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Application of Acoustic Sensing Technology for improving Building Energy Efficiency

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Abstract

Buildings are one of the leading energy consumers in Europe. To improve energy efficiency in the built environment means to optimise the operation of building systems. Acoustics potentially provide an important information source to support the assessment of the operation of buildings. Recently, different approaches to the application of acoustic sensing technology have been studied. This paper presents an overview of three on-going projects which look at how sounds can be utilized to reduce energy consumption in buildings. In the "Sounds for Energy Control of Buildings" (S4ECoB) project the primary goal is the establishment of more energy-efficient buildings through the optimization of existing BMS. The "Experimenting Acoustics in Real environment using Innovative Test-beds" (EAR-IT) project aims to develop acoustic mass flows maps which provide awareness of the flows of masses. The "Energy efficient & Cost competitive retrofitting solutions for Shopping buildings" (EcoShopping) project purpose is to increase the energy efficiency of a building and to optimize the investments necessary in building retrofitting. Diverse methodologies and technologies (wired, wireless and mobile) are tested in realistic conditions provided by each demonstrator.

Keywords: Acoustic sensors, Energy efficiency of buildings, S4ECoB, EAR-IT, EcoShopping.

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1. Applications and Projects in Smart Building Environments

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[1]. Due in large part to the political goals in reduction of energy consumption and CO_2 emissions[2] and increasing urgency for action on climate change[3], buildings have become a primary target for energy saving efforts. Given the fact that human activities add sound to living and working environments, acoustic based technologies can be particularly useful in providing valuable information, such as the building occupancy, to the building management system (BMS). Three projects focusing on improving built environments through the development of audio based occupancy estimation systems are brought together to demonstrate the different technologies and how they can be applied to utilize occupancy data.

In the "Sounds for Energy Control of Buildings" (S4ECoB) project[4] the primary goal is the establishment of more energy-efficient buildings through the optimization of existing BMS' by means of acquiring, identifying and monitoring the parameter of occupancy level based on acoustic data in buildings and its surroundings to enhance operations and eliminate unnecessary consumption of energy without compromising comfort or privacy of the users.

The "Experimenting Acoustics in Real environment using Innovative Test-beds" (EAR-IT)[5] project one of the solutions being looked at is the development of acoustic mass flows maps providing awareness of the flows of masses using acoustics in a given environment and made available as a real-time monitoring of mass flows. This can be monitoring crowds' flows (masses of people, not individuals alone) in buildings/cities to create these "acoustic images" of flow patterns of people for supporting energy efficiency solutions (e.g. advanced air-conditioning control, energy efficiency scoring, etc.). The wireless acoustic sensor and processing infrastructure furthermore allows for an implementation of applications beyond energy efficiency, e.g. safety and security related applications. Additionally and complementary to S4ECoB, EAR-IT aims for the development of resource and complexity scalable acoustic sensing solutions.

The intention of the "Energy efficient & Cost competitive retrofitting solutions for Shopping buildings" (EcoShopping) project[6] is to increase the energy efficiency of a building and, additionally to optimize the investments necessary to achieve this major goal by incorporating innovative approaches and new technology that adds additional value. One solution being developed is a multipurpose mobile robot platform equipped with, but not limited to, acoustic sensing technology. This will be introduced to the environment, allowing an accurate, real user oriented, flexible sensing solution for indoor comfort monitoring and assessment of a commercial building. In the context of all three projects, EcoShopping aims for the quantification of value of the different acoustic sensing technologies in terms of cost-benefit analysis.

2. Demonstrators

2.1. Audio-based Occupancy Level Estimation for Smart Buildings (S4ECoB)

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. In buildings 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]. The S4ECoB system is based on an acoustic processing system consisting of a wired infrastructure of embedded 24-channel FPGA based front-ends and multi-core microcontroller

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

subsystems. It is specifically designed for a smart building solution estimating the occupancy level of rooms and areas solely based on acoustic features. This is integrated with TRNSYS building simulation to develop occupancy based control strategies for the HVAC system.

Audio monitoring is performed by a network of microphones grouped into separate microphone arrays with up to eight microphones each and an Audio Satellite Unit (ASU) for A/D conversion (see Fig. 1). The audio stream (ADAT protocol encoded) is transmitted in real-time to an Audio Processing Unit (APU), up to three ASU's can be connected to a single APU. 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 and an overall very low APU power consumption (in contrast to conventional PC's) are results of an extensive performance and power consumption analysis. The acoustic preprocessing and occupancy estimation is realized by a plugin-like approach on the APU, allowing exchange of audio processing algorithms even at run-time. APU's are time synchronized using the PTP protocol (IEEE-1588-2008) with a clock deviation of less than 300µs.

For building energy management purposes the mapping of the number of people on a relative metric with a small number of intervals is seen to be sufficient. 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. For each grid-element of the monitored area the acoustic map indicates a pseudo probability for an active audio source. The second approach is based on machine learning algorithms, using Gaussian mixtures and Hidden Markovs to distinguish between occupancy levels using audio samples recorded before. This approach offers the possibility to include potential noise sources (fans, TV, radio) and initially unknown events into the set of events to be detected.

2.2. Demonstrators in EAR-IT

The EAR-IT demonstrator will exhibit intelligent acoustic solutions for indoor environments. EAR-IT research experiments focuses on the use of many basic/cheap Internet-of-Things (IoT) technologies (audio-ready wireless motes that can provide basic acoustic functions, see fig. 2) together with few advanced/costly embedded systems (so called Acoustic Processing Units (APU), capable of performing advanced audio signal processing tasks) as a source of valuable data for smart applications. EAR-IT experiments run on top of MANDAT HobNet Indoor Test-bed in Geneva[7]. A graphical user interface provides feedback as shown in fig. 3. Demonstrations are to showcase the research experiments conducted in the context of EAR-IT project, e.g. presence detection for office environments for increased energy efficiency, emergency monitoring system for healthcare environments as one example of an alternative application scenario as well as free-field speech-command interfaces for a variety of technological back-ends, and to promote awareness to the untapped potential of sounds and intelligent acoustics as a relevant data source for added-value applications in smart buildings and cities.

Figure 2 - IoT for EAR-IT indoor use case.

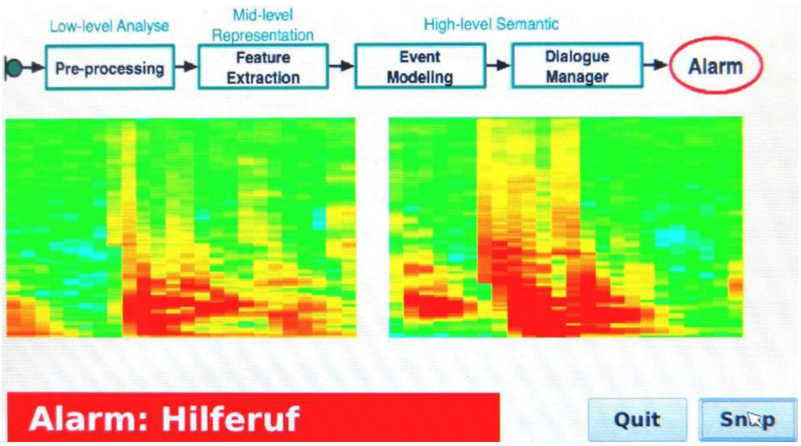

Figure 3 - snap-shot of indoor EAR-IT demo GUI.

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