Real-time Characterization of Noise Sources with Computationally Optimised Wireless Sensor Networks

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Introduction

Active Noise Control (ANC) applications with distributed sensor and actuator arrays have very restrictive synchronization and computation requirements. Traditionally, microphones and actuators are plugged to a central controller by wires. Wireless solutions enable more flexibility and increase the range of potential ANC scenarios but introduce at the same time new issues regarding synchronization and computational efficiency of the system. Low latency is one of the most important aspect of control applications and can only be achieved with high performance acquisition, processing and communication hardware.

In this paper, we present a wireless sensing and actuating system tailored for the processing of vibration data. We illustrate our setup with an application for identification and localization of acoustic sources.

Platform

We use an innovative platform for real-time wireless applications with high computation requirements developed in our institute [3]. The wireless platform (Figure 1) combines an FPGA (Field Programmable Gate Array) from Xilinx and a RF chip specialized in low power wireless communication. FPGAs enable custom implementations of digital logic circuits with high efficiency, accelerating signal processing algorithms between one and two orders of magnitude in comparison to DSP or microcontroller implementations, traditionally used in low power embedded systems applications.

Figure 1: The FPGA wireless platform with debugging extension

Two extension slots allows the user to plug custom sensor and actuator boards in order to adapt the node to specific applications. An ultrasonic transceiver and a microphone are for example plugged in the configuration shown in figure 1.

A 32-bits processor has been embedded on the FPGA logic for high performance handling of communication and processing tasks. Specialized hardware computation blocks are directly plugged to the processor bus in order to reduce the communication delay between the different entities.

Localization of acoustic sources

We demonstrated the performance of our system with an acoustic monitoring application. An array of wireless sensor nodes equipped with low-cost microphones was deployed in a small room. The goal of the application is to identify and localize an acoustic noise source within the environment [1]. Acoustic waves reach microphones at slightly different instants, so that with sufficiently high sampling rates, it is possible to precisely define time differences on arrival of a given sound on the different nodes. Thus, distances to the source and then its position can be inferred. This information can be later on used to predict vibrations on nodes far from the source with data collected on other nodes close to it.

First, times of arrival of the sound have to be evaluated. When the signal amplitude reach a predefined threshold, record of decimated data is started and a timestamp is saved. The first node which detects the signal broadcasts a packet containing the first samples of the record. Other nodes use cross-correlation with their own record to determine their time on arrival value (Post-Facto synchronization). Fast and efficient signal processing is essential here in order to obtain precise synchronization. Long delays would increase synchronization errors. The FPGA architecture for the cross-correlation block is depicted in figure 2. The value is then transmitted to a central controller responsible to compute the position of the node using a least-squares solver [2] also implemented on the reconfigurable hardware.

When the number of available nodes is sufficient, the computation can be further distributed among groups of nodes by using a divide-and-conquer strategy [4]. Estimates from different groups are weighted according their theoretical Cramér-Rao lower bound and combined on a central coordinator node to generate a final estimate. This approach has the advantage to decrease the complexity of the computation while improving its precision. Distributed computation strategies will reduce the latency of the system thanks to parallelization and lower communication overhead.

FPGA implementations of the different processing algorithms (decimation, cross-correlation, localization,

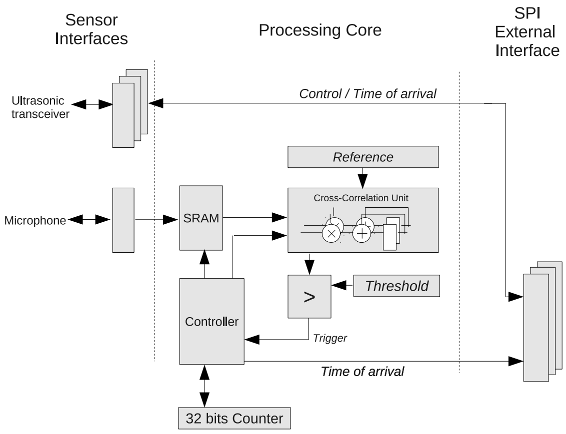

Figure 2: Time on Arrival Estimator

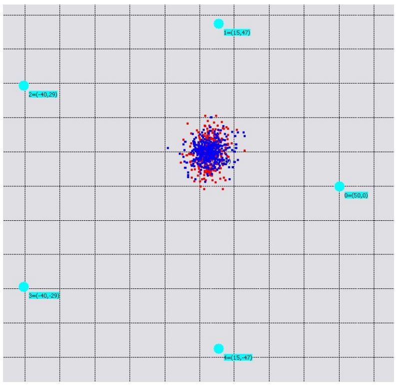

Figure 3: Visualization of localization results

weighting) accelerates the overall estimation process to a few milliseconds whereas low power microcontrollers normally used on wireless sensor nodes require up to half a second for a similar functionality. The performance of the system is now limited by the bandwidth of the wireless communication (250kbps) and can be improved by using faster wireless protocols.

Simulation, Visualization and Experiment

The efficiency and functionality of the developed algorithms have been first tested with a simulation tool written in Java (Figure 3) before the implementation on the hardware. The speed and energy consumption of the system have been then evaluated with a model of the wireless sensor node architecture written in hardware description language (HDL). Optimization of the sensor node architecture regarding latency, precision and energy consumption could be thus realized.

By using a sniffer node, wireless communication between nodes is logged and computed locations are displayed on a graphical user interface in real-time. Experiments realized with an array of five nodes deployed on a circle with a diameter of two meters gave results with very good precision (about 5 centimeters). Imprecision on the nodes positions is one of the main error source. Indeed, nodes determine their position dynamically using the ultrasonic transceivers so that nodes may be freely moved during the experiment. Using fixed positions, the precision can be enhanced to 3 centimeters when localizing a sound in a clear environment.

Conclusion

A wireless distributed system for real-time processing and analysis of high-bandwidth vibration data with improved computation capabilities has been introduced in this paper. The functionality of the platform has been successfully proven for an acoustic localization application. This system will be further extended to active noise control of periodic sources using adaptive computation techniques. By using the position of its source and extracting specific features from the signals, predictive models can be used to optimally tune the actuators of the control system and reduce delays introduced by wireless communication.

Distributed wireless sensor and actuator systems are a challenging area where latencies have to be reduced to the minimum. With new high performance hardware for autonomous embedded systems and reliable communication protocols, wireless control systems can achieve performance close to wired solutions.

Acknowledgments

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