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Vibroacoustic Monitoring Techniques for Human Gait Analysis in Smart Homes

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Introduction

The aim of this research project is to automatically analyze human gait in indoor environments using vibration sensors attached to the floor. The technology preserves the private sphere of monitored persons and is used in an absolute passive manner.

The main part of this work focuses on methods for localization of seismic sources on the two-dimensional floor surface. We describe the main challenges namely dispersion, multipath propagation space variance and noice sources. To conclude our work we introduce potential application scenarios.

Principles of Vibroacoustic Monitoring

Classification

Because the heel strike content is the persistent part within the huge variety of footstep signals, we developed a heel strike classifier in order to detect footsteps.

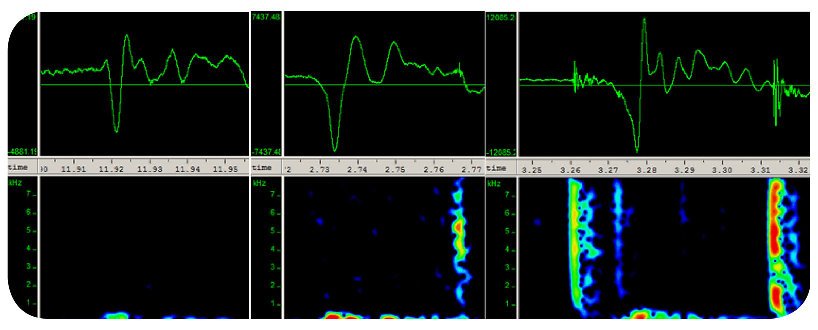

Figure 1: Exemplary footstep signals

Localization

The first method (1) is an extension of the conventional TDOA (Time Difference of Arrival) approach. We are estimating the so called range differences between every pair of sensors and subsequently formulate the nonlinear system of equations that describes the localization problem in a mathematical way (Fabiani, 2006). The second approach (2), (AOA (Angle of Arrival)-approach), uses tri-axial sensors and consequently processes the acquired surface wave as a vector-wave. The interpretation of the three vector-components reveals the angle at which a surface wave impinges at the sensor (Zhang, 2011). We compute the exact location of the seismic event by triangulation using two or more tri-axial sensors. We are also working on a localization-scheme making use of only one tri-axial sensor station (3). Besides the usual AOA-estimation process, we try to exploit the effect of dispersion in order to estimate the distance to the seismic source.

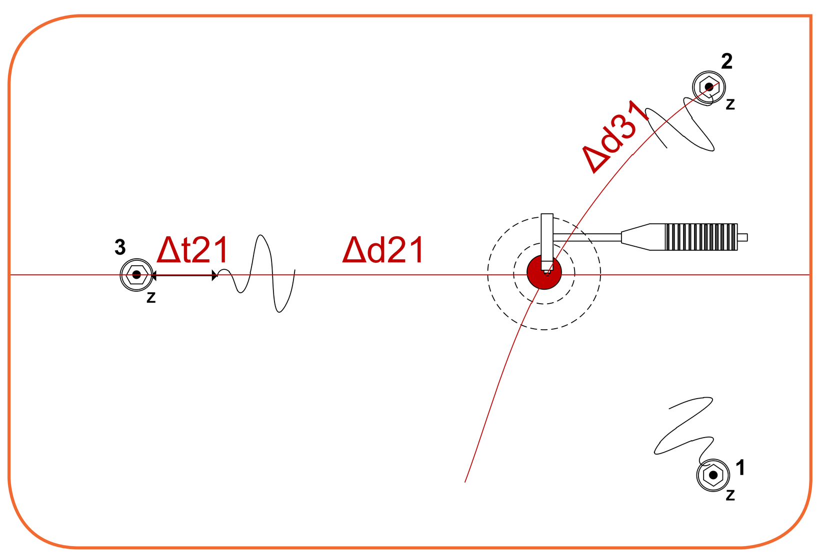

Figure 2: TDOA - Approach (1)

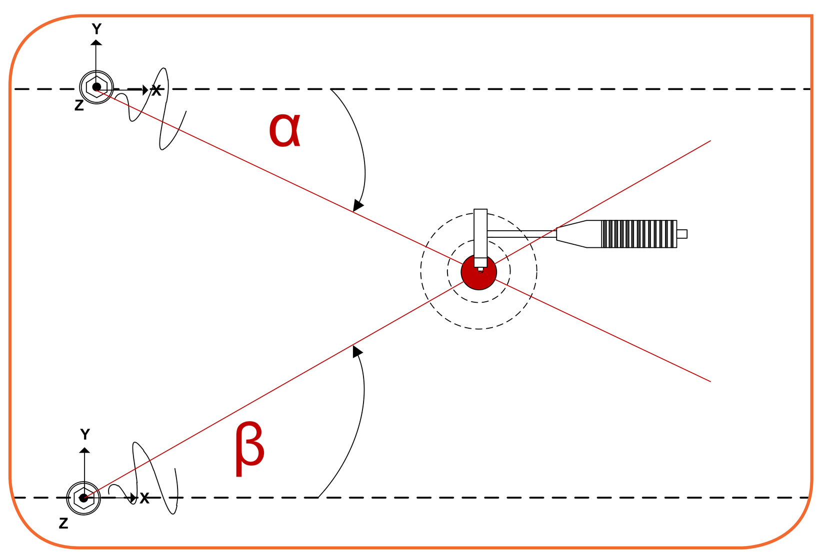

Figure 3: AOA - Approach (2)

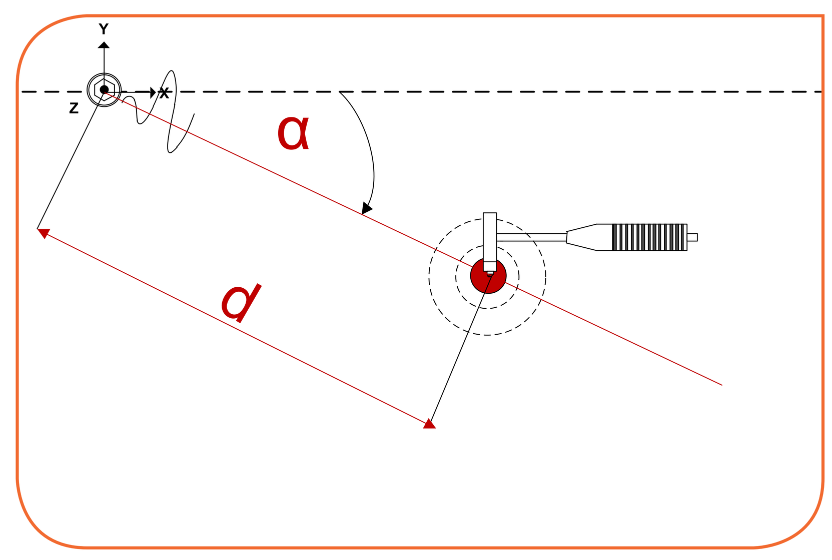

Figure 4: Single-Station - Approach (3)

Challenges

Multipath Propagation

- noiseless signal stemming from a single-mode surface wave assumed
- body wave reflections from the bottom side of the floor
- surface wave reflections from bordering walls

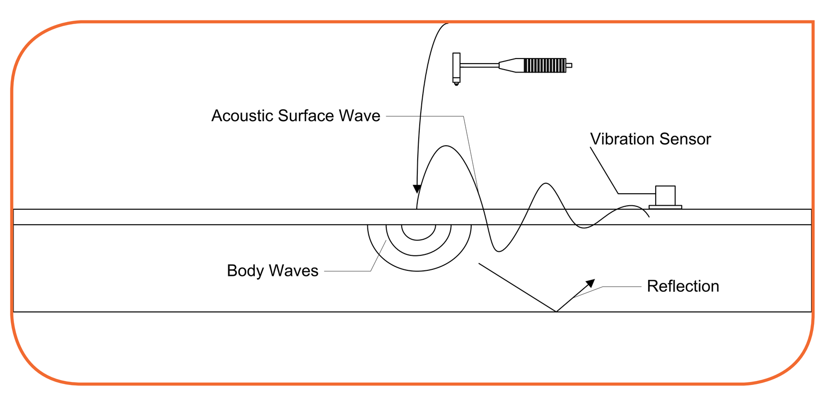

Figure 5: Illustration of solid-borne sound propagation

Noise

- road noise
- furnishing
- sound pressure stemming from TV or other (Lee & Helal, 2009)

Dispersion

- propagation speed is frequency dependent
- methods known from air borne sound signal processing inapplicable (Chun, 2010)
- ➔ techniques for a reliable estimation of the dispersion characteristics of the floors

Space Variance

- floor is an inhomogeneous anisotropic propagation medium
- ➔ dispersion behavior which is dependent on the excitation point and differs for propagation into different directions

Real-time Footstep Detection and Localization System

In order to further test the developed algorithms in real life scenarios, we are implementing a real-time footstep detection and localization system.

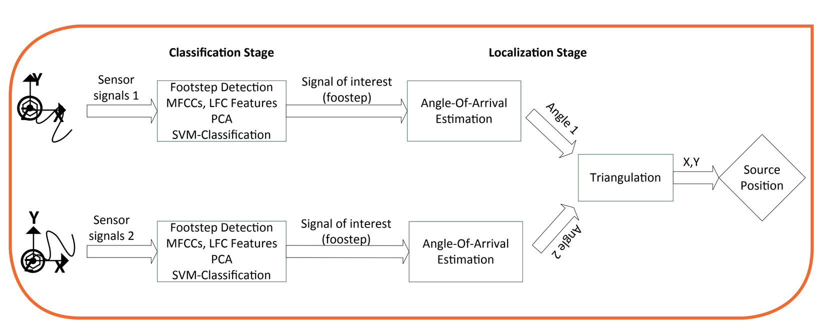

Figure 6: Overall structure of real-time system

Applications

We assess that the introduced technology has great potential to be deployed in **Ambient Assisted Living** and **Surveillance** solutions.

- **Activity-Recognition/Quantification:** How mobile is a monitored person? Ratio Activity/Passivity?
- **Abnormality-Recognition:** Falls, falling objects
- **Localization/Tracking:** Analysis of motion patterns, Multi-Person-Recognition
- **Tangible Acoustic Interfaces (TAI):** Interaction with solid objects for user input or rehabilitation purposes

Summary

We introduced the concept of vibroacoustic monitoring by means of classification and localization of seismic events. AOA-estimation of two sensor stations followed by triangulation seems to be the most promising localization approach. The deployment of the described technology in a real world application will raise the need to account for external noise sources in order to ensure operational localization functionality.

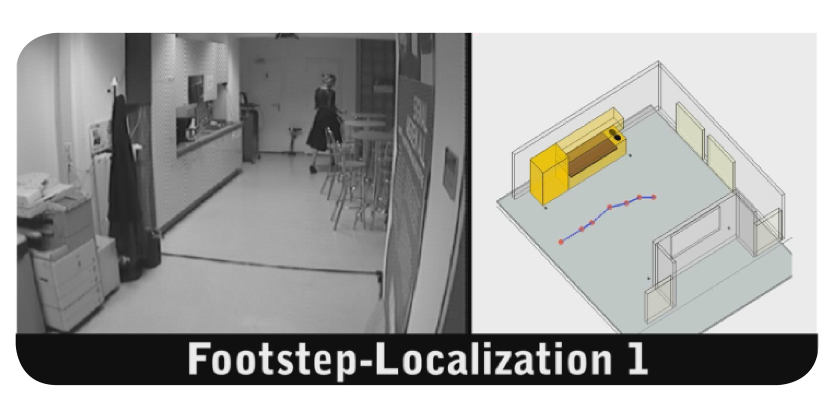

Figure 7: Screenshot of footstep localization demo video

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