per decade in premenopausal women,10-11% per decade in Postmenopausal women and 7-8% per decade in men. Human bones are subjected to high strain rate of loading during daily activities. It is important to study bone's dynamic characteristics in order to understand its response to more realistic loading conditions (Lakes and Saha, 1980).The dynamic response of a mechanical structure can readily be determined by impulse force testing .Stress wave propagation generated by impact force has a advantage of providing information about the density, structure and mechanical properties of bone Development of such a technique can be used in clinical applications, as in evaluation of fracture healing and diagnosis of osteoporosis (M.S.Holi,2003).

III.SYSTEM DESCRIPTION

In the following subsections, we will describe the system architecture , hardware and software components.

A. SYSTEM ARCHITECTURE

As shown in the figure 1, the architecture of the system mainly consists of a mechanical section for producing knock and a electrical section for automatically operate the hammer to make knock on bone with predefined uniform force and time duration and a Data Acquisition card for interfacing the hardware part with PC. The mechanical section consists of a less weight hammer which is driven by the motor. Two actuators The accelerometer –I is placed on the fascies medialis tibia at a distance of 6cm from the medical condoyle and accelerometer- II placed at a distance of 18cm from the accelerometer-I.

The automated hammer that runs by the DC motor hits the Medialisis Condolosis region in the leg. The automated hammer is controlled by switches When the hammer hits the Medialisis Condolosis region, the impulse response that propagates through the bone of the leg. The accelerometers will receive the impulse responses that are acquired from the hammer and are collected by the DAQ (Data Acquisition card) system. Tracer DAQ software included for acquiring and displaying data and generating signals. From the signals, we can analyse the mechanical strength of the bone.

B.HARDWARE COMPONENTS

The Hardware part consists of a microcontroller AT89552 is used for controlling the knock as desired. The microprocessor is running under the core of 8051 principle. Flash programming which is used, so that it can be

made rewritable in order to increase or decrease the speed of the motor setup. It has 4 ports namely PORT 0,PORT 1,PORT 2 and PORT 3..PORT 0 is used for controlling the switches. PORT 1 is used for controlling the Digital to Analog converter. Microprocessor circuit consists of crystal oscillator used for timing control purpose.The DAC 0808 is used which has 8 data output. From the microcontroller, PORT 1 is connected to theDAC0808 combined with an Integrated circuit(IC) operational amplifier 74, for the amplification purpose of the signals generated. DC motors are part of the electrical section using DC power as energy source. The ADXL335 is a small, thin, low power, complete 3-axis accelerometer with signal conditioned voltage outputs. The product measures acceleration with a minimum full-scale range of ±3 g. It can measure the dynamic acceleration resulting from motion, shock, or vibration. The user selects the bandwidth of the accelerometer using the C_X, C_Y, and C_Z capacitors at the X_{OUT}, Y_{OUT}, and Z_{OUT} pins. Bandwidths can be selected to suit the application, with a range of 0.5 Hz to 1600 Hz for X and Y axes, and a range of 0.5 Hz to 550 Hz for the Z axis.

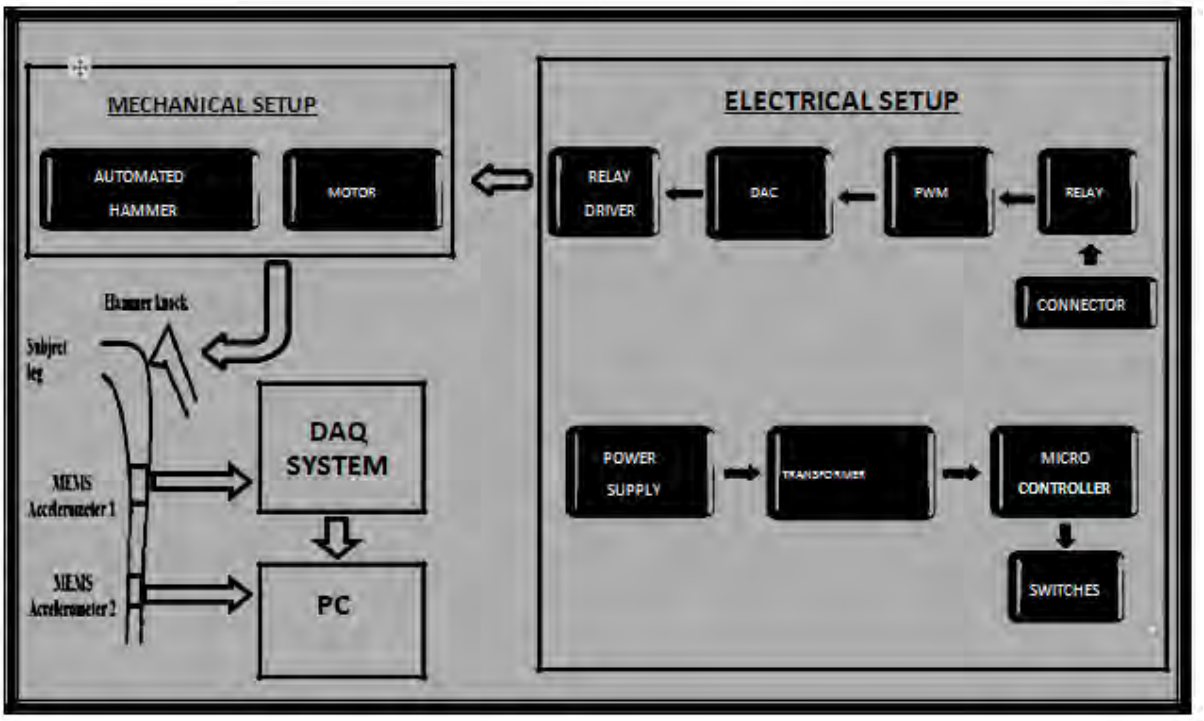


Fig.1 Schematic block diagram of the hardware setup

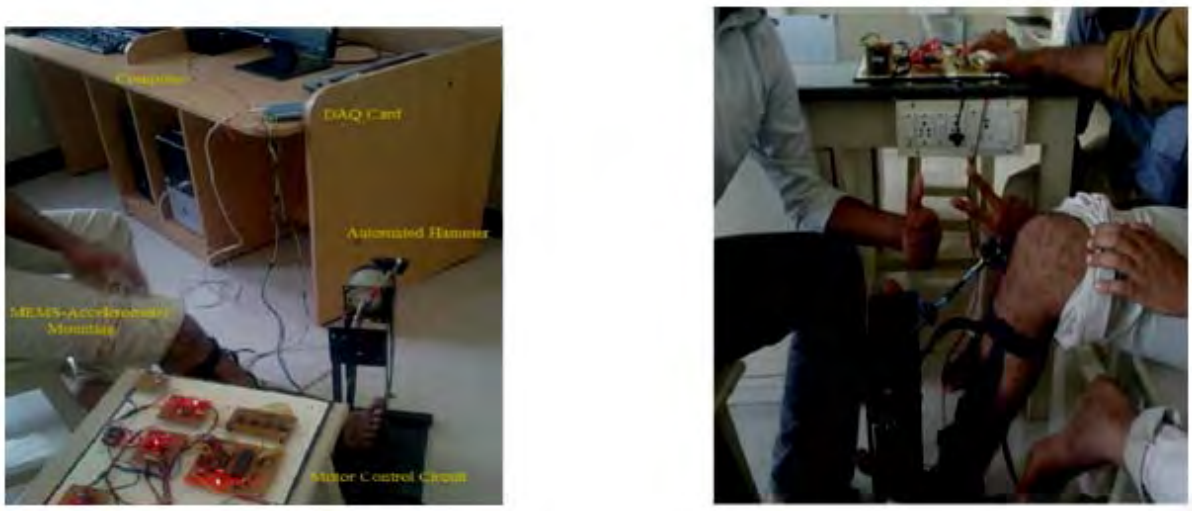


Fig.2 Camera view of the hardware setup

The ADXL335 is available in a small, low profile, 4 mm × 4 mm × 1.45 mm, 16-lead, plastic lead frame chip scale package (LFCSP_LQ). MEMS accelerometers and its subsystems that reliably and accurately detect and measure acceleration, tilt, shock and vibration in performance-driven applications. A fixed power of 5V dc is

applied th the sensor for its operation.

C. SOFTWARE COMPONENTS

USB-1208 Series DAQ modules are low-cost, PC-based analog and digital I/O devices available in USB high-speed (USB-1208HS Series), full-speed (USB-1208FS/1408FS), and low-speed (USB-1208LS) models. All of these modules offer up to four DIFF or eight SE analog inputs, up to 16 digital I/O channels, and up to two counter inputs. The USB-1208LS offers two, 10-bit analog output channels with DAC rates up to 100 S/s. The USB-1208FS/1408FS both offer two, 12-bit analog output channels with DAC rates up to 10 kS/s. The USB-1208HS-2AO offers two 12-bit analog outputs and the USB-1208HS-4AO offers four, 12-bit analog outputs, each with DAC rates up to 1 MS/s.

InstaCal Installation, calibration, and test software in one package simplifies these important steps as you turn your PC into a measurement system. Installation detects new hardware and configures your computer and board. Calibration software automates this critical step and keeps your measurements accurate. Test routines verify that all the board's features are operating, and will speed you to a quick resolution. Tracer DAQ is an out-of-the-box application that allows data to be generated, acquired, analyzed, displayed and exported within seconds of installing data acquisition hardware. It offers four different data acquisition applications; a Strip Chart, an Oscilloscope, a Function Generator and a Rate Generator, all of which are accessed via a common, easy-to-use menu page.

IV.EXPERIMENTAL RESULTS

In this study, 25 subjects had participated with different sex and age group between 18-20. Before start the experimental procedure, the subjects were asked to answer the questionnaire that contains the questions regarding the age, weight height, medication, Medical history, occupation, exercising habit etc. From that we can screen the subjects from normal and abnormal. The sampling time and sampling rates are made constant for all the subjects during acquisition of signals. We used 2 channels of the DAQ card to acquire signals from 2 sensors in Y direction. From the results obtained, we can concluded that the acceleration value obtained in terms of milli volts in channel 2 (Y-Axis of second accelerometer) is found low magnitude compared to the output of channel -1 (Y-axis of First accelerometer).

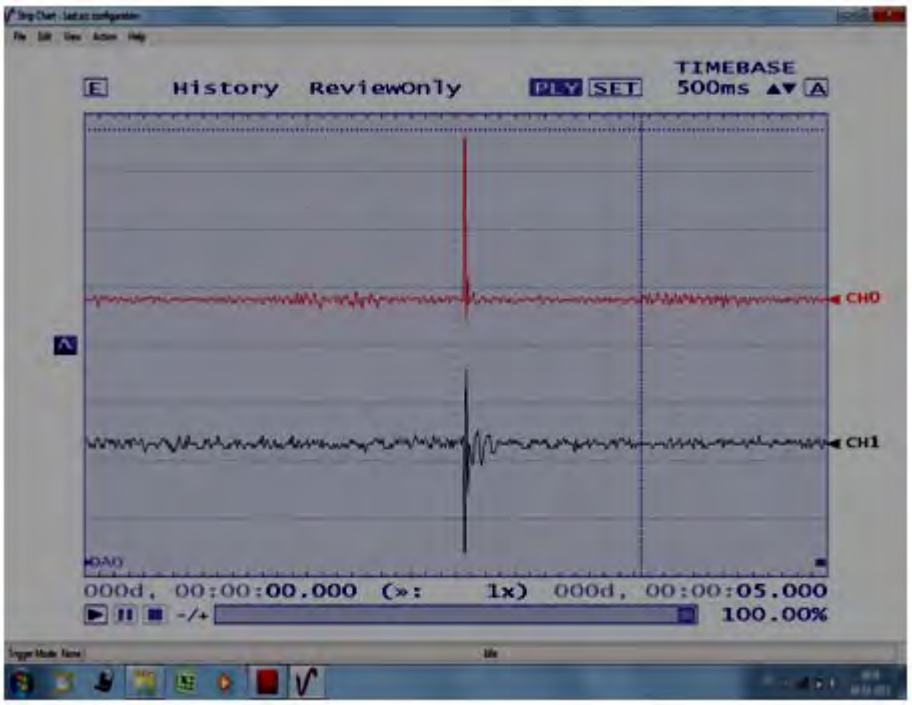


Fig.3 Typical impulse response of tibia of normal subject

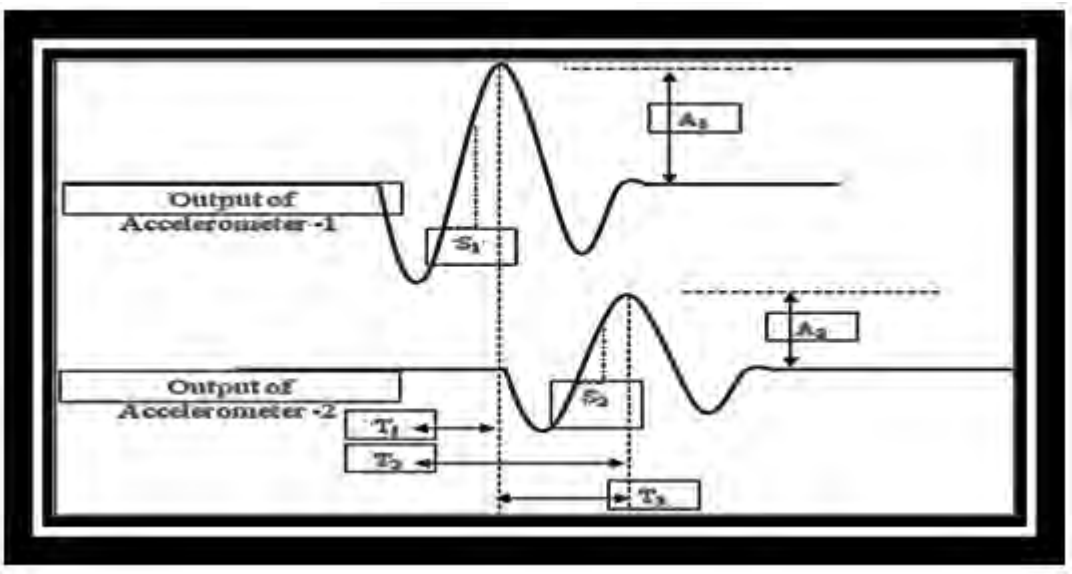


Fig.4 Impulse response curve

- **Wave velocity:**

V=d/T3 [Ref.10]

d- distance between accelerometers 1 & 2 in cm

T_3 – time duration between the two acceleration peaks in ec.

- **Amplitude Ratio:**

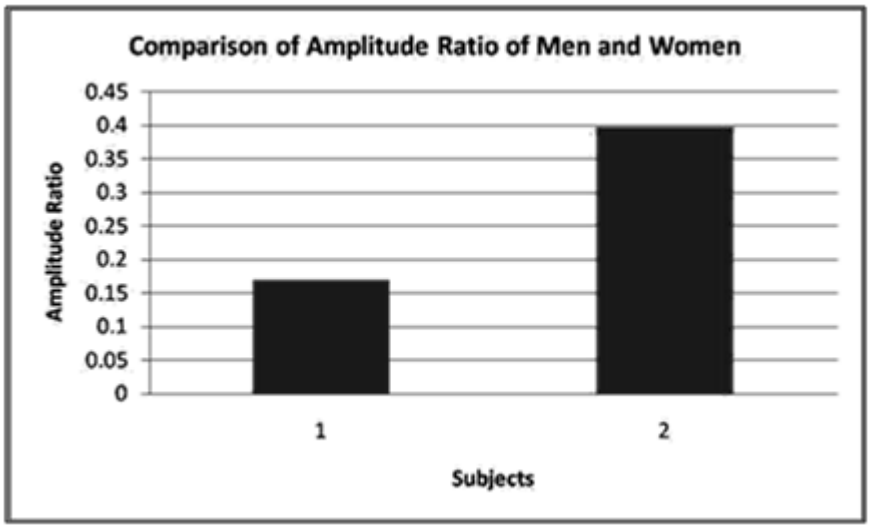
AR= A2/A1 [Ref.10]

Where, A1 and A2 are the peak amplitudes of I and II accelerometers

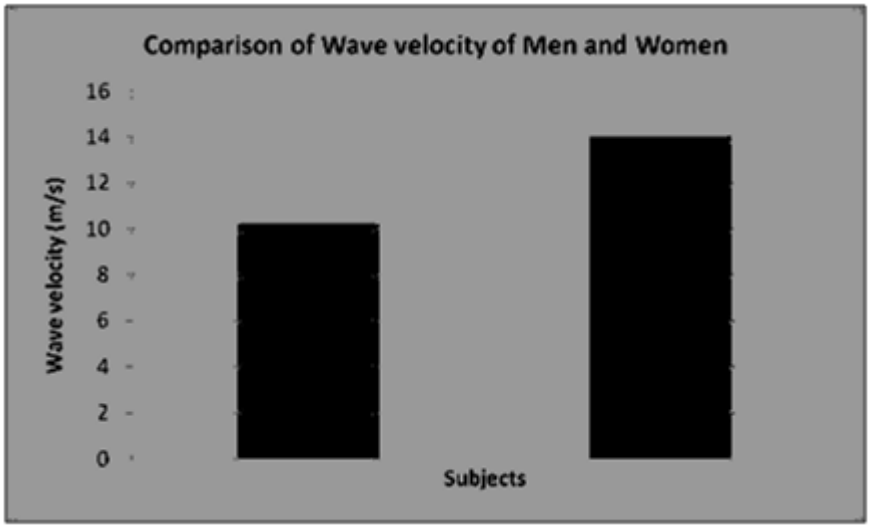
The following table shows the result of the parameters from the impulse response curves.

Sl.No.	Subject classification	Impulse response parameters	Student's t-test p-value
1.	Normal Men Vs. Normal Women (Age18-20), N=25	Wave velocity (m/s)	0.009
		Amplitude ratio	0.015

Table:1Impulse response parameters



Graph:1



Graph:2

It is found that the variation is observed more clearly in the Y-axis than X and Z-axes since the vibration from the electronic automated hammer is transmitted clearly in vertical through the bone than in horizontal direction. From the above comparison graphs it is found that the acceleration peak value is high for women compared to men .Hence the wave velocity and the amplitude ratio of men is lower than women.

V.CONCLUSION

A Instrumentation system is developed for assessing the bone quality and described how this can be used to diagnose and distinguish different subjects. By incorporating the precision accelerometer sensor and the automating knocking mechanism in the system good response is obtained. The experimental results have shown the usefulness of the system in assessing the quality of bone. Moreover further analysis can be done using this setup by selecting more parameters in order to strengthen the results. The technique gives a better understanding of the dynamic behaviour of bone under impact force. The study is non-invasive, reliable, easy to operate, inexpensive and has diagnostic potential in the assessment of bone quality. Further analysis has to be done by obtaining more number of data from older age group men and women (with menopause stage) and also with abnormal cases as a extension work in order to justify strongly that our system is highly reliable and can be used as a diagnosing tool for assessment of bone quality non-invasively it is required to .

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