Adaptive FIR Filter Processing of Vibroarthrographic Signal

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Abstract

The knee is one of the most important and injured site in human body. Current evaluation of the knee joint status are based on imaging such as CT and MRI, which are sensitive to knee joint disorders and expensive too, and others include the semi- invasive procedures. In order to overcome these problems a vibroarthrography is introduced. The aims of the present study were to investigate the most suitable location for vibroarthrography measurements of the knee joint to distinguish a healthy knee from knee osteoarthritis. Vibroarthrography appear as an innovative and non-invasive approach to solve this problem. Mechanical vibratory signals arising from the defected knee joint can be recorded recurring to a tiny accelerometer. Healthy cartilage is smooth and slippery, producing minimum vibration while deteriorated cartilage is more irregular, producing additional vibrations. Vibrations generated by the friction of deteriorated articular surfaces are different in terms of frequency and amplitude originating distinct and representative vibroarthrographic signals which allows the differentiation of a healthy and a pathological knee. In this work, the normal and pathological knee vibrations is acquired and processed by LMS Adaptive filter and its frequencies is obtained.
Keywords- Vibroarthrography, LMS Adaptive filter, MRI, CT, Cartilage, Accelerometer

I. INTRODUCTION

Knee problems are very common, and they occur in people of all ages. Knee problems can interfere with many things, from participation in sports to simply getting up from a chair and walking [9].This can have a big impact on human life. The most common disease affecting the knee is osteoarthritis [3]. The cartilage in the knee gradually wears away, causing pain and swelling. Injuries to ligaments and tendons also cause knee problems. A common injury is to the anterior cruciate ligament (ACL). ACL usually injure by a sudden twisting motion. ACL and other knee injuries are common sports injuries. Arthrography is medical imaging used to help evaluate and diagnose joint conditions and unexplained pain. It is very effective at detecting disease within the ligaments, tendons and cartilage. It may be indirect, where contrast material is injected into the bloodstream, or direct, where contrast material is injected into the joint. Arthrography may use computed tomography (CT) scanning, magnetic resonance imaging (MRI) or fluoroscopy – a form of real-time x-ray. Magnetic resonance imaging of the knee uses a powerful magnetic field, radio waves and a computer to produce detailed pictures of the structures within the knee joint. It is typically used to help diagnose or evaluate pain, weakness, swelling or bleeding in and around the joint. Knee MRI does not use ionizing radiation, and it can help determine whether you require surgery.

The vibration signals emitted from knee joints during their flexion or extension provide valuable clues regarding their pathological condition or physiological state. As a result, vibroarthrography (VAG), specifically the recording of human knee joint vibrations or acoustic signals during active movement of the leg, provides an invaluable noninvasive diagnostic tool for the early detection of articular cartilage degeneration [1]. Moreover, the resulting signal interference is not stable, but varies over time, from swing to swing, and from one individual to another. Therefore, effective interference cancellation techniques are required to reduce the variability of the vibration signal so that more reliable diagnostic results can be obtained.

A. Vibroarthrography

The word Vibro has Latin roots means Vibration.
The word Arthro is a Greek word which means Joints.
The word graphy is originated from French word graphie which means process of writing or recording.
So, Vibroarthrography etymologically means the process of recording of Knee joint Sounds. The Knee Joint sounds are primarily generated during flexion and extension. The Knee joint sounds recorded by an Accelerometer sensor are converted to digital signals and are plotted and termed as VAG (Vibroarthrograph) signal [2].

II. VIBROARTHROGRAM

Vibroarthrography (VAG), the recording of vibrations or acoustic signals from the knee joint during flexion and extension, can be used as a non-invasive diagnostic tool to detect articular cartilage degeneration [1]. VAG signal is the acoustic and vibrational signal generated during a leg active flexion and extension caused by the vibration of articular surfaces of the defected joint. Healthy cartilage is smooth and slippery producing minimum vibration while deteriorated cartilage is more irregular producing additional vibrations which can be audible in some cases [2]. Vibrations generated by the friction of deteriorated articular surfaces are different in terms of frequency and amplitude compared to healthy ones, originating distinct VAG signals. Mechanical vibratory signals arising from the defected joint were recorded recurring to miniature accelerometers, giving place to a new method for joint assessment, so called vibroarthrography. VAG signals analysis may allow the differentiation between a healthy and an injured knee. Despite the great potential of this method, several signal processing techniques must be applied to the VAG signal in order to eliminate background noise, muscular activity and knee joint movement-related component. These undesirables' components obscure the truly wanted signal since they basically mask the low amplitude component that corresponds to knee joint abnormal vibrations.

A. Vibroathrography Instrument

Vibroarthrogarphy involves picking up the vibrations from the knee through accelerometer and fed into the arduino, where they are recorded on PLX DAQ. The Fig 2.1 shows the block diagram of a recording setup used for VAG.

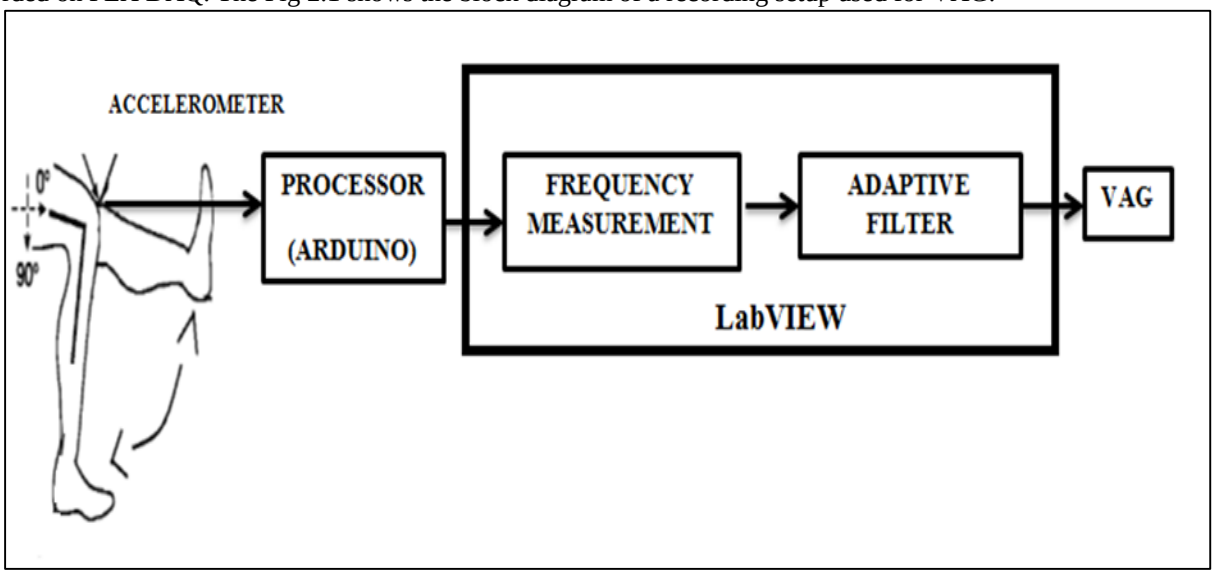

Fig. 2.1: Recording Setup of Vibroarthrography

VAG signals recorded using accelerometer placed at the mid patella or mid tibial shaft position of a subject during isometric contraction of the rectus femoris muscle. Accelerometers were attached to the subject's skin in the region of the knee. The accelerometers were positioned such that the majority of the sensors detected the VAG signal, while the remainder monitored variations in the signal along the leg, providing information with which to discriminate the noise signals from the VAG signals. The recorded signals were digitized and processed using LabVIEW software [6].

B. Signal Acquisition

In order to obtain a reliable and feasible signal that describes and fully characterizes the knee joint status several considerations must be taken into account [6]. Among them it must be considered the type of used sensors, its inherent limitations, its placing on the knee joint, the preprocessing techniques and signal analysis methodologies.

C. Accelrometer

Accelerometer is one of the most common inertial sensors, a dynamic sensor capable of a vast range of sensing. Accelerometers are available that can measure acceleration in one, two, or three orthogonal axes as shown in Fig 2.2. They are typically used in one of three modes:

1) As an inertial measurement of velocity and position;
2) As a sensor of inclination, tilt, or orientation in 2 or 3 dimensions, as referenced from the acceleration of gravity (1 g = 9.8m/s2);

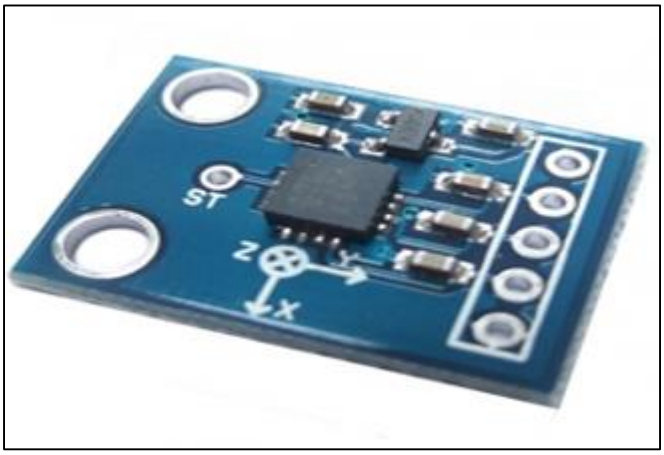

Fig. 2.2: Accelerometer

D. Principles of Operation

The basic principle of operation behind the MEMS accelerometer is the displacement of a small proof mass etched into the silicon surface of the integrated circuit and suspended by small beams. Consistent with Newton's second law of motion (F = ma), as an acceleration is applied to the device, a force develops which displaces the mass. The support beams act as a spring, and the fluid (usually air) trapped inside the IC acts as a damper, resulting in a second order lumped physical system. This is the source of the limited operational bandwidth and non-uniform frequency response of accelerometers.

E. Arduino

Arduino is a single-board microcontroller to make using electronics in multidisciplinary projects more accessible. The hardware consists of a simple open source hardware board designed around an 8-bit Atmel AVR microcontroller, or a 32-bit Atmel ARM. The software consists of a standard programming language compiler and a boot loader that executes on the microcontroller. Figure 2.3 shows the Arduino board.

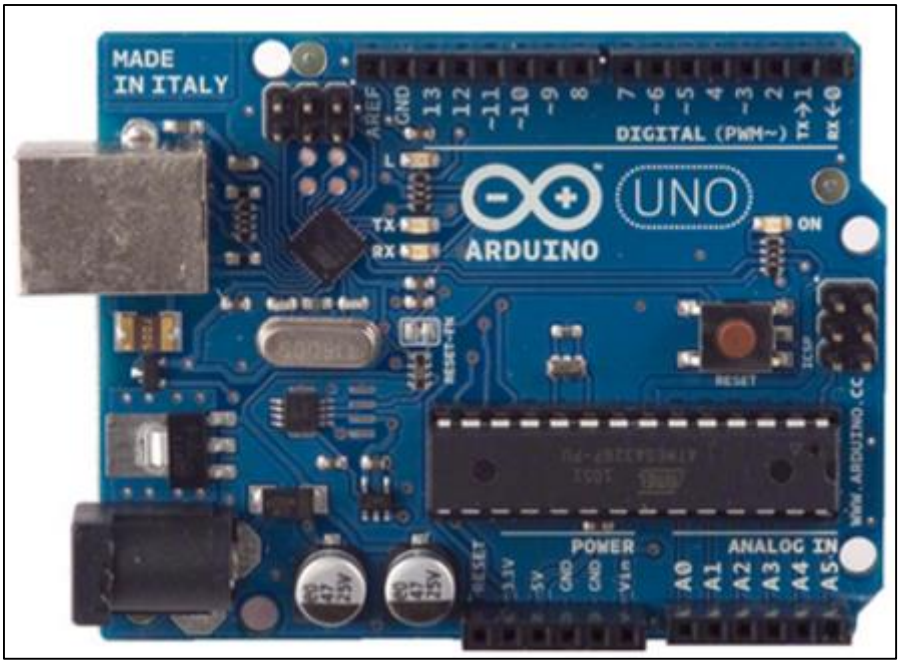

Fig. 2.3: Arduino

F. Positioning of Sensors

The correct positioning of sensors is crucial for an accurate and feasible assessment of knee joint condition. Regarding this matter, the optimal location is generally accepted to be the best contact area for knee auscultation, as the medial compartment slightly below the midline of the patella [8] (medial condyle on the patella). Fig 2.4 shows the position of sensor placement.

Fig. 2.4: Position of Sensor

G. Experimental Protocol

The most common performed tasks for knee joint assessment is the knee motion from flexion to extension whereas in the extension position the knee is making an certain angle between the femur and the tibia while in the flexion position the knee is making an angle up to 90° angle [2]. This movement from the full flexion to extension is defined as one cycle. During the task, the subject is always seated and without their feet touching the ground, performing the mentioned movement. VAG signal was taken from different ages of person from age of 5 to 70 and also from patients having knee pain.

III. SIGNAL PROCESSING

Signal processing is an enabling technology that encompasses the fundamental theory, applications, algorithms, and implementations of processing or transferring information contained in many physical, symbolic, or abstract formats broadly designated as signals.

A. Adaptive Filter

A filter which self adjust its transfer function is called adaptive filter. It required two signals: input signal (signal and noise) and desired signal. The error signal is used as feedback in the form of signal in adaptive filter which is used to refine the transfer function to match changing parameters [4,5]. Mostly the adaptive filters are used for reducing the noise content.

An adaptive filter is a system with a linear filter that has a transfer function controlled by variable parameters and a means to adjust those parameters according to an optimization algorithm. Because of the complexity of the optimization algorithms, almost all adaptive filters are digital filters.

An adaptive filter is defined by four aspects:

1) The signals being processed by the filter
2) The structure that defines how the output signal of the filter is computed from its input signal
3) The parameters within this structure that can be iteratively changed to alter the filter's input-output relationship
4) The adaptive algorithm that describes how the parameters are adjusted from one time instant to the next.
5) By choosing a particular adaptive filter structure, one specifies the number and type of parameters that can be adjusted.

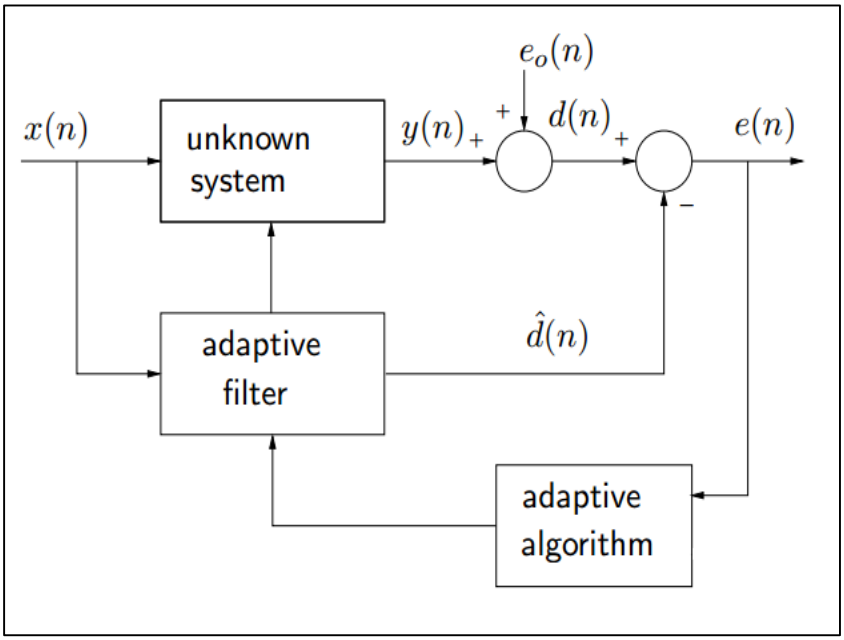

Fig. 3.5: Block Diagram of Adaptive Filter

Where
x(n) – input signal
y(n) – output signal
d(n) – desired signal
e(n) – error signal

Fig 3.5 shows a block diagram in which a sample from a digital input signal x(n) is fed into a device, called an adaptive filter, that computes a corresponding output signal sample y(n) at time n. For the moment, the structure of the adaptive filter is not important, except for the fact that it contains adjustable parameters whose values affect how y (n) is computed. The output signal is compared to a second signal d (n) called the desired response signal, by subtracting the two sample sat time n. This difference signal can be calculated by the equation

$$e(n) = d(n) - y(n)$$

Which is known as the error signal.

B. Adaptive Noise Cancelling

When collecting measurements of certain signals or processes, physical constraints often limit our ability to cleanly measure the quantities of interest. Typically, a signal of interest is linearly mixed with other extraneous noises in the measurement process, and these extraneous noises introduce unacceptable errors in the measurements. However, if a linearly related reference version of any one of the extraneous noises can be cleanly sensed at some other physical location in the system, an adaptive filter can be used to determine the relationship between the noise reference x(n) and the component of this noise that is contained in the measured signal d(n) [4]. After adaptively subtracting out this component, what remains in e(n) is the signal of interest. If several extraneous noises corrupt the measurement of interest, several adaptive filters can be used in parallel as long as suitable noise reference signals are available within the system.

C. Least Mean Square Algorithm

It is a search algorithm in which gradient vector computation is simplified by modifying the objective function. Least mean squares algorithms are the class of adaptive filter by finding the filter coefficients to minimize the cost function and also less complicated. It produces the least mean squares of the error signal which is the difference between the desired and actual signal .The standard LMS Algorithm [4] performs the following operations to update the coefficients of the adaptive filter.

Calculate the output signal y (n) from the adaptive filter,

$$y(n) = w'(n)*x(n) \qquad (3.1)$$

Calculate the error signal e (n) by

$$e(n) = d(n) - y(n) \qquad (3.2)$$

Update the filter coefficients by using the equation (3.3):

$$w(n+1) = w(n) + \mu * e(n) * u(n) \qquad (3.3)$$

Where
μ = step size of the adaptive filter
x (n) = input vector

w (n) = filter coefficients vector ,
u (n)=filter input vector
The LMS algorithm is a widely used algorithm for adaptive filtering. The algorithm is described by the following equations:

$$y(n) = \sum_{i=0}^{M-1} w_i(n) * x(n-i) \quad (3.4)$$

Where i = 0

$$e(n) = d(n) - y(n) \quad (3.5)$$

$$w_i(n+1) = w_i(n) + 2ue(n)x(n-i) \quad (3.6)$$

In these equations, the tap inputs x(n),x(n- 1),……,x(n-M+1) form the elements of the reference signal x(n), where M-1 is the number of delay elements. d(n) denotes the primary input signal, e(n) denotes the error signal and constitutes the overall system output. wi(n) denotes the tap weight at the nth iteration. In equation (3.6), the tap weights update in accordance with the estimation error. And the scaling factor u is the step size parameter u controls the stability and convergence speed of the LMS algorithm.

D. Mean Square Error (MSE)

MSE value indicates the performance of the adaptive filter. The MSE value can be calculated by the equation (3.7)

$$MSE = \sum\{((X(n)-Y(n))^2 / Length(X(n))\} \quad (3.7)$$

Smaller the MSE value betters the performance of the filter [5].

E. LMS Adaptive Filter Structure

The VAG data is collected in PLX DAQ and the file is loaded to LabVIEW environment as .lvm file to Read from measurement file. The VAG signal is severed as the input x(n) for LMS adaptive algorithm. The input signal x(n) is filtered using "filter" function and the output of this function is known as desired signal d(n) [7]. The same x(n) signal is given as the input to both LMS adaptive algorithm. The value of weight w(n) is initialized. LMS filter is designed using filter size and step size (μ). The output of the algorithm y(n) is calculated from LMS filter, desired signal d(n) and x(n). The error signal is calculated by subtracting the output signal y(n) from desired signal d(n).

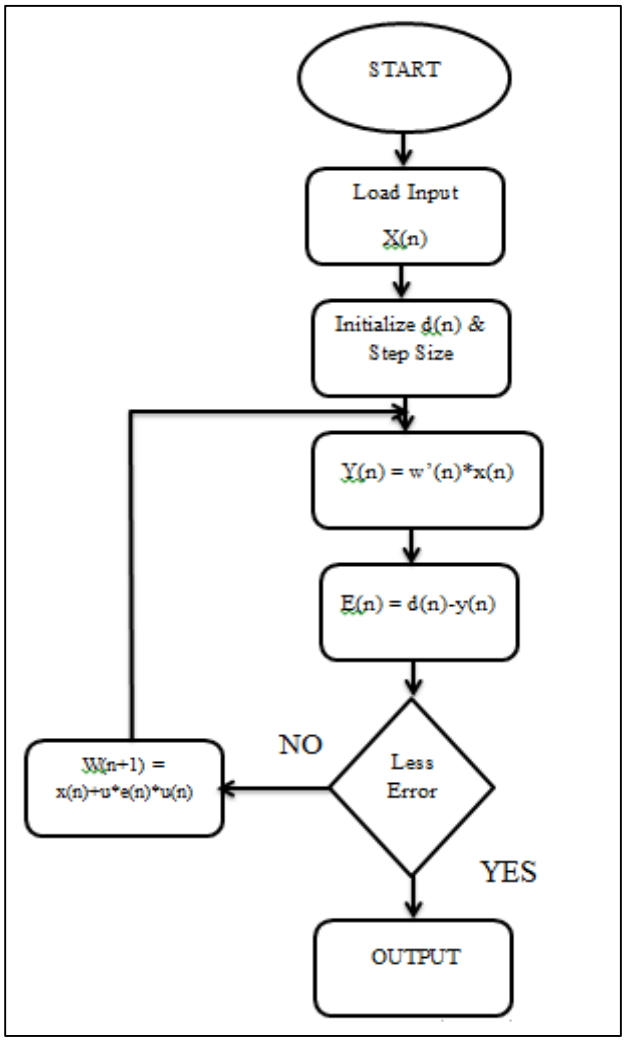

Fig. 3.2: Flow Chart of LMS Adaptive Algorithm

Fig 3.2 explains the flow of LMS adaptive algorithm. The program continues until the error is minimized. The control structure used is for loop. For loop enable to have an operation repeated a specified number of times. This may be required in summing terms of a series, or specifying the elements of a Non-uniformly spaced vector such as the first terms of a sequence defined recursively. When the error value is maximum the weight w (n) is updated and the cycle repeats. The loop is terminated when the error is zero.

IV. RESULT AND CONCLUSION

A. VAG Signal

The simulated outputs of the VAG signal are discussed below.

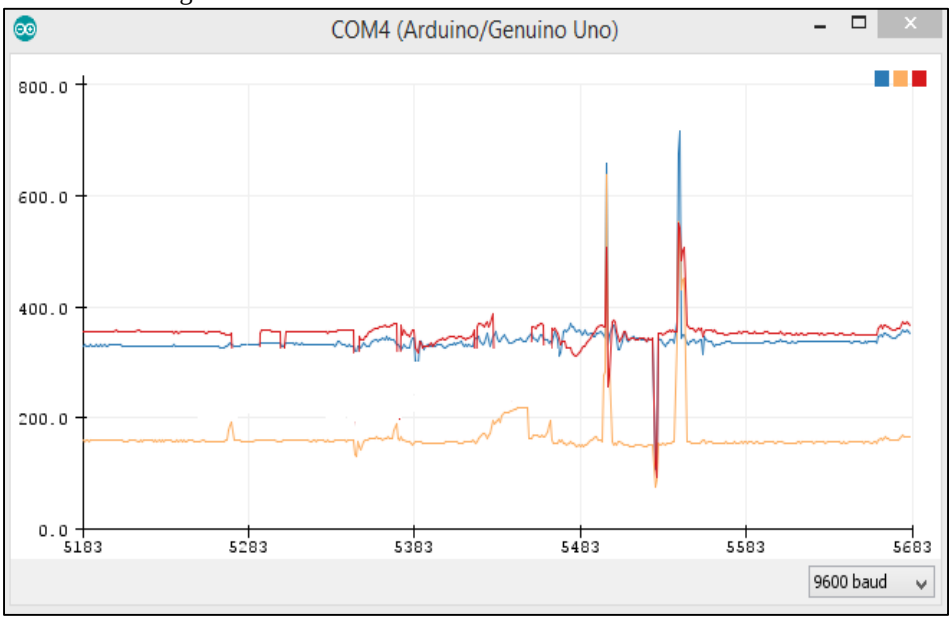

Fig. 4.1: Output of Normal VAG Signal

The above Fig 4.1 shows the normal VAG signal. This VAG Signal is obtained from Arduino output. In this figure 3 signals are obtained ie x output, y output and z output of accelerometer respectively. These signals are converted in to data by PLX DAQ.

B. LMS Output

The output of LMS algorithm is discussed below in detail.

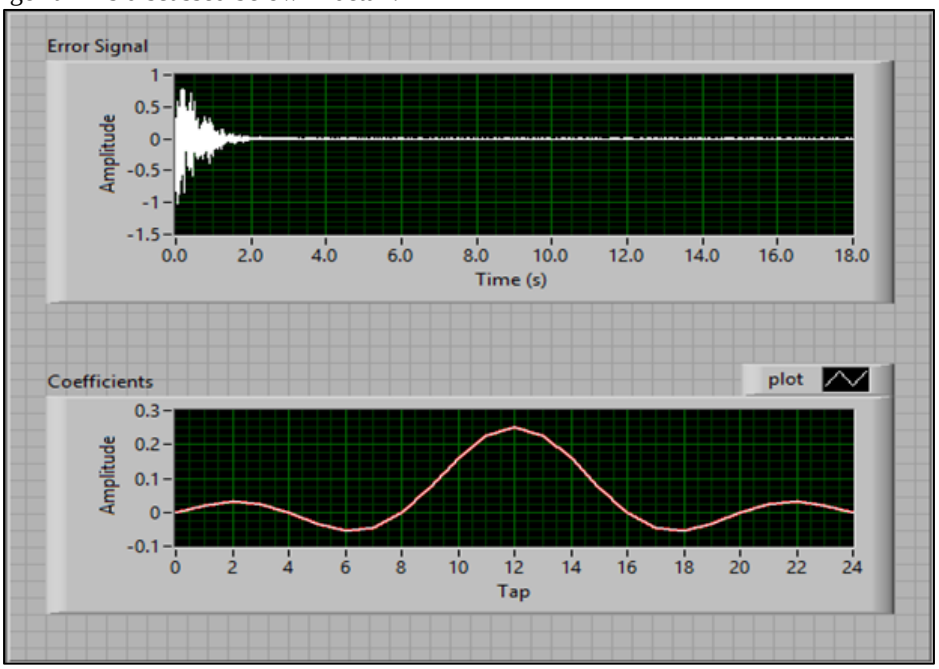

Fig. 4.2: LMS output and Error Signal

The above Fig 4.2 is a result of LMS adaptive filter algorithm with the step size of 0.002. This figure shows the LMS output signal and the error signal. The error signal is gradually decreased; it signifies the efficiency of the LMS algorithm.

Table 4.1: Performance of LMS Adaptive Filter

S.No	STEP SIZE	FILTER LENGTH	MSE
1.	0.002	25	0.57
2.	0.025	25	0.927
3.	0.002	50	0.448
4.	0.025	50	0.842

Table 4.1 infers the MSE values for different filter size and step size. The increase in step size increases the MSE value. The same for increase in filter size.

C. VAG Signal Datas

Table 4.2 infers the normal VAG signal collected from 26 normal patients (without knee pain) and 10 patients having knee pain.

Table 4.2: VAG Signal Data

S.NO	*AGE*	*GENDER*	*WEIGHT Kg*	*FREQUENCY Hz*
1	*11*	*M*	*25*	*68.99*
2	*13*	*F*	*36*	*71.98*
3	*9*	*M*	*22*	*45.63*
4	*15*	*M*	*42*	*74.20*
5	*9*	*M*	*28*	*63.23*
6	*21*	*F*	*74*	*85.94*
7	*42*	*F*	*65*	*220.34*
8	*45*	*M*	*88*	*170.95*
9	*42*	*F*	*90*	*445.39*
10	*54*	*F*	*65*	*204.58*

V. CONCLUSION AND FUTURE ENHANCEMENT

The development of a vibrational-based classification system for knee joint assessment was successfully obtained by accelerometer during a knee extension/flexion test. This system showed that it may provide the differentiation between a healthy and pathological knee, as reported in several other studies. Such system could be used as a reliable, accurate, cheap and non-invasive screening diagnostic tool in the clinical practice. Additionally, it would provide detailed insight, at cartilage level, about the knee joint status and affected structures that may not be detected with other current diagnostic tool (only gross and symptomatic changes are detected with the current image-based techniques), possibly enabling the early detection of knee joint disorders Moreover, such system may also be used as potential monitoring tool in combination with physiotherapy which would improve the overall rehabilitation process. Despite the promising results, future work needs to be performed in the data gathering and analysis process to increase the overall robustness of the classification system. As for future work, it is suggested to study the biomechanical properties of the knee joint emitted vibrations under different types of friction and or loading conditions, increase the sensor's sampling frequency, optimize the experimental protocol (differences in the leg swing velocity and knee size must be considered for a better classification) and testing several other different classifier (e.g. neural networks).

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