Poster Abstract: Step-Level Person Localization Through Sparse Sensing Of Structural Vibration

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ABSTRACT

We describe a step-level indoor localization system which uses the ground vibration induced by human footsteps. Indoor localization is important for various smart building applications, including resources arrangement optimization, patient/customer tracking, etc. Geophones are used to measure the ground vibrations and time difference of arrival (TDoA) for different sensors are used to solve the multilateration localization problem. The advantages of this system include its sparsity and also its stability over time. Lesser dependency on instrument people is another upside of this system. The results of pilot tests show that this system can be successfully used for indoor localization.

Keywords

vibration, footstep, indoor localization, time difference of arrival, multilateration, indirect sensing

1. INTRODUCTION

Step-level indoor localization can enable various ubiquitous computing applications of smart buildings. For example, it can be used for space/energy usage optimization, which based on the number of people inside a place can determine how much energy is needed for it. As another instance, together with person identification it can be used for senior housing monitoring to track long term patients activity which can result in better design of facilities necessary for patient's safety and comfort[5]. The main advantages regarding the proposed system are its sparsity and also stability over time. Another benefit of this system is that there is no need to instrument people.

These sensing methods are mainly categorized into two types: personal device based and personal device free. Personal device based methods often utilize devices such as smart phones/wearable devices to track people. While the personal device free methods use existing or installed infrastructure for localization purposes. Personal device based methods collect information such as vision [9], inertial measurement of motion [2], social encounter/non-encounter events [3], multi-path of the signals [8], scanned access point in the environment [10] through sensors on individual devices. Device free methods, on the other hand, sense the target directly with the infrastructure sensors, such as RF transceivers [7, 6, 1].

In this paper, we present our structural sensing based localization system that utilizes the measurement of vibrations of the structure due to human footsteps to locate a person. This system is designed as a device free system which will result in sparse and also less intrusive nature of it and make it more suitable for smart structure applications.

2. SYSTEM OVERVIEW

For indoor localization, we use the ground vibration due to people walking. The procedure includes system calibration, footstep event detection, and footstep event localization as shown in Figure 1. In order to make sure that the environmental difference will not affect the system performance, the first step is system calibration. Following that, the footstep events can be detected and consequently localized. The general principle behind localization algorithm is that the time of arrival of the ground vibration signal for a specific excitation (i.e., human footsteps) is different due to different distances between each sensor and the excitation source location. By finding the time difference of arrival (TDoA) between a pair of sensors, the possible locations of the excitation can form half of a hyperboloid. Consequently, we can close down on the excitation source location by using additional sensors. In our system, four sensors are needed for localizing an excitation.

The hardware to be used for localization consists of three main components: geophone, amplifier, and data acquisition module. Geophone is a sensor which converts the vibration of the ground to voltage. The model of the used geophone is SM-24 and the sensitivity of this sensor is 28.8 V/m/s. The sampling frequency of 25000 hz is going to be used for measurement. Considering the small amplitude of vibration signals resulted from human footstep to decrease the false-

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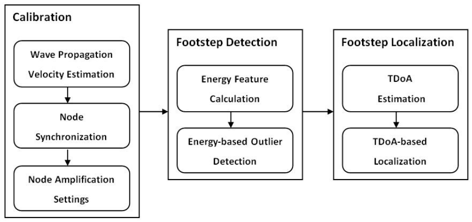

Figure 1: System Overview

negative rate (i.e. missing footstep events), amplifiers should be used.

2.1 System Calibration

For calibration step, the first issue which should be addressed is the velocity of propagation of the wave resulted from ground vibration. This velocity can be found by series of pilot tests in which location of impacts are known. Furthermore, node synchronization is an important step in calibration of the system as the method localizes the footstep events based on difference in arrival time of vibration signal to different sensors and accuracy of TDoA estimation is and important factor in localization accuracy. The amplitude of ground vibration signals are dependent on several factors, including the floor type, existence of carpet, and the shoe type and walking pattern of people. Therefore, as the final step we should calibrate the amplification setting of nodes to make sure that the vibration signal due to footsteps can be detected in experiment settings.

2.2 Footstep Detection

Detecting the footsteps is a necessary step for indoor localization based on footstep vibration. Considering the time domain representation of the signal resulted from step vibrations, energy is selected as the measure to be used for anomaly detection as proposed by [4]. A Gaussian noise distribution is chosen for creating the noise model which is to be used as a baseline for outlier detection procedure. The threshold which will be used for this procedure can be determined by choosing an allowable false alarm rate.

2.3 Footstep Localization

As discussed the general idea is to find the TDoA between pairs of sensors and using them to localize the excitation source. After detecting the step event, TDoA can be computed for each pair of sensors for the respective time frame. TDoA can be found by maximizing the cross-correlation between the received signals. Cross correlation is a measure which represents the similarity of two signals when different shifts in time are applied to one of them. The first peak resulted from a specific impact or step event may have different signs, i.e. positive or negative. To overcome this problem, absolute values of the signals are to be used for TDoA determination.

After determining the TDoA, the source localization algorithm should be performed. The following equation shows the general equation governing the localization problem.

$$\|x - p_i\|_2 = v\,(t_i - t_c) + \|x - p_c\|_2 \tag{1}$$

in which p_c is the location of the sensor with the first arrival, p_i is the location of the ith sensor, x is the location of the excitation (i.e., footstep), $\|.\|_2$ is the Euclidean Norm, and v is wave propagation velocity. To solve this multilateration problem, it has been reduced to linear form. Using the linear form and knowing the time differences of arrival between sensors and the wave propagation velocity, the excitation location can be estimated.

3. EVALUATION

To Evaluate the method proposed, an experiment based on impact loads have been conducted. Four sensors are placed at the corner of the eight by eight feet square and the effect of impact loads in different points between them has been explored. The preliminary experiment results were promising and justified the use of this approach.

4. CONCLUSIONS

We present indirect sensing in civil infrastructures that enables the structures to be a general sensing platform for users and environment monitoring. This can be done using the vibration due to footsteps for detection and localization and can potentially obtain information for multiple sensing targets (e.g., senior care, energy usage optimization, etc.). Sparse nature ,stability over time, and lesser dependency on instrument people are the main advantages of this system. The results of the pilot tests show that this method can successfully be used for indoor localization.

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