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A novel distance estimation algorithm for periodic surface vibrations based on frequency band energy percentage feature

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ABSTRACT

Earth surface vibration signal processing becomes attractive recently due to its significance in source detection and localization, which can be adopted in a number of real world applications, such as footstep detection, underground pipeline network surveillance, etc. In this paper, we investigate the distance estimation problem for earth surface periodic vibration signal localization. The signal attenuation principle between the propagation distance and the signal frequency is exploited and a novel frequency band energy percentage (FBEP) feature is developed to characterize the energy distribution property within different frequency bands of different propagation distances. To obtain the fundamental frequency of periodic vibrations, the cepstrum approach is employed. An enhanced computationally efficient k nearest neighborhood (EH-kNN) algorithm is developed to perform the distance estimation. Experiments on real periodic vibration signals generated by an electric hammer under different collecting distances and transmission medias are conducted to show the superiority of the proposed distance estimation method in this paper.

1. Introduction

Vibration signal processing has become attractive in recent years due to its significance in a wide number of real world applications [1–6]. Poletkin et al. [1] and Reju et al. [2] investigated the taps localization for human-computer touch interface through exploiting the vibration signal. Venkatraman et al. [3,4] studied the footstep detection using seismic signals by the Quatrernion based approach and polarization method, respectively. Tsurushiro and Nagaosa [5] employed the vibration signal caused by road surface roughness to realize vehicle localizations. Recently, we studied the periodic earth surface vibrations in [6]. The fundamental frequency estimation and its relationship to the propagation distance for periodic surface vibrations generated by electric devices have been researched. An improved peak interval selection method based on the auto-correlation function (ACF) has been developed for fundamental frequency estimation in [6]. However, only preliminary studies on the energy distribution and its relation to propagation distance are presented in [6]. Recently, the popular extreme learning machine and support vector machine algorithms have been adopted for propagation distance prediction in [7]. But

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they suffer the time-consuming issue in training the estimation model. Besides these literatures, a large number of vibration signal processing based applications and theoretical results can be found in the research community [8–11].

Although extensive analyses on the vibration signal processing have been presented in the past years, few of them focused on the surface vibration signal localization and distance estimation, which has been recently shown importance in many surveillance systems [12–15]. For example, it is recently discussed in [12,13] that the distance estimation approaches of vibration signals can be adopted for urban earthmoving excavation devices detection and localization because the underground pipeline network suffered severe external breakages caused by earthmoving devices in road excavation, real estate constructions, etc. Existing image/video [18–20] and acoustic [12,13,15–17] signal based algorithms are capable of detecting and recognizing the excavation devices but fail in source localization. Since the urban underground pipeline network has its own layout and laying directions, an accurate localization of the potential working excavation devices can help to reduce the false alarm rate in a surveillance system. Conventional approaches usually recur to using the fiber sensor for the vibration detection. However, the relatively short detection range makes it unsuitable for pipeline protection.

With this objective, we investigate an intelligent distance estimation algorithm for the periodic earth surface vibration localization in this paper. The energy attenuation principle and its relationship between the propagation distance and the signal frequency are exploited. Along with the flow of the proposed algorithm, the contributions of this paper are listed as follows.

1. Firstly, a fundamental frequency estimation algorithm based on the cepstrum is first introduced. Although prior ACF based fundamental frequency estimation approach has been studied in [6], we find that the computational complexity of ACF is high and its estimation performance is ruined due to signal shifts caused by attenuation.
2. Secondly, a novel feature extraction approach named the FBEP is developed to characterize the energy distribution property within different frequency bands of different propagation distances for periodic vibration signals in this paper. A database containing the FBEP features extracted from periodic vibration signals collected in various propagation distances to the sensor location is constructed.
3. Finally, a new intelligent distance prediction system built on a computationally efficient EH-kNN algorithm is proposed.

For performance demonstration, a vibration signal collection system is designed and a piezoelectric transducer based sensor AWA14400 is equipped for signal recording in this paper. Real periodic vibration signals generated by an electric hammer under various distances to the sensor location are captured to test the effectiveness of the proposed algorithm. Fig. 1 shows the flowchart of the proposed distance prediction system for the earth surface periodic vibration signal developed in this paper. It is noted that we have presented prior studies on the fundamental frequency estimation for periodic vibration signals in [6]. However, only analyses on the time-domain ACF based fundamental frequency estimation algorithm for the periodic vibration signal have been presented while the feature analysis and the source localization algorithm are not discussed.

Organization of the rest paper is as follows. A brief overview on the proposed distance prediction system for the periodic vibration signal is first given in Section 2. Then, the designed vibration signal collection circuit system is presented. The cepstrum based fundamental frequency detection algorithm is shown in Section 3 and the proposed FBEP extraction approach is described in Section 4. The proposed EH-kNN based distance prediction system for periodic surface vibration signal employing the FBEP feature database is illustrated in Section 5. Experiments and conclusions are given in Sections 6 and 7, respectively.

2. Vibration signal collection circuit

For the vibration signal collection, a piezoelectric transducer based sensor AWA14400 is adopted. It measures the acceleration of vibrations through converting it into a proportional voltage. It can be used to collect the earth surface vertical vibrations as well as the horizontal vibrations. The sensitivity is 40 $mV/m{\cdot}s^{-2}$ and the working frequency range is 1 Hz$\sim$300 Hz. At the meantime, a vibration signal collection circuit is designed to achieve a better detection effect in the detection of periodic vibration signals in this paper. Fig. 2 depicts the used vibration signal recording sensor and the designed signal processing and detection circuit. The detailed module diagram of the collection circuit is shown in Fig. 3.

The collection circuit consists of 5 parts: the sensor interface circuit, the programmable amplifier circuit, the low-pass filter circuit, the analog-to-digital (AD) conversion interface circuit and the AD module. The sensor interface circuit provides the matching interface between the vibration sensor and the subsequent circuit; programmable amplifier circuit provides dynamic gain in accordance with the large dynamic range of vibration signal; low-pass filter circuit improves the signal-to-noise ratio by filtering the high frequency components; AD interface circuit provides the voltage matching function

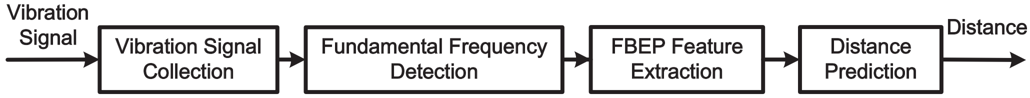

Fig. 1. The flowchart of the proposed distance prediction system for periodic vibration signal.

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