Networked Embedded Acoustic Processing System for Smart Building Applications

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***Abstract*—A system to estimate the occupancy level of rooms and buildings solely based on acoustic features will be presented in this paper. It is the goal to use this occupancy estimate to increase the energy-efficiency of modern buildings. An overview of the underlying hardware and software concept as well as a brief description of the acoustic occupancy level estimation is given. The demonstrator shows a working prototype which was developed as part of the EU FP7 project - Sounds for Energy Control of Buildings (S4ECoB) [1].**

I. Introduction

The building sector is responsible for about 40% of the energy consumption in industrial countries and one third of CO_2 emissions. More than 60% of building energy consumption is used for heating, ventilation, air conditioning (HVAC) and lighting [2]. Due to the political goals in reduction of energy consumption and CO_2 emissions [3], buildings have become a main objective for energy saving efforts.

Energy-efficient operation of buildings depends on the number of occupants. Therefore, sensing the occupancy leads to better utilization of the HVAC equipment, which is mostly oversized in order to deal with the maximum number of people expected. Current state-of-the-art systems to provide real-time occupancy information, like pre-set occupancy information or presence sensors have energy-saving potentials, but have several drawbacks like insufficient accuracy, installation and maintenance pitfalls, including high costs. A solution for occupancy estimation that is sufficiently accurate, cost-efficient and easy to integrate into existing Building Management Systems (BMS) still needs to be found [4].

Given the fact that human activities add sound to living and working environments, acoustically based technologies can be particularly useful in providing valuable information, such as the building occupancy, to the BMS. The intention of the *Sounds for Energy Control of Buildings* (S4ECoB) project is the establishment of more Energy-efficient Buildings through the optimization of existent BMSs by means of acquiring, identifying, monitoring and adding the parameter of occupancy level in buildings and its surroundings to enhance operations and eliminate unnecessary consumption of energy without compromising comfort or privacy of the users. The core of the S4ECoB solution is a networked embedded acoustic processing system proposed in this paper.

II. Hardware and Software Architecture

The audio monitoring is performed by a network of microphones grouped into separate microphone arrays with up to eight microphones each and the input signals are A/D converted in short distance to the microphones by means of a Audio Satellite Unit (ASU) (see Figure 1). The audio stream (ADAT protocol encoded) is transmitted in real-time to an Audio Processing Unit (APU) using standard CAT5 cables, up to three ASU's can be connected to a single APU. The overall system architecture is shown in Figure 2. The APU consists of an FPGA based audio interface / preprocessing board and an embedded CPU board connected via external memory interface (GPMC). The selection of an ARM Cortex A9 dual core processor as target CPU and an overall very low APU power consumption is the result of an extensive performance and power consumption analysis of different embedded platforms with typical audio algorithms.

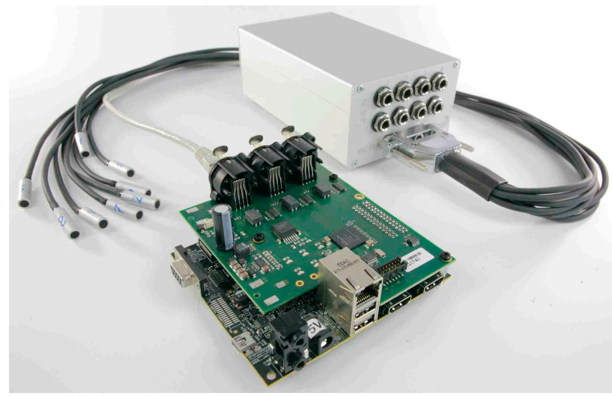

Fig. 1. Embedded acoustic processing unit together with audio satellite unit and 8 microphones.

The acoustic preprocessing and occupancy estimation is realized by a plugin-like approach on the APU, allowing integration and exchange of different audio processing algorithms even at run-time. For the need of raw audio data transmission a multichannel audio data stream into the main memory of the APU is realized with the FPGA in combination with a Linux device driver using a parallel DMA CPU interface. On the APU data values are distributed using the D-Bus interprocess communication system. All APU's are time synchronized using the PTP protocol (IEEE-1588-2008) with a clock deviation of less then 300μs. Data combination and further distribution from several APU's is done by the Building Energy Management Optimizer (BEMO) server connected with the building's BEM system. Using a TCP/IP network connection this component is responsible for managing all APU's in the S4ECoB installation, and providing status information and

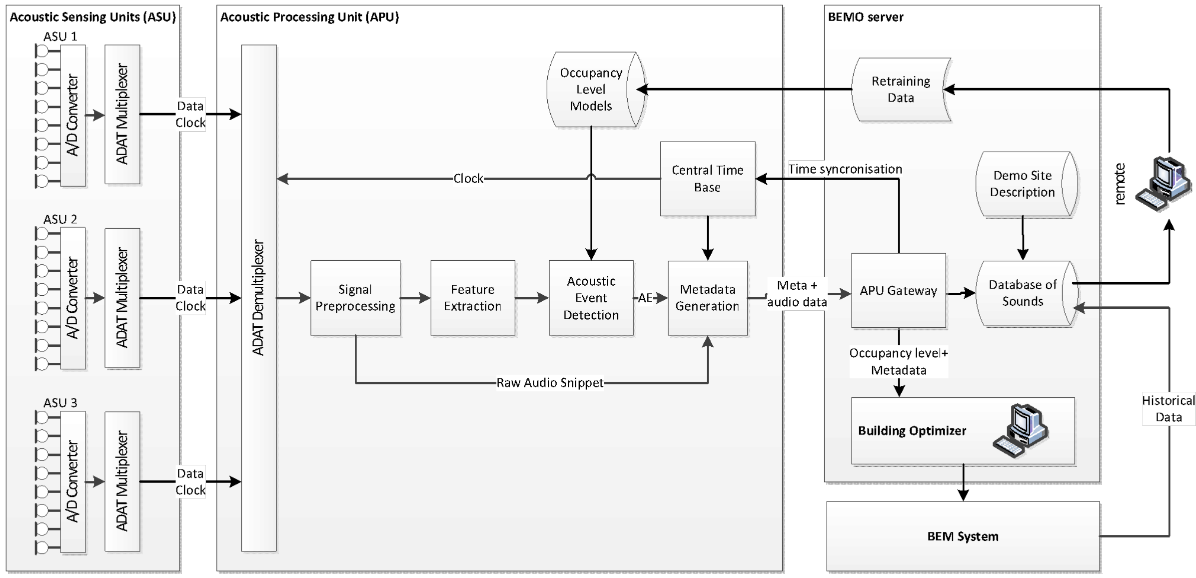

Fig. 2. Overall system architecture of the S4ECoB distributed acoustic occupancy level sensor system

sensor values on the BEMO server. To ensure security, all network traffic between APUs and server is either SSL/TLS encrypted or tunnelled over a VPN.

III. Occupancy Estimation Algorithms

Acoustic occupancy level determination is a non-trivial task, due to the complex mixture of sounds that define occupancy. However, the determination of the exact number of people is not necessary in the S4ECoB context since the BMS cannot make use of this detailed information anyway. Hence, mapping the number of people on a relative metric with a small number of intervals is seen to be sufficient and already beneficial enough. Finding suitable audio signal descriptors for each interval in the metric to automatically differentiate between them is still a challenge.

Two different approaches are investigated to calculate the occupancy level. The first approach is based on acoustic localization algorithms, e.g. global coherence field (GCF). Scanning the monitored area with the localization algorithm in a predefined grid-size results in a so called acoustic map [5], [6]. For each grid-element of the monitored area the acoustic map indicates a pseudo probability for an active audio source. The acoustic map of the monitored area can be used subsequently to generate a single occupancy level value. To increase its robustness, the incorporation of heuristic information, i.e. the location of sound sources not related to occupancy, is foreseen.

The second approach is based on machine learning algorithms, using Gaussian mixtures and hidden Markovs to distinguish between occupancy levels using audio samples recorded by the network embedded acoustic processing system proposed in this paper. Feature Vectors are made of five mel-frequency cepstral coefficients (MFCC) and their first and second order derivatives. This approach further offers the possibility to include potential noise sources (fans, tv, radio) and initially unknown events into the set of events to be detected, leading to an overall increased reliability of the occupancy estimates while being expandable in terms of new events at the same time.

IV. Conclusion

We have introduced a novel network embedded acoustic processing system for estimating the occupancy level in rooms and buildings. In the S4ECoB project the proposed system will be deployed and validated in three large commercial and public buildings such as shopping malls and airport gateway areas in real operational situation in order to demonstrate the potential of occupancy driven BMS to increase the energy savings of public buildings. The demonstrator described in this paper consists of a sphere serving as housing for an ASU and its 8 microphones connected to an APU executing the occupancy estimation algorithms outlined above. The results are further transferred to a pseudo BEMO server showing the occupancy level on a screen as part of the demonstrator. Other possible applications for this acoustic processing system are sound source localization and real-time detection of particular, e.g. safety and security related sounds.

Acknowledgment

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