Integrating WSN into the fabric of the future

Wireless sensor networks (WSN) could have a major impact on society if they are successfully integrated. **Professor Panagiotis Tsakalides**, coordinator of ASPIRE, and his colleague **Professor Athanasios Mouchtaris**, elaborate on the project and a sound related application

The ASPIRE (Collaborative Signal Processing for Efficient Wireless Sensor Networks) project is pushing the boundaries of wireless sensor networks. By approaching traditional, entrenched problems from innovative new angles, the project is breaking through the 'wireless sensor node' glass ceiling. The project is funded under the EU Sixth Framework Programme.

Wireless sensor networks are an emerging technology with a goal to monitor the physical world by means of a densely distributed network of wireless sensor nodes. With WSN it will soon become feasible to deploy substantial amounts of inexpensive devices to observe large ground surfaces, underwater regions, and areas in the atmosphere. These devices will be integrated with: a miniature power supply, multiple modality sensors, on-board processors and radio communication modules. They will be capable of forming large-scale, information collecting, decentralised entities. If judiciously and successfully deployed, WSN will be able to provide – to the benefit of society – unprecedented opportunities for instrumenting and controlling the environment and our cities.

Research Topic and Key Goals

Indeed, networked microsensors are a key technology for the growth of WSN and for societal progress in the 21st century. They offer an opportunity to develop a broad spectrum of applications and new capabilities in various disciplines such as:

- Environmental monitoring – including wildlife habitat sensing and preservation, air and water pollution monitoring, control of water reserves and watershed monitoring, climate observation and prediction, and seismic activity monitoring / impact

- Industrial sensing and diagnostics – including factory and appliance management

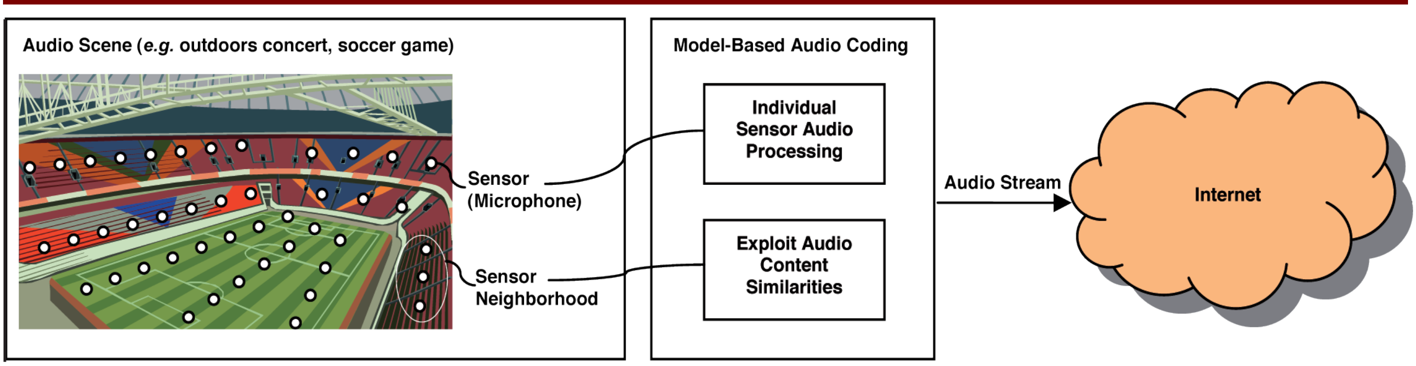
- Infrastructure integrity – comprising power grid and public construction control and command, and intelligent buildings

- Art – entertainment and art education; enabling exciting virtual and immersive digital spaces

Realising the potential of large, distributed sensor networks requires major advances in the theory, fundamental understanding, and practice of: distributed data processing, self-organised communications, and information fusion in highly uncertain scenarios using sensing/communications nodes that are severely constrained in power, computation, and communication capabilities.

Hence, ASPIRE's basic research focuses on furthering the basic theory and understanding of WSN by addressing the following problems: adaptive collaborative processing in highly non-stationary scenarios,

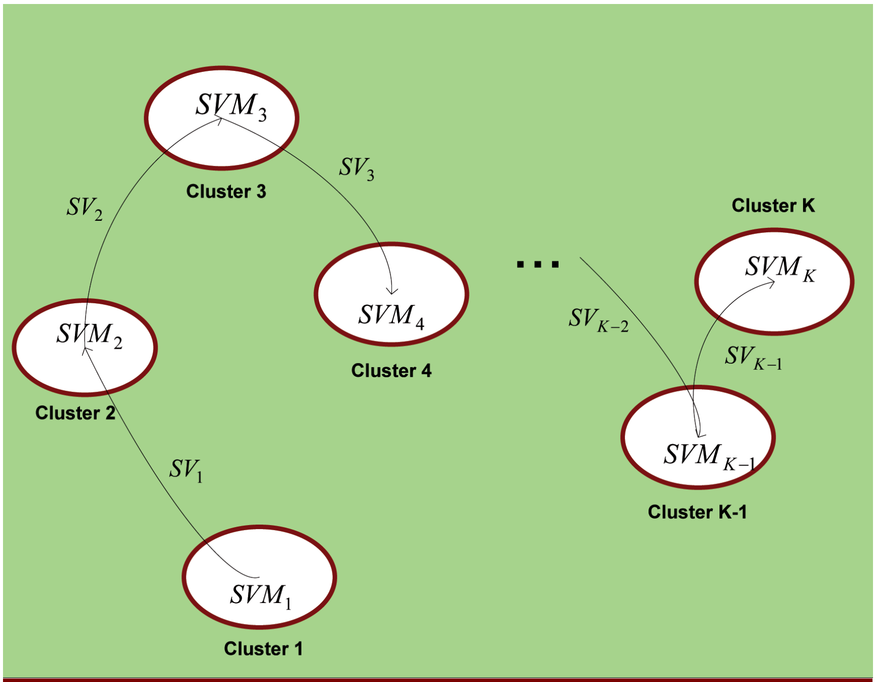
An application of WSN to immersive audio



consistent fusion algorithms for networked sensors and representation/transmission of information in large and uncertain networks. Indeed, this is a highly diverse field which combines disciplines such as signal processing, wireless communications, networking, information theory and data acquisition.

In addition to ASPIRE's basic theoretical research, our mission is to investigate challenging, high-impact research application projects. The application project that tests the developed theories and heuristics is related to 'immersive multimedia environments.' Art, entertainment, and education have always served as unique and demanding laboratories for information science and ubiquitous computing research. ASPIRE demonstrates that WSN can be a provocative catalyst for creative expression. In particular, we focus on multi-channel sound capture via wireless sensors (microphones) for immersive audio rendering.

Immersive audio, as opposed to multi-channel audio, is based on giving the listener the option to interact with the sound environment. This translates into the listener having access to a large number of recordings, which he can process and mix himself – possibly with the help of the reproduction system using some pre-defined mixing parameters. These objectives cannot be fulfilled by current multi-channel audio coding approaches. Furthermore it is simply impossible to apply – especially for large venues which are possibly outdoors or even underwater, and for a recording time of days or even months – the traditional practice of deploying a high-quality high-cost recording system which cannot operate autonomously. We would like to enable immersive presence for the user in any event where sound is of interest. This includes: concert-hall performances, outdoors concerts performed in large stadiums; wildlife preserves and refuges, studying the everyday activities of wild animals, underwater regions and recording the sounds of marine mammals. The capturing, processing, coding and transmission of the audio content through multiple sensors – as well as the reconstruction of the captured audio signals so that immersive presence can be facilitated in real-time to any listener – are the ultimate application goals of this project.

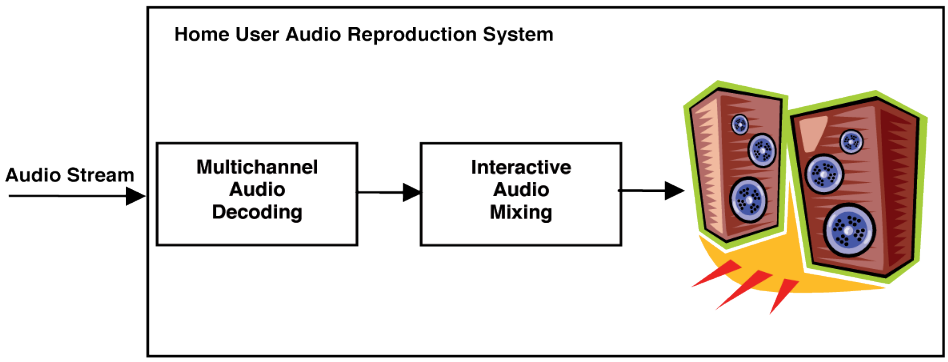


The ASPIRE project develops distributed optimisation methodologies for the efficient training of classifiers in sensor networks

Achievements

At ASPIRE we have introduced mathematical models specifically directed towards understanding the distributed signal acquisition and representation problem, and further, we have developed distributed classification and data compression techniques. In the multi-sensor, immersive audio application, we tested and validated novel algorithms that allow compression of the audio content and at the same time allow for this processing to be performed on resource-constrained platforms such as sensor networks. This methodology is groundbreaking since it manages to combine, in a practical manner, the theory of sensor networks with audio coding. It is the use of the sensor networks theory that allows for audio encoding to be performed on sensors with limited resources regarding: computational power, communications bandwidth and battery life etc. The approach proposed by ASPIRE differs from current state-of-art methods in that it moves the complexity from the transmitter to the receiver, and it takes advantage of the plurality of sensors in a sensor network, so as to encode high-quality audio with a low bit-rate.

At the same time, the proposed approach is focused on encoding multiple audio signals (including multi-channel and immersive audio content) in bit-rates which are significantly lower than in



other state-of-the-art approaches. This is because ASPIRE's system is based on sparse signal representations and compressive sensing (CS) theory which allows sampling of signals significantly below the Nyquist rate (two times the bandwidth of a band-limited signal or channel). This is the first time that a feasible high-quality audio coding system has been proposed in the context of wireless sensor networks.

captured by the various microphones placed in a venue, before the mixing process produces the final multi-channel mix. Coding these signals makes them available to the decoder, allowing for interactive audio reproduction (a necessary component in immersive applications).

- Distributed Parameter Estimation and Object Classification in WSN

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So far, ASPIRE has made advances in:

- Advanced Coding and Compressive Sensing for Audio Sensor Networks

Compressed Sensing seeks to represent a signal using a number of linear, non-adaptive measurements. Usually the number of measurements is much lower than the number of samples needed if the signal is sampled at the Nyquist rate, thus providing the benefits of reduced storage space and transmission bandwidth due to the substantial compression achieved. We investigated how CS might be applied to audio signals, particularly when combined with multiple sensors as in a wireless sensor network.

In addition to detection and estimation of audio signals through WSN, we were also able to apply the CS methodology to audio coding. This task is more difficult than detection and estimation, since the challenge now is to compress the information in the audio signal without sacrificing the quality of the initial recording.

- Design of Multi-channel Coding and Compression Techniques

In this research direction, a multi-channel version of the sinusoids plus noise model was proposed and applied to multi-channel signals obtained by a network of multiple (microphone) sensors. These are the recordings

The emergence of smart low-power devices, which have micro-sensing, on-board processing, and wireless communication capabilities, has impelled research in distributed and on-line learning under communication constraints. In our work, we considered the distributed training of a Support Vector Machine (SVM) using measurements collected by the nodes of a wireless sensor network in order to achieve a global consensus with the minimum possible inter-node communications for data exchange.

Impact on the Future

In the future, ASPIRE aims to develop new sensing and information processing technologies that will enable new forms of interactive experience and expression. Our research on both theoretical information and applied aspects of sensor networks will facilitate, mediate and augment human perception and interaction. Our aspirations are geared towards finally implementing exciting new ideas, such as the immersive presence of a user in a concert hall performance in real-time, implying interaction with the environment (being able to move around in the hall and appreciate the hall acoustics), virtual music performances (where the musicians are located all around the world), and collaborative environments for the production of music. ★

At a glance

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ASPIRE - Collaborative Signal Processing for Efficient Wireless Sensor Networks

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Project Partners
FORTH-ICS (project coordinator). University of Valencia, Spain and University of Southern California, USA (partners)

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Panagiotis Tsakalides and Athanasios Mouchtaris hold a Ph.D. degree from the University of Southern California (1995 and 2003, respectively). It happens that they both did their undergraduate studies in electrical engineering at the University of Thessaloniki, Greece. Currently, they are faculty members at the University of Crete, Greece and associated researchers at FORTH-ICS.

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