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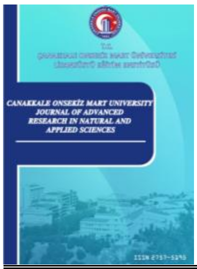

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Analysis of Acoustic Signals of Footsteps from the Piezoelectric Sensor

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Research Article

Abstract −Some materials can change their electrical polarization under the influence of a mechanical stress due to the piezoelectric effect. This stress-induced change in polarization produces a potential difference across the material. For this reason, the piezoelectric material generates an electrical signal when it is subjected to a pressure from acoustic energy. In this study, analysis of acoustic signals of footsteps from the piezoelectric sensor, especially for human footsteps, have been studied by considering the analytical relationship between the electrical signal generated from the sensor and the acoustic signal that provides the effect. We analyzed the acoustic signal data by assuming that the electrical output voltage of the piezoelectric sensor completely coincides with the frequency of the acoustic signals. The original signal was pre-processed using filtering systems and analyzed by the fast Fourier transform and power spectral density methods to extract descriptive spectral features of the signal. This preliminary study proposed a method as a sensor based piezoelectric security system to detect the acoustic signals that can indicate possible dangers to the safety of people or property. The source of the acoustic signal can be determined by matching it with the existing database using machine learning algorithms like face recognition systems for future goals.

Keywords *– Acoustics, piezoelectric, sensors, signal processing, spectral analysis*

1. Introduction

The Curie brothers discovered the piezoelectric phenomenon in 1880 by demonstrating the formation of surface charges on well-prepared crystals due to mechanical pressure. In piezoelectric systems, the conversion between mechanical energy and electrical energy has many applications in industry (Smith, 2005). Nowadays, piezoelectric elements find numerous applications in precise positioning systems (Li, Zhang, Jia, & Qian, 2009; Liu, Yan, & Özbay, 2018; Qiu, Wang, Zhang, & Han, 2013; Salvador, Plazas, Gimeno, & Carreres, 2012; Stefanski, Minorowicz, Persson, Plummer, & Bowen, 2017; Tian et al., 2019; Wang, Ho, & Jiang, 2021), hard disc drive systems (Khasawneh, Jaradat, Naji, & Al-Azzeh, 2018; Lim & Choi, 2007; Ohashi, Kajiwara, Iwadare, & Arisaka, 2005), vibration control (Chuaqui, Roque, & Ribeiro, 2018; Høgsberg, 2021; Pu, Zhou, & Meng, 2019), energy harnessing (Chelli et al., 2021; Guigon, Chaillout, Jager, & Despesse, 2008; Jacquelin, Adhikari, & Friswell, 2011; Kundu & Nemade, 2016; Moro & Benasciutti, 2010; Peigney & Siegert, 2013; van den Ende, van de Wiel, Groen, & van der Zwaag, 2011; Wu, Bao, & Wang, 2021; Xiang, Wang, Shi, & Zhang, 2013; Yatim, Ismail, S.J, hj.bakri, & Effendy, 2018) etc. Due to the interaction between the foot and the contact surface during walking, human footsteps produce vibrations and sound from a few Hertz to ultra-sonic frequencies(A. Ekimov & J. Sabatier, 2006). The sound vibrations of different types of walking styles were measured on the outdoor floor surface with an ultrasonic ceramic sensor by Ekimov et.al.(A. Ekimov &

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J. Sabatier, 2006; A. Ekimov & J. M. Sabatier, 2006). Some test measurements were also conducted in air to see the difference the sound measurement on the ground where the vibration absorption is much higher. The results reveal that frictions of a footstep on the ground generate ultrasonic sound wave. It was shown that there is no remarkable dependence on the human footstep style for ultrasonic signals magnitude in air, unlike the seismic vibration signals (Ekimov & Sabatier, 2007). Recently, miniature seismometer networks have been used to protect areas requiring high security against unauthorized access. Against the disadvantages of existing seismometers such as high-power consumption and limited sensing range, Levy et. al. has developed a miniature seismometer with high resolution, low power consumption to detect intrusion in a protected area (Levy, Moras, & Pannetier, 2017).

In this study, we propose an approach to determine acoustic sound sources by considering the analytical relationship between the electrical signal generated from the sensor and the stimulating acoustic signal. We predict that the output signal spectrum obtained by Fast Fourier Transform (FFT) analysis of the step signals received in time-domain with sensor can be compatible with the frequencies of the applied acoustic signal. Thus, the signal can be interpreted by deriving the frequency values of the stimulating signal from the electrical signal generated by the piezoelectric sensor. Our preliminary study proposes a method to detect the acoustic signals that can indicate trespassing activities. In addition, the source of the acoustic signal can be determined by matching it with the existing database using machine learning algorithms like face recognition systems for future goals.

2. Materials and Methods

Polyvinylidene fluoride piezoelectric thin film sensors, also known as a low-cost vibration sensor, have become an attractive alternative to piezoelectric ceramics due to their properties such as flexibility, high chemical resistance, and thermal stability (Bregar, Starc, Čepon, & Boltežar, 2021). In general, piezoelectric ceramic materials are used in high frequency applications (200 Hz and above) while in low frequency applications, piezoelectric polymers are preferred. The acoustic pressure force acting on the piezoelectric sensor gives a certain voltage value at the exit of the strip. Since there is a direct relationship between the electrical signal obtained from the piezoelectric strip and the acoustic signal applied, the piezoelectric strip deforms in proportion to the frequency of the acoustic signals. High amplitude responses are obtained from low frequency signals. In this way, the low frequency acoustic signal generated by the human footstep can be perceived as a higher amplitude electrical signal. The acoustic signals detected by the piezoelectric strip are converted into digital signals at the piezoelectric sensor output**.** The flowchart of our algorithm for data processes is shown in Figure1.

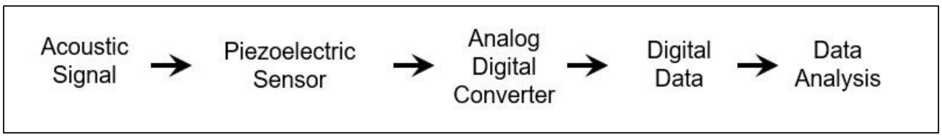

Figure 1.The schematic view of the system

In the process of listening to human footsteps on the computer, the sound data is read in the storage devices, transferred to the microprocessor, and transmitted to the Digital Signal Processor (DSP) on the sound card. The data decoded by the DSP is converted into analog audio signals by the sound card's digital-to-analog converter (DAC) and transmitted to the sound card's output and then to the speaker. After the digital audio signals in the computer are converted into analog form by the sound card and transmitted to the speakers, the vibrating speaker diaphragm converts the electrical signals into sound waves. Sound waves from the speaker are received by the piezoelectric structure. The piezoelectric strip structure deforms according to the acoustic signals of different frequencies. Acoustic signals coming to the piezoelectric material are taken from the output of the piezoelectric material and converted into digital signals via data acquisition system.

Signals detected in a system are usually measured as a function of time and then by using Fourier analysis they were transferred from time domain to frequency domain. Footsteps are complex sounds made up of many different frequencies. Analysis of the frequency components of these harmonic sounds are done by the Fourier method and complex waves are decomposed in the form of simple harmonics. The analysis of the received signals is performed in MATLAB code for human step detection.

3. Results and Discussion

In Figure 2, we compare audio signals produced by a human walking on snow and hardwood floor in time and frequency domains. To investigate the spectral frequency details of the digitally recorded audio signals in Figure 2 (a) and (d), we applied the FFT algorithm as seen in Figure 2 (b) and (e), respectively. The signals in Figure 2 (b) and (e) have sampling rate at 48 kHz, FFT size of 854016 and time duration of about 18 seconds and sampling rate at 48 kHz, FFT size of 462863 and time duration of about 10 seconds, respectively. By using a median filter, we eliminated the noise without distorting the shape of the signals as seen in Figure 2 (c) and (f). We can clearly extract descriptive spectral features of the human footstep walking on snow and hardwood floor in frequency and filtered frequency domain as comparing Figure 2 (b) and (e) and Figure 2 (c) and (f), respectively.

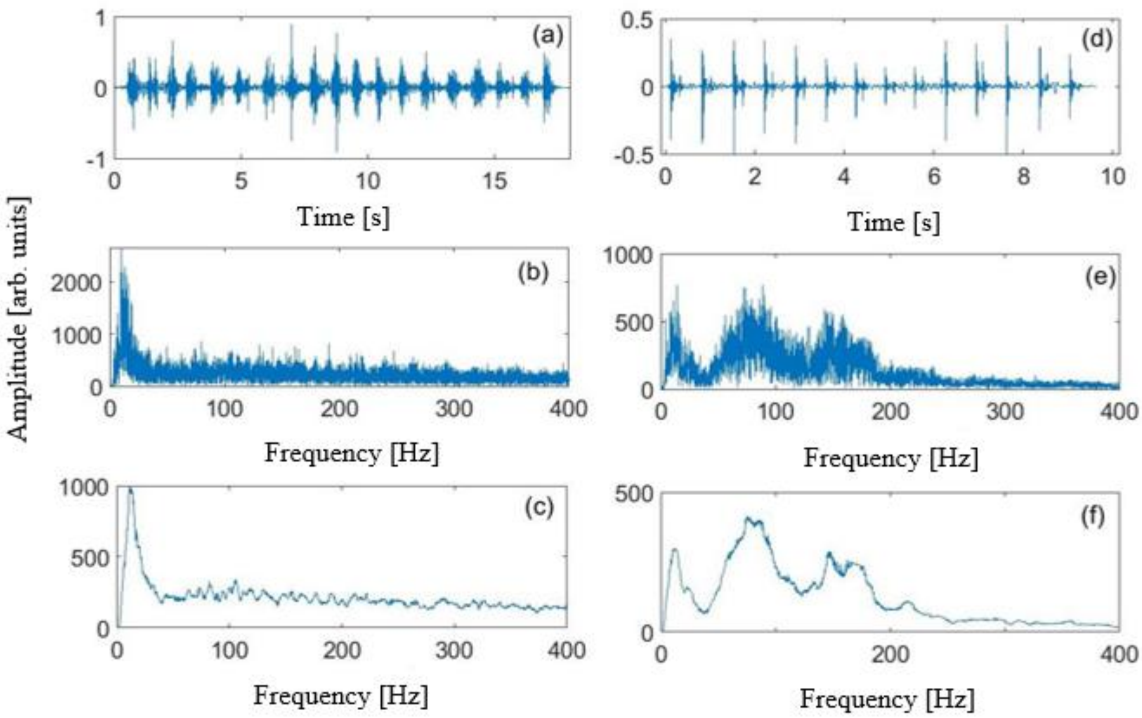

Figure 2. Human footstep walking on snow (a-c) and hardwood floor (d-f) in time domain, frequency domain, and filtered frequency.

A Power Spectral Density (PSD) is used to determine broadband random signals in the measure of signal power versus frequency. It is estimated by calculating the Fourier transform of the signal's autocorrelation function. In Figure 3, by the FFT and PSD we pre-processed original signals of a horse footsteps to extract descriptive spectral features of the signals. The signals of the footsteps are given in time domain, frequency domain and as frequency filtered. The sampling rate of the signal was measured at 44.1 kHz, FFT size 378726 and duration about 8 seconds. PSD estimates the power distribution of the signal in a specific frequency range. Figure 3 (d) which is PSD of the horse footsteps gives detailed on amplitude and locations of the peaks of the acoustic signal.

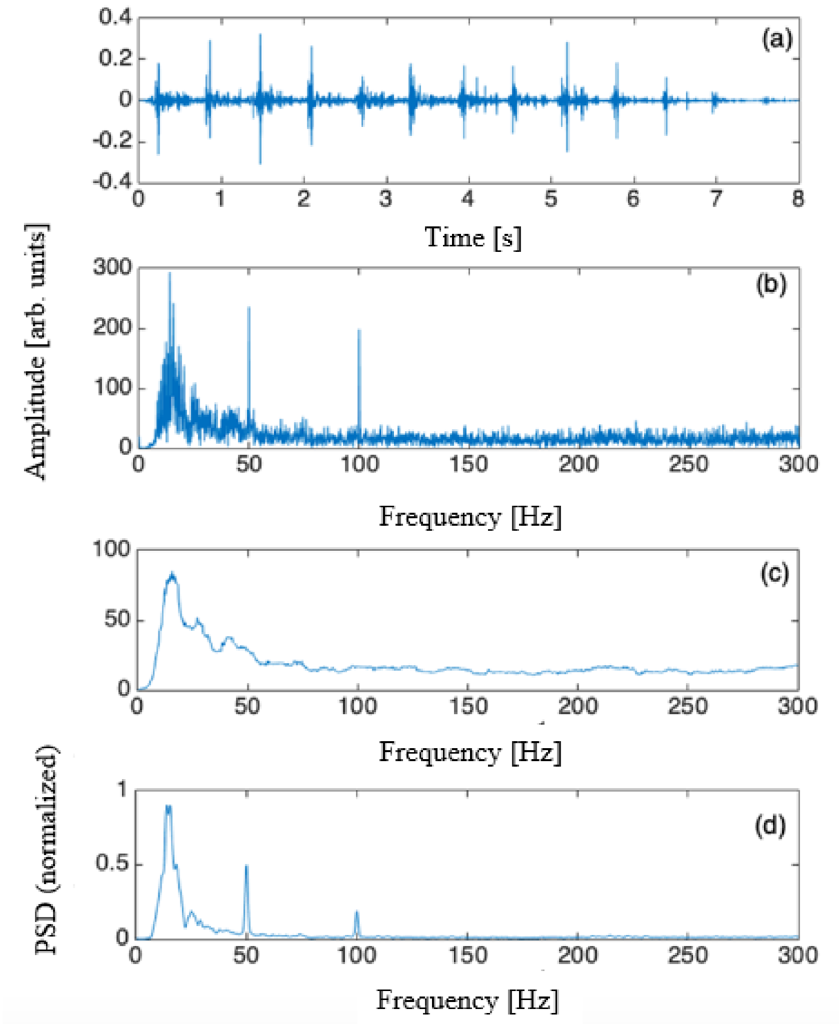

Figure 3. The horse footsteps (a) in time domain (b) in frequency domain (c) as filtered and (d) PSD frequency domain.

In Figure 4, we compare two different footsteps as labelled footsteps-1 and footsteps-2. The footsteps-1 and footsteps-2 were the footsteps of a person walking with shoes on hardwood floor and on rug over hardwood floor, respectively. Signals are compared using PSDs of signals. We can clearly observe that the extracted frequency information has the potential to discriminate between distinct acoustic sound sources. This study shows that our method can be used to detect and analyze acoustic signals.

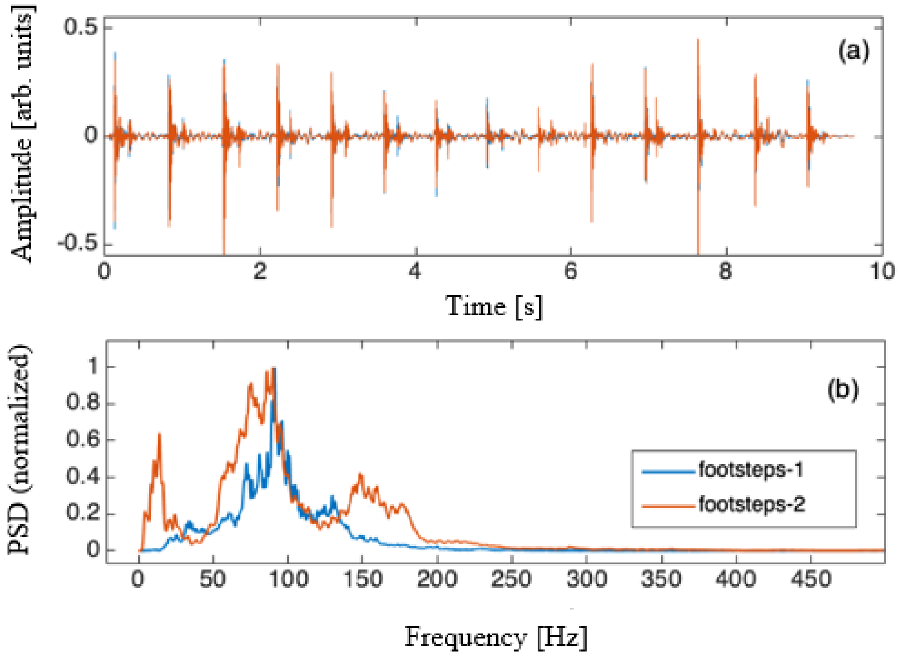

Figure 4. The signal of two different footsteps in (a) time domain and (b) frequency domain PSD.

4. Conclusion

By assuming that the electrical output voltage of the piezoelectric sensor completely coincides with the frequency of the acoustic signals, we analyzed the acoustic signal data. The original signal was pre-processed using filtering systems and analyzed by the FFT and PSD methods to extract descriptive spectral features of the signal. We observed that meaning of the signal can be obtained by deriving the values of the stimulating acoustic frequency from the electrical signal generated by the piezoelectric sensor because of the acoustic signal. The equivalent of the interpreted signal from the library to be created can be easily determined with a promoted program. This preliminary study proposes a method as a sensor based piezoelectric security system to detect the acoustic signals that can indicate trespassing activities. The source of the acoustic signal can be determined by matching it with the existing database using machine learning algorithms like face recognition systems for future goals.

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Author Contributions

Bilge Çiğdem Çiftçi: Collected data and performed data analysis.

Gamze Kaya: Collected data, performed data analysis, and wrote the paper.

Mustafa Kurt: Conceived the concept, designed the analysis, and wrote the paper.

Conflicts of Interest

The authors declare no conflict of interest.

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