Demo Abstract: An Ultra-Low-Power Custom Integrated Circuit based Sound-Source Localization System

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ABSTRACT

The aim of this demo is to explore the implementation of an ultra-low-power analog-to-feature ASIC to an IoT embedded system. The custom integrated circuit, designed to optimize the power consumption of a traditional sound-source localization systems, is capable of extracting the time-difference of arrival (TDoA) between 4 microphones consuming only 78.2nW. An end-to-end embedded system is presented; a microphone array is connected to the ASIC that converts the TDoA to digital information and sends it to a host computer. A machine-learning algorithm, running in the host, is then used to detect the bearing of the sound-source. During the demonstration, the audience is able to verify the benefits and drawbacks of the custom integrated circuit solution, both in the perspective of the signal-processing performance of the ASIC, and the impact it introduces to the complexity of the system's integration.

KEYWORDS

Embedded System, ASIC, Ultra-Low-Power

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1 INTRODUCTION

IoT systems are composed of various block with distinct functions, varying from sensing to communication to signal processing. Custom integrated circuits are becoming an accessible alternative for embedded systems designers, allowing for optimized implementations that can significantly enhance the performance of each block. But, while most of the ASICs presented in the literature are tested in isolation, there are factors that need to be accounted before introducing a custom integrated circuit to an embedded system. In this work an example of end-to-end prototype for vehicle-bearing estimation that uses an ultra-low-power ASIC is demonstrated.

Figure 1 illustrates how an ASIC can be use to reduce the power of the system. The ASIC presented at [2] is used to replace the digital signal processing required to extract the time-difference of arrival (TDoA) between analog inputs in the work presented by [1]. The time-delay-to-digital converter ASIC uses a polarity-coincidence correlation adaptive time-delay estimation [2]. The PCC-ATDE allows for a drastic reduction in power, consuming only 78.2nW instead of the mW required in standard generalized cross-correlation (GCC) based approaches [1]. But, together with the power reductions, come unique limitations to the technique. Because of the negative feedback architecture the PCC-ATDE, the microphones input signal maximum frequency, TDoA bandwidth, and settling time needs to be matched to the application. The demo provides the opportunity for the audience to verify, in real-time, the effect of parametric variation on the PCC-ATDE implementation in these limitations.

Aside from the challenge of using the PCC-ATDE appropriately, the demo also aims to illustrate the integration troubleshooting required for the system integration. The customizing of a mixed-signal processing block requires careful attention to the interfaces. In the presented system, microphone pre-amplifiers had to be designed so that the voltages didn't exceed the maximum swing allowed by the ASIC, and a optimized data-communication standard was used to read the digital data from the chip. The rational behind each of these decision involve a balance between the risk in mistakes that would catastrophically damage the functionality of the chip, the time required to implement a more complex solution, and the performance impact that each solution would provide. During the demo, with a complete integrated implementation, the audience is encouraged to question each decision.

2 ASIC BASED VEHICLE-BEARING SYSTEM

The system presented at the demo (Fig. 2) aims to detects the angle-of-arrival (AoA) of sound waves, and is used to estimate the bearing of approaching vehicles. The structure of the embedded IoT solution is divided in 5 main blocks.

The sensing node is composed of four microphones assembled in a fixed tetrahedral shape. Sound waves coming from a single source reach each microphone at a different time. The TDoA between the analog signal of the sensors is the feature used to determine the vehicle bearing.

The ultra-low-power analog-to-feature extraction is performed by the ASIC. Using the PCC-ATDE technique mentioned above, the custom chip digitizes the TDoA information.

The communication interface is implemented with serial USB form the ASIC to a host computer. An improved version where the data is sent via BLE to a smartphone is under development.

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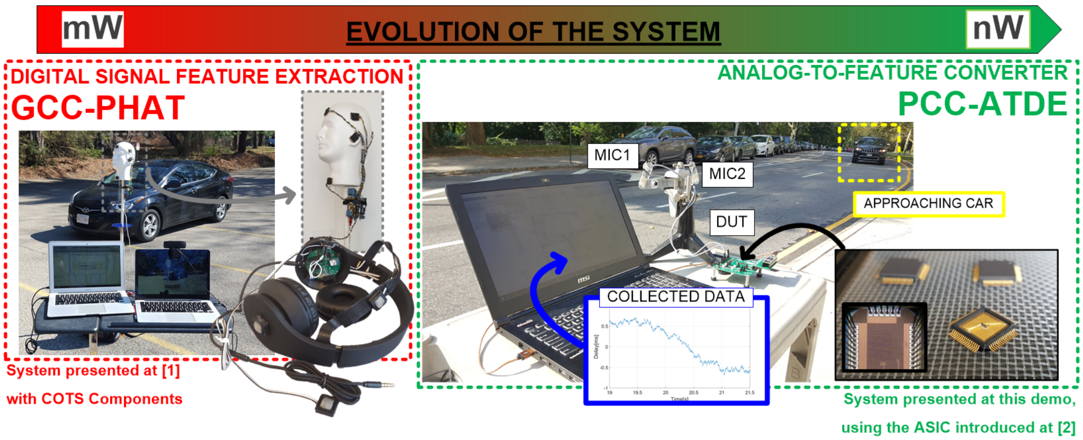

Figure 1: Illustration of the evolution of the system, from a commercial off-the-shelf implementation to an ASIC based approach. The custom integrated circuit is able to replace the digital signal processing block and reduce the required power from mW to less than 100nW.

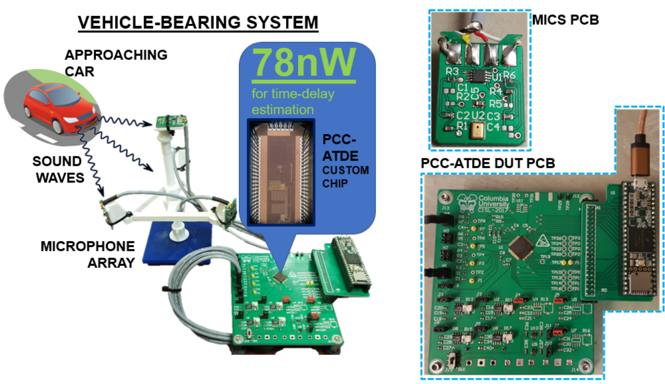

Figure 2: Main components of the embedded system.

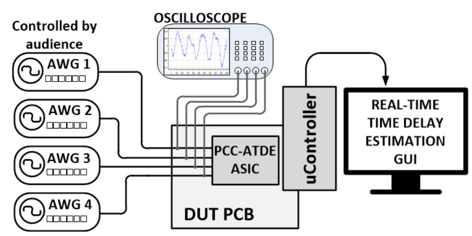

Figure 3: Section 1: controlled inputs demo.

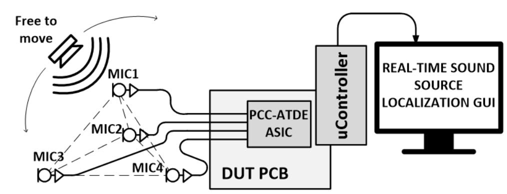

Figure 4: Section 2: microphones and speaker demo.

The host computer uses the features extracted by the ASIC to determine the AoA of the sound source using machine-learning classifiers. Both the AoA result and the TDoA features are displayed in real-time in a graphical user interface so that the audience is able to examine the perfomance of the ASIC.

2.1 System Demonstration Sections

The demo will simulate the presence of vehicles in two ways: one with controlled artificial stimuli, and another with microphones and pre-recorded car sounds replayed on speakers. Both sections are structured to highlight the advantages of the PCC-ATDE, always making a parallel to the application it is used to solve, and how would that affect the design parameters of the system.

Figure 3 illustrates the first demo section. In this section, the audience will test the limits of the PCC-ATDE using artificially generated analog inputs and verifying the results in real time. The user will be able to control 4 arbitrary waveform generators to change different aspects of the 4 inputs, such as bandwidth or shape of the signal, and verify the effect on the time-delay estimation. This section aims to expose the user to limits on range, maximum input frequency, settling time, and variance of the measurement under different conditions that can be applied to various applications. At all times, the analog signal from the microphones will be displayed in an oscilloscope for quick verification of the results.

Figure 4 illustrates the second demo section. Microphones will be connected to the PCC-ATDE ASIC to assemble a sound source localization system. The user will be able to freely move a speaker playing the sound of an approaching vehicle around the microphone array and the time delay feature from the ASIC will be used to estimate the source's location in real time. This section will illustrate how the PCC-ATDE can be used as a building bock in an end-to-end embedded system.

By the end of the demo it is expected that the audience will have enough information to start investigating the use of the PCC-ATDE in their own research/product solutions.

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