Poster Abstract: Structural Sensing System with Networked Dynamic Sensing Configuration

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1. INTRODUCTION

The dynamic responses of the structure provide a variety of information about the structure as well as people inside. Compared with traditional sensing methods, structural sensing method serves more general sensing purposes due to the diversity of information it can infer from structural responses. For example, by sensing the structural vibration, a system can track and identify a person through vibration caused by their gaits [5, 6]. Such non-intrusive identification and tracking system enables various smart building applications, such as patient monitoring system at advanced hospitals and nursing homes.

In order to accomplish various indoor sensing purposes, many sensing methods and apparatuses are explored. A common problem these systems face is inflexibility of sensitivity to the environmental changes. Structural responses are inherently highly sensitive to the environmental changes. For instance, structural vibration signals induced by footsteps can be of diverse amplitude due to various factors (floor type, shoe type, footstep strength, location etc.) [5, 6]. When sensed by the same sensor, some signals may be clipped, while others are difficult to distinguish due to the low amplitude. In both cases, features of the signal are distorted, which will affect the processing.

Different approaches are proposed to tackle the sensing problems caused by dynamic environments. System calibration [2] allows systems to extract environmental parameters for further calculation, which is usually stable and has relatively long response delay. Signal processing algorithms [3] are developed to predict and interpolate the clipped portion after the data is collected, which is not reliable enough for feature-sensitive applications such as identification. Amplification adjusting based on clipping prediction [4] is an efficient solution for traditional audio signal preservation. However, it is limited to the problem with continuous audio sensing signals and vulnerable to sudden changes.

Our structural sensing system monitors structural vibrations induced by footsteps to infer gait-based information of persons. In order to adapt to various sensing conditions, our system obtains the information of its sensing quality and dynamically adjusts its sensing configuration based on such information. In addition, as a networked structural sensing system, the parameters of the sensing environments and sensing targets are propagated to help other parts of the system improve sensing performance as well.

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2. SYSTEM OVERVIEW

Our system (shown in Figure 1) consists of two major components: the sensing node and the central control. The dynamic sensing configuration is achieved with two types of feedback control: the local feed back control and the central feedback control. A *sensing node* senses the structural vibration within its sensing range. It adjusts its sensing configuration based on the local feedback control information including signal resolution analysis and sensing target properties. The *central control* communicates with different nodes, and achieves central feedback control by propagating configuration information between nodes based on the prediction of the person's trajectory. The local feedback in each sensing node controls the system configuration with step-level delay, while the central feedback provides configuration changes more stably with trace-level delay.

2.1 Local Feedback Control in a Node

A sensing node conducts three tasks: 1) sensing, 2) processing signal, and 3) updating sensing configuration based on the sensing signal. These tasks form the local feedback control as shown in Figure 1 with hollow arrows.

The structural vibration signal is captured by the low-cost commercial seismometer, geophone. A geophone converts ground motion to relative motion of the coil through its mechanical system, and then converts such relative motion into voltage output by its electrical system [1]. Once the signal is obtained, the signal processing conducted on the node includes footstep extraction, signal resolution analysis, and sensing configuration prediction. Footstep signals are extracted by anomaly detection based on environmental Gaussian noise model [5]. The *signal resolution analysis* determines whether the signal is 1) of insufficient resolution, 2) in proper resolution ranges or 3) clipped. In addition, continuously detected footstep signals' amplitude will increase when the person is approaching the sensor and decrease when the person is leaving the sensing range [5]. Such changes imply *sensing target properties*, including stride length, stride strength, etc. Then based on current signal resolution and the sensing target properties, we predict the optimal sensing configuration for the next coming footstep event. For example, if a sensing node detects footsteps of insufficient resolution and the amplitudes of detected footstep sequence is increasing, then the amplifier gain should be increased with a relatively small rate; while if the amplitudes sequence

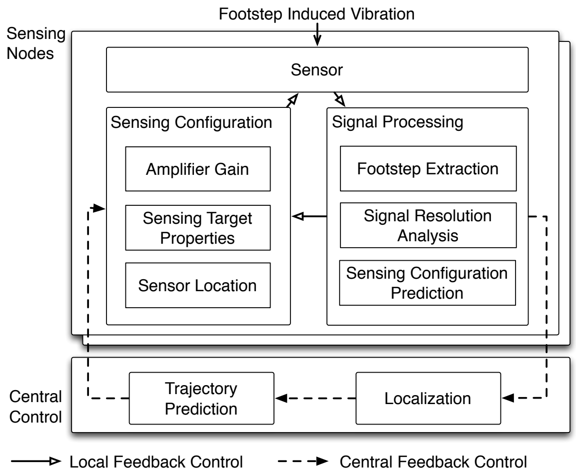

Figure 1: System Overview

shows a decreasing trend, the amplifier gain should be increased with a relatively large rate.

If the predicted optimal sensing configuration is different than the current one, corresponding changes to it will be made. Such changes control the sensing condition of the sensor automatically, as shown in Figure 1.

2.2 Central Feedback Control through Information Propagation

Due to the variance of sensing targets and the complexity of environments, it is possible that each node continuously updates its sensing configuration based on the node sensing resolution analysis and adjusts estimated sensing target properties as we discussed in section 2.1. In that sense, the local feedback control on each sensing node may not be stable at first, and it might take the time of the entire trace to adjust the sensing configuration and sensing target properties to optimal. However, the sensing target properties can also be applied to other sensors when the sensing target approaches their sensing areas. That means, if the sensing nodes can obtain such information before sensing, the local feedback control can converge on the sensing target property estimation faster than without such information.

In order to enable such feedback control using neighboring nodes, we design the central feedback control as shown in Figure 1 with dash-line arrows. The system localizes the person based on sensing footstep signals and predicts the trajectory of the person, i.e., which sensing area the person is approaching. Then the system propagates the local optimal sensing target property information of one node to the other neighboring nodes in the sensing area, so that the next sensing node can use such information as a starting point for its configuration prediction and achieve faster convergence.

3. PRELIMINARY RESULT

We collected vibration data of some impulses on the structure with a sensing node. Figure 2 shows two impulse examples we observed. Each example demonstrates signals collected with different amplification configuration. From top to bottom, the amplification gain is 4000X, 2000X and 500X, respectively. Signals on the right hand side indicate that large amplification achieves high resolution on weak impulses. Signals on the left show that small amplification avoids the signal clipping on large amplitude impulses.

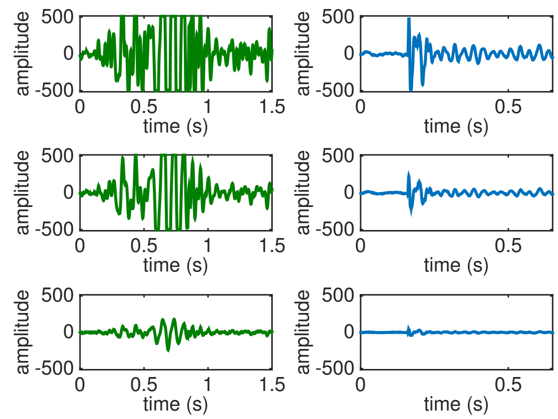

Figure 2: Sensing impulse examples: The left hand side are signals of a relative strong impulse, amplified by X4000, X2000 and X500 (top to bottom), respectively . The X4000 and X2000 signals are clipped. The right hand side is signals of a relatively weak impulse, amplified by X4000, X2000, and X500 (top to bottom), respectively. The resolution of the X500 signal is too low to be extracted.

4. CONCLUSION

We propose our networked dynamic sensing configuration solution to achieve robust structural sensing in our system. Further analysis and design are expected, and large scale deployments and experiments will be conducted to evaluate the system.

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