Acoustic emission technique as an adaptive biomarker in integrity analysis of knee joint

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Abstract. Acoustic emission (AE) technique has been applied as an adaptive biomarker for evaluating the disorder of knee joint. Integrity analysis of knee joint involves a detail study of several anatomical parts of knee joint like bones, cartilage, tendons etc. Any damage of these anatomical parts causes several knee diseases like osteoarthritis (OA). The incidence of knee OA, a widely manifested knee disease, particularly in aging society, increases due to some damages in the cartilage of knee joint. The major concern of this disease (OA) is its incurability at its matured stage. However, early detection for adopting appropriate measures can reduce the risk of this disease [1], [2]. The present investigation focuses on the dynamical behavioral characterization of knee joint for its integrity analysis with acoustic emission (AE) characterizing parametric features. AE signals have been collected from different positions of tibia, patella, femur etc. by AE sensors with adaptive frequency bands for getting sufficient information about the condition of cartilage in knee joint. Data has been collected from the participants with different age groups without any knee problems as well as participants with knee diseases. All data have been clarified effectively to identify the proposed technique as an adaptive biomarker for monitoring knee condition in early stage of OA effectively.

1. Introduction

The knee joint is anatomically made up of three bones and various ligaments. Femur (the thigh bone), tibia (the shin bone), and patella (the kneecap) are the major components of this joint [1]. Knee joint provides necessary supports to the skeleton for allowing them to be flexible in movements. The motion control as well as the protection of the knee joint is done by several muscles and ligaments [2]. These ligaments of the knee ensure that the body-weight must be transmitted through the knee axis for minimizing the amount of wear and tear on the cartilage inside the knee [3].

Bones in knee joint are receiving cushiony supports by cartilage, synovial membrane and fluid inside the joint [4]. Moreover, muscles and ligaments provide the appropriate forces and strength to this joint for its stable movements. However, due to getting ages, the quality of bones including the cushiony items are degenerated. Furthermore, the quality as well as the quantity of muscle and synovial tissues are also degraded due to aging and thus, the balance movements of knee joint are decreased. Therefore, the surface roughness of the articular cartilage is increased and the risk of happening the osteoarthritis (OA) is also increased [5], [6].

The dynamic analysis of knee joint consists of the integrity analysis of knee’s anatomical parts for several movements of sitting and standing. Major objectives of this study are to develop a simple bio-
marker for clarifying the initiation of knee disorder responsible for OA due to aging, and also to diagnosis the matured OA in knee joint. The disease of OA increases with age due to some damages in cartilage of knee joint [7], [8].

Potential methods like X-ray, magnetic resonance imaging (MRI) etc. are presently using for clinical diagnosis of knee diseases. However, externally inserted high energy to the body for diagnosis of these technique and their static sensitivity with high cost make them unpleasant to the patient. In the contrary, proposed acoustic emission (AE) technique is considered safe and user-friendly diagnosis of knee joint with low cost in dynamic analysis mode.

In the present research, integrity analysis of knee joint is planned to be conducted by applying AE technique to young aged, middle aged and old aged volunteers with no knee pain or knee problems (self-declared) as well as knee patients in dynamic movements (sit-stand-sit) of their knees. In the next section, experimental methodology is discussed, after which results and discussion and finally conclusions and references are presented.

2. Experimental Methodology

According to the objectives of the present research, four AE sensors are attached to the knee joint. For avoiding noise from muscle, tendon etc. sensors are placed to nearest to the knee bones as two to femur and tow to tibia according to the experimental observations [9]. The positioning of sensors is mentioned in Figure 1(a) by numbering as (1) ~ (4) to a knee model (3B Scientific GmbH, Germany). AE sensors are attached to the mentioned positions of knee joint with high elastic medical tape for avoiding undesirable noise during sit-stand-sit movements. Furthermore, coupling gel is used between the surface of the sensor and the contact place of the knee for keeping continuous contact of the sensing surface to the anatomical site of the knee. For getting an angular position of the knee during the movement, electronic goniometer is attached to the knee with double-stick tape. In one set of movement (sit-stand-sit) the goniometer angle is recorded as 180 degrees. Ten sets of movement are considered as 1 cycle, while 1 minute is taken as intermittent rest time. For AE signals 1MHz and for goniometer 100 Hz are used as sampling frequencies.

![Figure 1](image)

**Figure 1.** Experimental apparatus of AE integrity analysis of knee joint. (a) AE sensor positions, (b) schematics of AE signal acquisition set up.

Acquisition of AE signals from knee joint has been designed according to the schematic views as shown in Figure 1 (b). An array (2x2) of AE sensors (R6®, Physical Acoustics Corporation) with an operating frequency range of 35 to 100 kHz and resonant frequency of 55 is used in the experiment. The sensors are connected to a digital oscilloscope through pre- and main amplifiers and finally the data has been transferred to the personal computer (PC). For the acquisition of angular movements, a two channel
goniometer (SG150, Biometrics Ltd.) is also connected to the oscilloscope as shown in the figure and the data has been recorded into the PC similarly.

3. Experimental Results and Discussion

Experimental results for the integrity analysis of knee joint have been focused in two major divisions. One division consists of different aged participants without any self-realizing knee problems. Another division has been consisted with knee patients who have been taking knee surgery for their knee damage with osteoarthritis or other similar knee disease. Again, participants without any knee problem have been grouped into three based on their ages. For example, young participants with below the age of 30 years old, are defined as 20 yrs. group and is coded as A. Similarly, middle aged people with near 40 years old or above, however, below 60 years old are grouped into 40 yrs. group and is coded as B and the participants with 60 years or above are grouped into 60 yrs. and is coded as C. All of these volunteer participants are self-declared participants with no knee problems. Major objectives of these experiments are to identify the bio-marker for the identification of knee problem initiation stage. However, the objectives of experiments with group D participants is to diagnosis of knee problems with damage intensity and position as well. Detail specifications of these participants are summarized in Table 1.

| Participants                  | Code name | Spacing |
|-------------------------------|-----------|---------|
| 20 yrs. Group                 | A         | 10      |
| 40 yrs. Group                 | B         | 14      |
| 60 yrs. Group                 | C         | 14      |
| Patients of knee problem      | D         | 11      |

Experimental results are evaluated based on the damage intensity and the intensity has been identified with maximum amplitude of AE hits, based on percent of occurrence of AE hits, and the concentration angle of AE hits in a complete cycle of knee extension-flexion dynamic motion generated by one sit-stand-sit movement. Detail explanation of these biometric parameters are given below.

3.1. Maximum amplitude distribution as bio-marker of knee evaluation

As mentioned in Table 1, 49 volunteer participants joint the present experiment, out of which 10 people for A, 14 people as each group of B and C, and 11 patients as D. The participants of A to C are self-declared healthy people and never went to the hospital for their knee pain. However, the participants of D group are those who possess knee disease of OA. They took knee operations following day of joining to our experiments. As the intensity of AE signals depends on the intensity of transient elastic wave generated from sudden redistribution of stresses, in the present experiment, AE signals are generated similarly due to the frictional effects of cartilage during sit-stand-sit movements of the people. Therefore, surface roughness is a major criterion in increasing the signal amplitudes or increasing signal intensity. Thus, in the present experiment, participant who has damage to knee cartilage (OA patients), generates increased friction force and thus, shows the significantly increased amplitudes in AE hits during sit-stand-sit dynamic motion. Similarly, participants of C group, also exhibit increasing signal amplitude compared with 20 yrs. or 40 yrs. groups of participants, however, it is much less than D group. Similar significance is also found in group B, although, the increasing level of amplitude is very small (around 2 dB). Thus, it can be concluded that the surface condition of knee cartilage has been started degrading in group B, when the condition of young people is considered healthy knees. Of course, a lot of observations regarding the declaration of threshold values (for considering young people as standard healthy knee) are needed to be investigated with many participants. The total results of the maximum amplitude distribution for A, B, C, D participants are shown in Figure 2. Average values of all participants in each group are represented in the graph. Increasing of signal amplitudes with increasing the participants ages are indicated by arrow indication as well.
3.2. Maximum amplitude distribution as bio-marker of knee evaluation
The percent occurrence of AE hits is defined as the percent of the ratio of total required sit-stand-sit movements for a fixed number of AE hits in one cycle. As explained in above that the rate of transient AE hit generation increases due to surface condition of knee cartilage decreases. Experimental results show that increasing of aging increasing the percent occurrence of AE hits and it increases more for OA patients. Thus, according to the observation, percent occurrence of AE hit works as an acceptable bio-marker for knee integrity analysis.

3.3. Concentrated distribution of AE hits as bio-marker of damage position in knee joint
The position of cartilage damage of knee joint can be identified by analyzing its angular position as well. Therefore, in the present research angular position of knee movements has been clarified by goniometer. MRI technique has been applied and examined the damage position of OA participants (patients). It is found that AE hits are also concentrated to the position of knee joint. It is found in Table 2 and in Figure 4 that AE hit data are concentrated than other non-damage places. In Table 2, it is found that 50% AE hits concentrated to 0 to 30 degrees and 90 to 60 degrees of knee surface. MRI data also shows the damage location at 60 to 90 degrees (at 0 to 30 degrees, the damage location is obscured due to standing image). Based on this observation, it is also found that concentrated distribution of AE hits can be considered as a bio-marker in knee integrity analysis as well.

| Angle range (°) | Occurrence (%) |
|-----------------|----------------|
| 90 - 60         | 50.0           |
| 60 - 30         | 0.0            |
| 30 - 0          | 50.0           |

**Figure 4.** Concentrated distribution of AE hits and the knee integrity evaluation by MRI imaging. (a) Indicates the concentrated AE hits distribution showing damage positions, (b) MRI imaging of an OA knee.

**4. Conclusions**

The integrity of knee joint has been identified by AE technique. Three bio-markers for knee osteoarthritis (OA) diagnosis based on AE technique have been explained with experimental validations. According to the objectives, two major findings have been clarified by the proposed system. Degeneration of knee cartilage by aging have been successfully identified by the proposed AE technique. Furthermore, integrity analysis of damaged knee by OA is also discussed satisfactorily. Maximum amplitude distribution of AE hits, percent occurrence of AE hits and concentrated distribution of AE hits are presented as three successful bio-markers in the AE diagnosis system of knee problems including OA. Damage places of knee joint are also identified by clarifying AE hits with respect to the angular position evaluation by goniometer. MRI examinations are also employed successfully in the present research for the validation of the proposed technique of integrity analysis of knee problems by AE technique.
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