Microcontroller-Based Test Bed for Airborne & Structure-Borne Audio Processing & Transfer

Design, Implementation, and Evaluation of a Flexible Platform for Vibration and Acoustic Sensing

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Introduction: Modern cyber-physical systems can use a wide range of sensor modalities to acquire acoustic and vibration information. Besides conventional electret and MEMS microphones for airborne sound, MEMS inertial and piezoelectric sensors can be used to measure structure-borne vibrations. Selecting and integrating a suitable sensor modality remains a challenging task, especially when the system must support signal acquisition, embedded processing, and interpretation using on-device machine learning inference.

Approach: The goal of this thesis was the design, implementation, and evaluation of a modular microcontroller-based test bed for airborne and structure-borne audio sensing, processing, and communication. The platform supports multiple input modalities, including microphones, IMUs, and piezoelectric sensors (Fig. 1). In addition, it provides options for material excitation using audio transducers. Since the required processing hardware may change depending on the application, the platform is designed to support interchangeable microcontroller boards. A portable software library accompanies the hardware in order to simplify the integration of different microcontrollers and peripheral devices.

First, existing commercial solutions and relevant sensing principles were reviewed to identify the requirements for such a platform. Based on these requirements, the hardware architecture was specified (Fig. 1) and an audio main board was developed (Fig. 2).
The board was set up and tested with selected sensors, actuators, and microcontroller components. In parallel, a portable C library was implemented to abstract hardware-dependent functionality such as communication interfaces, digital I/O, and device drivers. The platform was then evaluated through representative application scenarios, including material characterization, embedded classification, and acoustic communication through solid media.

Result: The developed hardware platform was successfully brought into operation. It was used to acquire and process acoustic and vibration signals. The first application characterized material samples in the audible frequency range (Fig. 3) and extracted Young's modulus as well as the phase velocity of flexural waves. Using a piezoelectric sensor and edge AI, the platform also classified 3D-printed structures into conforming and defective parts. For this task, several models were evaluated, of which the multilayer perceptron (MLP) and support vector machine (SVM) performed best with a test accuracy of around 80%. In addition, a frequency-shift keying communication scheme was implemented and tested over two transmission channels in different media (metal and air), achieving a data rate of 500 bit/s. The accompanying library was tested on an STM32H753-based platform and on the Daisy Seed embedded DSP module, demonstrating the intended portability across microcontroller boards. Although several aspects remain open for further investigation, the results indicate that the test bed provides a suitable basis for experimenting with embedded acoustic sensing, processing, and communication concepts.

Fig. 1. Block diagram of the audio platform architecture and signal flow.
Own presentment

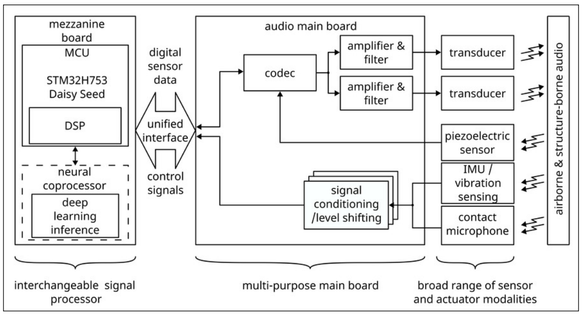


Fig. 2. Audio platform with a range of supported devices attached: 1 microphones, 2 IMUs, 3 piezo sensor, 4 actuators.
Own presentment

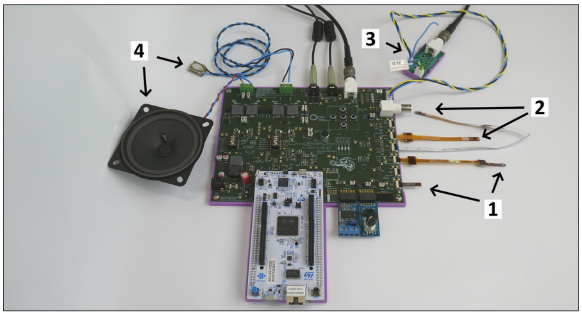
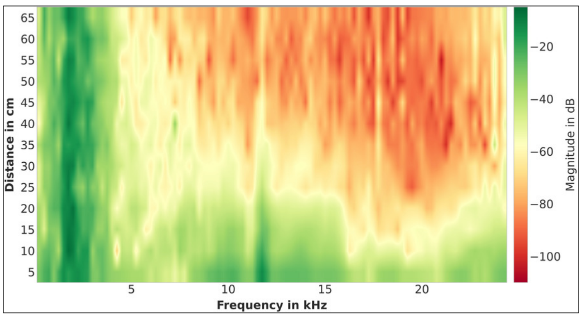


Fig. 3. Frequency response of a 67 cm x 20 cm x 2 cm cardboard sheet, used to determine Young's modulus.
Own presentment



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