Signal processing of acoustic emissions to identify Osteoarthritis in the knee joint

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Background

- Global life expectancy is on the rise with obesity becoming an increased health concern.
- This is coupled with an increasing number of individuals with Osteoarthritis (OA).
- OA is a painful degenerative musculoskeletal disease that causes a restriction in joint movement due to narrowing and degradation.
- In 2011 98% of primary knee replacements in the UK were as a result of OA [1], due to this prominence OA was chosen as the project focus.

Currently diagnosis of OA is a time consuming process which can be achieved though:

- X-ray / computed tomography (CT) scans
- Magnetic Resonance Imaging (MRI) scans

Figure 1 - Normal knee (left) compared to a knee with OA (right) [2]

- Whilst no cure for OA is available early intervention can help to alleviate symptoms and reduce the potential negative impacts, improving a patients quality of life.
- Treatments include: diet, exercise, physiotherapy and in some cases joint replacement / surgery.

This project used acoustic emission (AE) which is a release of energy as the result of a deformation process in a structure.

- AE sensors are normally piezoelectric and functional throughout the ultrasonic spectrum (20 kHz - 1 MHz)
- Possible sources of AE from an arthritic joint include osteophytes and the potential for bone-on-bone contact.

Figure 2 shows the typical AE parameters obtained from tests (setup shown in Figure 3), these include but are not limited to: Arrival time, peak amplitude, rise time, signal duration, counts, energy , root mean square (RMS).

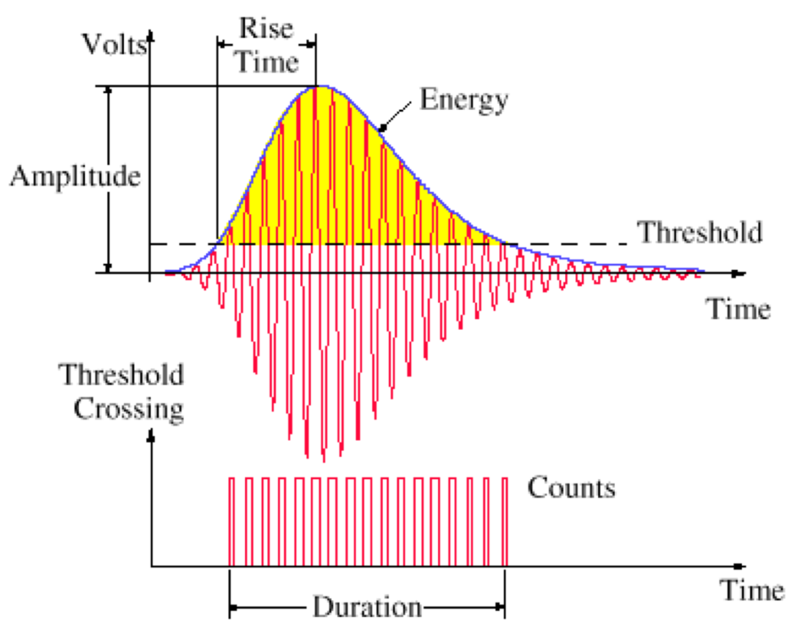

Figure 2 – AE test parameters [3]

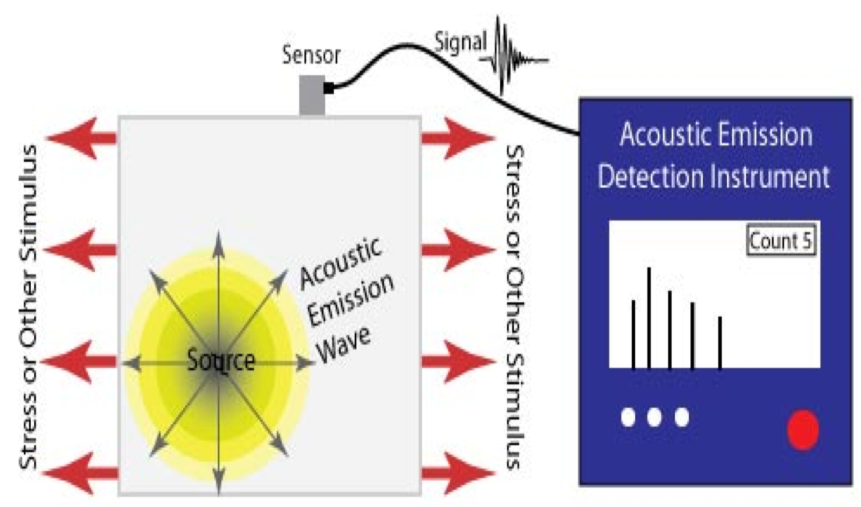

Figure 3 – AE test apparatus [4]

Aims

- To provide a non-invasive, easy to use, cost-effective device which is able to diagnose a patient's degree of knee joint degeneration.
- To further previous work done at the University of Southampton regarding the potential of using AE testing to test for the earliest stages of OA. Further data analysis will be performed on previous data with the aim of creating a model able to predict a joint condition solely from its acoustic signature. Specifically, the methods used consisted of: principal component analysis (PCA) and linear discriminant analysis (LDA).

Method

- Testing was undertaken at Spire Southampton Hospital. This project tested arthritic individuals as well as nominally healthy young patients (needed for LDA model validation).
- 2 piezoelectric sensors were mounted on the medial and lateral sides of a patent's knee (Figure 4). 'Arthritic' and nominally 'healthy' class labels were used to categorise the condition of a patient's knee joint.
- The patient was then asked to sit and stand 3 times. AE data was recorded into the (4-channel) Vallen AMSY6 and amplified by the AEP5 preamplifier.

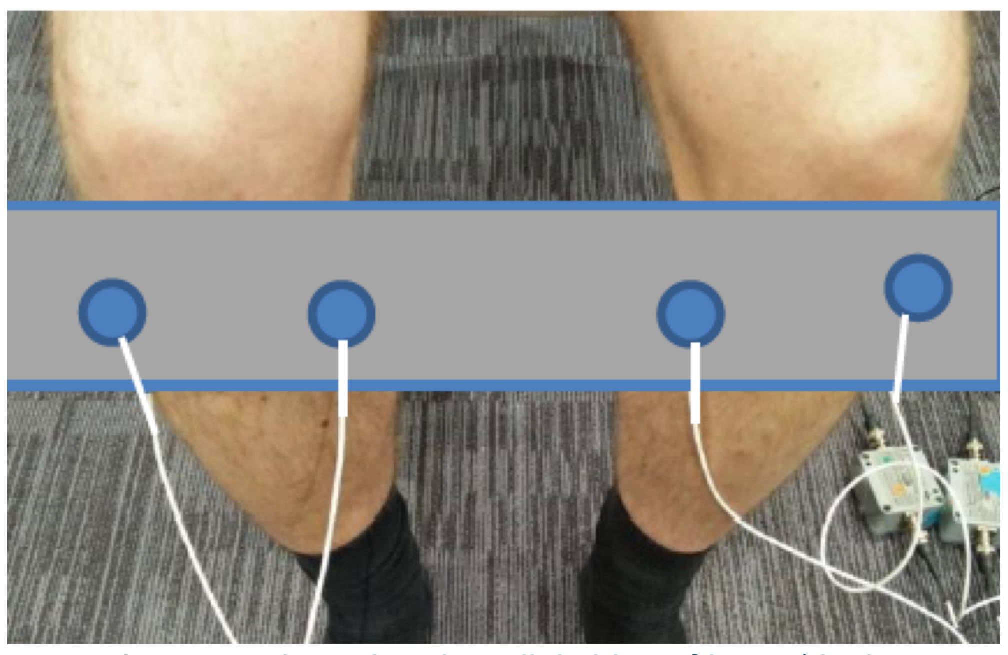

Figure 4 – Sensor attachment on lateral and medial sides of knee (design removed on request)

The results of these tests were then subjected to:

- Dimensionality reduction (through PCA)
- The PCA output was then used to create a supervised machine learning (LDA) model. Which could in turn predicted the condition of a set of new test data (shown in Figures 5 and 6). The most dominant features were found to be amplitude (A) and energy (E).

Results

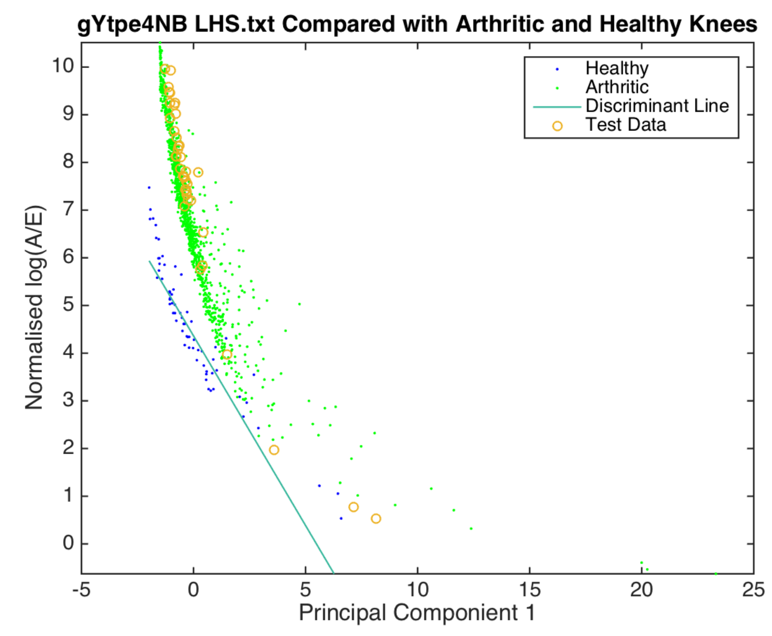

Figure 5 – 'Arthritic' patient

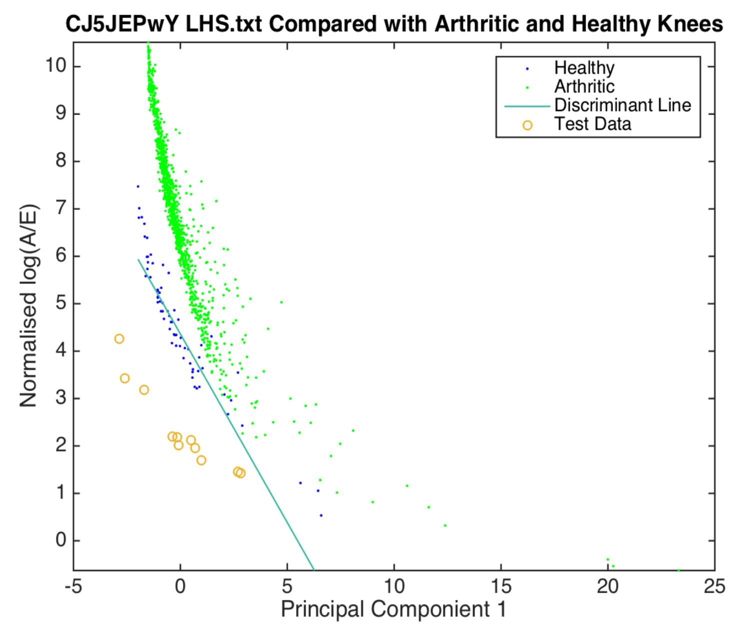

Figure 6 – 'Healthy' patient

- Figures 5 and 6 show the LDA output prediction model for 'arthritic' and 'healthy' knees respectively.
- The LDA model created was passed a ratio of the most dominant features - A/E. The logarithm of this quantity was taken as this was found to produce an almost linear relationship enabling a discriminant line to be produced.
- The test data was analysed, if (the majority of) the data points it was above or below this line then a prediction of 'arthritic' or 'healthy' was given respectively.
- Due to the complexity of OA and potential patient conditions it was chosen to use generalised class labels of (nominally) 'healthy and 'arthritic' throughout the project.

The LDA model created was tested on blind data from 5 patients (whose knees were either arthritic or nominally healthy). In all 5 cases the model correctly predicted the diagnosed condition.

Summary

•This project found that PCA and LDA are viable methods of assessing trends within AE test data. Promising results were obtained from the LDA model.
•The logarithm of normalised A/E was found to be a useful parameter in showing the presence of OA within a knee joint. This extends on previous methods as current literature normally only considers amplitude when determining condition.
•Further work should focus on quantifying the level of damage stage of OA though distance from the discriminant line. Clustering analysis, support vector machines and other machine learning approaches should also be investigated.
•If these techniques were used the National Health Service (NHS) would save time, money and resources.

References

[1] Arthritis Research UK, "OSTEOARTHRITIS IN GENERAL PRACTICE - Data and perspectives", Arthritis Research UK, 2013.

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[3] Huang, Miinshiou, Liang Jiang, Peter K. Liaw, Charlie R. Brooks, Rodger Seeley, and Dwaine L. Klarstrom. "Using acoustic emission in fatigue and fracture materials research." JOM 50, no. 11 (1998): 1-14.

[4] "Acoustic emission testing". [Online]. Available: https://www.nde-ed.org/EducationResources/CommunityCollege/Other%20Methods/AE/AE_Equipment.php. [Accessed: 20- Nov- 2016].

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