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Signal processing techniques for accurate screening of wrist fractures.

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ABSTRACT The common way for doctors to differentiate wrist injury in to a sprain or a fracture, is to take radiographs (X-ray), which expose patients to radiation. The purpose of this study is to explore a non-invasive method to screen for potential fractures. A small, computer run system has been developed which consists of a vibration induction mechanism and a sensing system for capturing the vibration signals. Two analyzing techniques were considered. The first involves extraction of wavelet coefficients from decomposition of data and the second applies Fast Fourier Transform to the data. Results of both techniques were then cluster analyzed to partition between fracture and sprain. The data were acquired from both the injured and uninjured wrists of six adult patients. This study is currently being evaluated on children's wrists.

Keywords: Vibration analysis, Fast Fourier Transform, Wavelet decomposition, Fracture screening.

1 INTRODUCTION

Use of ionizing radiation (x-rays) to produce radiographs is the most common procedure for doctors to differentiate wrist injury into a sprain or a fracture. Each wrist radiograph costs around £60 in the United Kingdom and almost 60 percent of these show no fracture. Thus, a non-invasive technique is required to minimize both radiation exposure and cost.

Various technological systems in both industry and medicine apply either Fast Fourier Transform (FFT) or Wavelet Coefficient extraction to process acquired signals. In this study, we have applied *both* methods on signals obtained from human wrist bones and then compared the results to find out which method is more accurate to screen for fracture.

Vibration analysis is an established method used in industry for monitoring or diagnosing faults in electric machines by means of signal analysis and signal processing. Mechanical vibrations cause one or more inputs and outputs of a system to change over time and the signals produced are then evaluated for type and severity

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[1] Please note that the LNCS Editorial assumes that all authors have used the western naming convention, with given names preceding surnames. This determines the structure of the names in the running heads and the author index.

of defect [1]. Studying the vibration effects, fault detection and capability of this method of machine maintenance is an on-going process [2] [3].

By comparison, vibration analysis in the medical field is still in its infancy. In 1932, Lippmann percussed his finger to cause vibration, used his stethoscope to sense it and explained the benefits for using the method in clinical diagnostics. He suggested that analysis of percussion appeared more accurate than x-ray for the diagnosis of fractures [4]. Some researchers developed a finite model of a dry tibia for predicting its natural frequencies of vibration [5]. Nokes published a major study where he proposed the idea of monitoring various pathological and trauma-induced conditions by applying a stimulus to bone [6]. Experiments demonstrated that vibration induced by mechanical means can indicate mechanical properties of bones, such as density and biological state. [7]. The influence and results of low-frequency vibrations in the lower limbs have been accurately determined for the analyses based studies [8]. The effects of skin and muscle on the bone's low frequency vibration signals have been demonstrated [9]. We have previously used samples of frequency spectra from adults with and without wrist injuries, to cluster analyze into fractured and sprained bones [10].

Application of vibration analysis is still developing. Additionally, studies are being conducted to find out if its advantages outweigh the disadvantages. However, in the context of health care, the practical applications of vibration analysis are in the near rather than distant future.

2 Smart Systems

Smart systems are defined as devices that incorporate the functions of sensing, actuation, control and adaptation. They can describe and analyze situations, and take decisions based on the available data in a predictive or adaptive manner, thereby performing smart (intelligent) actions [11].

Smart systems are found in many applications such as automotive, manufacturing, environment, energy and health care. These systems have the capability to solve very complex problems, including taking over human cognitive functions [12].

In the case of health care and medical applications, smart systems are mainly used to improve the quality of diagnosis and treatment. The system described in this paper shows the utilization of miniature smart hardware devices to produce and procure energy through a medium. The device used in this study is a modified version of a device previously developed by our group [13]. The data acquired from this method is stored and analyzed using complex programmed routines through specific software.

2.1 Device

Hardware: The device comprises of the following parts.
- Electrical Vibration Inducer the forward movement of which produces the impact.

- Piezoelectric Sensor with broad bandwidth, high sensitivity, light weight and low cost features.
- NI myDAQ Assistant used for frequency generation and causes the inducer to initiate and record the vibration response via the sensor.
- 12V Battery.
- Control Circuit.

Software: LabVIEW and MATLAB. The fundamental principle behind using LabVIEW is for its Integrated Development Environment (IDE) and the Graphical User Interface (GUI), which were used to develop the data acquisition feature for this device. MATLAB was used to process and analyze the acquired data.

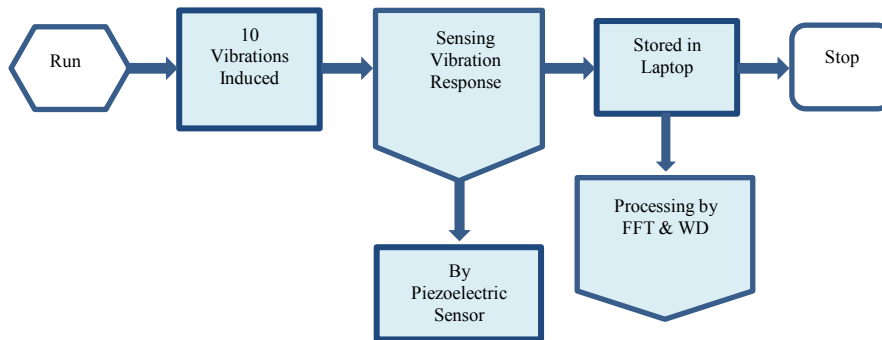Thus the system developed for this research, is undeniably a Smart System.

Figure 1: Process Flow Chart

3 Research Methodology and Results

Adult patients, aged between 20 to 70 years old, attending the Emergency Department of a local hospital, following a wrist injury, volunteered to take part in this study. Vibration data were collected from both injured and uninjured wrists of six patients and processed blinded to radiographic findings. This means that at the time the data were produced and analyzed, it was not known if the injured wrist had a sprain or a fracture. They all sat on a chair during recording. Vibration caused by mechanical excitation, was induced by impacting the most prominent bone in the elbow. The vibration responses were recorded by placing a piezoelectric sensor which has a maximum operating frequency, on a bony prominence at their wrists.

10 vibrations were induced over 10 seconds in total and each response was recorded at a rate of 60000 samples per second. These data were stored in the computer and then processed by Wavelet Decomposition (WD) and Fast Fourier Transform (FFT).

I.   The coefficients were extracted, after decomposition of the acquired data by Level 5 filtration. These were derived by a scaling function "Daubechies 5

(db5)" wavelet family. Two degree polynomials were plotted to find the best fitted curve among the number of coefficients derived from the WD. The equation of each of the polynomials was also calculated.

II.   The bone vibration recorded from six patients was converted to a magnitude frequency spectrum by application of FFT processing.

Figures 2 and 3 display the results produced by Fast Fourier Transform and Wavelet Decomposition.
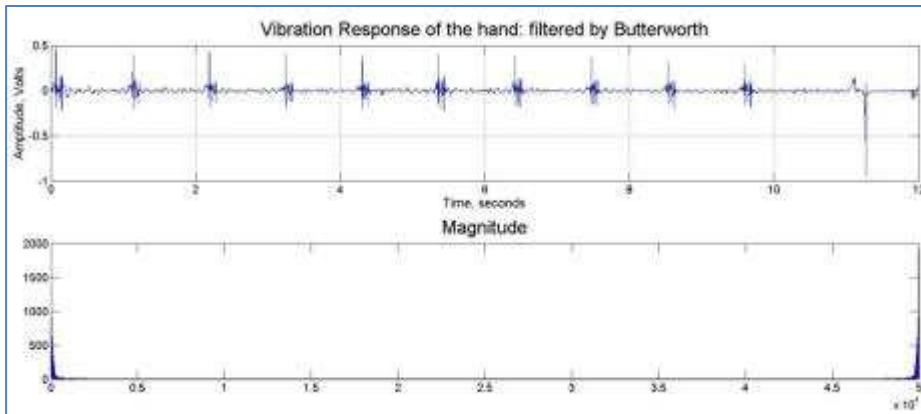
Figure 2: Filtered Vibration Response and Magnitude Spectrum by FFT.

Figure 3: Best fitting two degree polynomial among 18 Wavelet Decomposed Coefficients.

The frequencies produced by the FFT and the constants derived from the equation produced by the best fitted polynomial curve, were classified using the "dendrogram" (a hierarchical cluster tree diagram) to show which groups are similar. The "dendrogram" was plotted using a linkage of Euclidean distance between each data

set. The diagram produced by both FFT and Wavelet Decomposition was similar and is illustrated in Figure 2

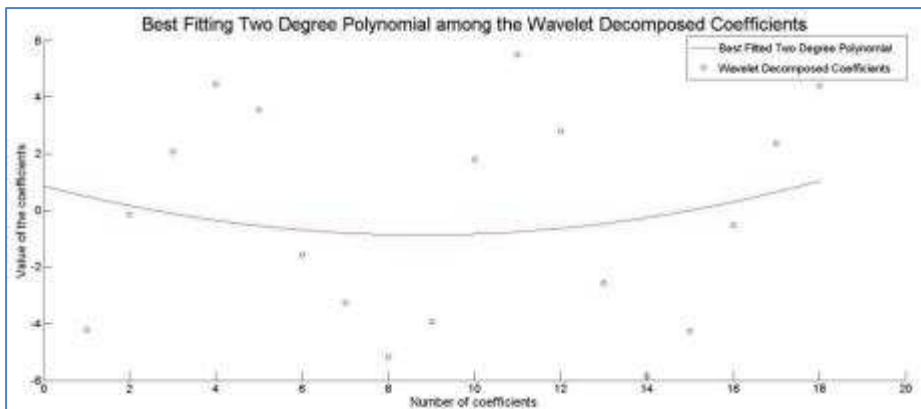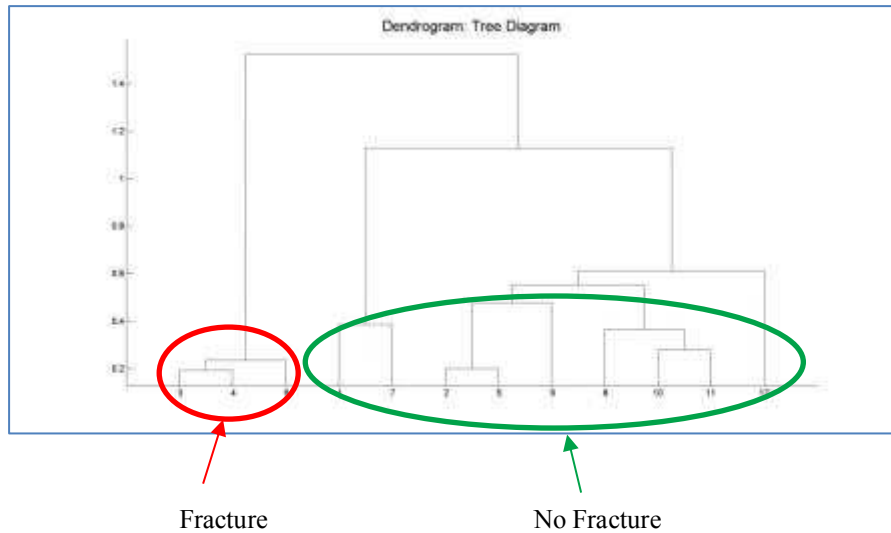Figure 2: Both FFT and Wavelet Decomposed Coefficients produced the same results by the dendrogram.

These data were then analyzed using Fuzzy C-means to find the membership percentages required for each data set to belong to a particular cluster. Although similar classes can be observed from the dendrogram, Fuzzy C-means was performed to ascertain the suitable percentage required for each group. The results of cluster analysis are shown in Tables 1 and 2.

Table 1: Fuzzy C-means cluster analysed results after Fast Fourier Transformations

Type	Gender	Probability of having Fracture	X-ray Results
Injured	Female	0.3397	No Fracture
Injured	Male	0.3227	No Fracture
Injured	Female	*0.9836*	Fracture
Injured	Male	0.9624	Fracture
Injured	Female	0.2429	No Fracture
Injured	Female	*0.9275*	Fracture
Normal	Female	0.2758	
Normal	Male	0.0733	
Normal	Female	0.3699	
Normal	Male	0.0520	
Normal	Female	0.1240	

Normal	Female	0.1854	

Table 2: Fuzzy C-means cluster analysed constants extracted from equation of the best-fitted polynomial among the Wavelet Decomposed coefficients.

Type	Gender	Probability of having Fracture	X-ray Results
Injured	Female	0.0405	No Fracture
Injured	Male	0.0102	No Fracture
Injured	Female	*0.9400*	Fracture
Injured	Male	*0.8288*	Fracture
Injured	Female	0.1933	No Fracture
Injured	Female	*0.9922*	Fracture
Normal	Female	0.0356	
Normal	Male	0.0343	
Normal	Female	0.0016	
Normal	Male	0.5663	
Normal	Female	0.0004	
Normal	Female	0.0123	

4 Discussion

Tables 1 and 2 clearly reflect the techniques used in this study.

WD produced comparatively similar results to FFT using both the dendrogram and Fuzzy C-means. However, there are some disadvantages and unreliable results of using the WD technique:

- it provides both Frequency and Time related information which makes it difficult to use, as the design which induced 10 vibrations must produce vibration responses very similar to each other over the 10 seconds to ensure that both frequencies and time domain information can be processed further.
- to make sure the above reason does not affect the accuracy of the data collected, the first few sets of data are left out when doing the analysis.
- there are a lot of steps before reaching the concluding stage of Fuzzy C-means cluster.
- one wrist which was not injured showed 0.5663 percent chance of being fractured which is not possible.

On the other hand, the frequencies produced by the FFT can easily be fed into the Fuzzy C-means code already built, to produce membership values. Less steps were involved in building FFT codes.

5 Conclusion and Further Works

Both FFT and WD techniques produced almost all correct results. However, the FFT is a hassle free and accurate process for future use. The efficiencies are to be checked by a larger volume of data. The discomfort level experienced by each patient for both wrists was recorded and every participant felt that the vibrations would not be uncomfortable to children aged between 0 and 15 years old. The study is being continued at a local Children's Hospital and aims to recruit a larger number of participants to test the accuracy of the techniques. More signal processing techniques are likely to be assessed once a larger volume of data is available.

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