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Student Paper

Design and Implementation of a Device Network Application for Distributed Line-crossing Recognition

Chung-Ching Shen, Roni Kupershtok, Shuvra S. Bhattacharyya, and Neil Goldsman
Dept. of Electrical and Computer Engineering, and Institute for Advanced Computer Studies
University of Maryland, College Park, USA
{*ccshen, akuper, ssb, neil*}*@umd.edu*

INTRODUCTION

Many application-specific distributed sensor systems that consist of so-called sensor nodes require small size and low power features due to their limited resources, and their use in distributed, wireless environments. A sensor node platform typically consists of various devices, including a microcontroller for data computation and peripheral control, a transceiver for communication with other nodes, one or more sensors for data acquisition, and a battery for energy support. Using off-the-shelf devices to build sensor node platforms generates unnecessary power/energy consumption and area. When their significantly increased cost can be tolerated, design of application-specific devices is desired to better achieve the goals of small size and low power consumption. In this paper, we present a complete distributed sensor system design with features of low energy usage and small size. In this system, a distributed application for line-crossing recognition (LCR) is demonstrated as a concrete example. This system includes optimizations associated with algorithm streamlining, communication protocol configuration, and hardware/software implementation. We summarize our developed light-weight distributed algorithm for line-crossing recognition [1, 2], together with its specific protocol implementation, and present the corresponding hardware implementation. We also describe a system prototype that we have built based on off-the-shelf devices, including a field programmable gate array (FPGA). The use here of an FPGA is an intermediate stage towards our development of digital application-specific integrated circuits (ASICs) that are fully specialized for our targeted sensor nodes. Our on-going and future work is to integrate the digital ASIC subsystem that we are developing with customized wireless communication, sensor, and antenna devices.

LIGHT-WEIGHT ALGORITHM AND PROTOCOL DESIGN FOR DISTRIBUTED LINE-CROSSING RECOGNITION

The LCR system that we have developed is sensor-supported with an acoustic sensor installed on each sensor node. Sound subjects are detected via acoustic signals. The system can be applied by deploying the sensor nodes in a circle inside a room (e.g., see Fig. 1). Sensors sense continuously, and an analog-to-digital converter (ADC) is used to convert sensed signals to raw samples. Each raw sample is then compared to a pre-defined threshold that is tunable to fit various scenarios. Once a sound source has been detected, the system recognizes and provides information about when and where the subject has crossed the circle. More specifically, all sensor nodes in the system periodically reach consensus in deciding whether or not the subject ("intruder") has crossed a specific boundary ("line") in a noisy environment that is being monitored. Furthermore, upon detecting an intrusion, the system determines where the line was crossed (i.e., between which nodes in the line).

To develop such an application-specific distributed algorithm and its associated communication protocol, we assume that there are N nodes in the system deployed within radio range of each other, and all node-to-node communications are based on a ring topology. We develop a two-phase distributed algorithm [1] with the property that either $O(logC)$ or $O(logN)$ data bits are needed depending on the protocol stage (i.e., synchronization stage or communication stage), instead of $O(N)$ bits. Furthermore, during most of its lifetime, our system communicates with only $O(logC)$ data bits. Here, C — a design parameter — is the minimum number of nodes that must sense the subject in order to reach consensus that an intruder is approaching and crossing the line. Higher values of C provide higher system accuracy at the expense of higher communication requirements and higher recognition latency. Since energy consumption during transmission and reception is high, our approach reduces energy

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consumption significantly by reducing the number bits that need to be communicated for overall system operation. Since the LCR system is fully distributed without using any base station, a self-organizing protocol is required to make sure that all sensor nodes communicate with each other effectively. We have also designed an efficient, specialized wireless TDMA protocol with useful fault tolerance features [2] so that every node receives and transmits at designated time slots, and sleeps during other times for saving energy.

SYSTEM PROTOTYPE INTEGRATION

We have built a system prototype based on off-the-shelf devices, including a field programmable gate array (FPGA), as shown in Fig. 1. The purpose of using the FPGA here is to build and validate a custom-logic prototype before further customizing the digital subsystem for ASIC development. We design digital communication modules that accommodate on-off keying (OOK)-based wireless communication devices to handle real-time packet stream processing.

Fig. 1 illustrates the verification of packet transmission and reception between a pair of wireless communication devices. The digital subsystem for the LCR application has been demonstrated on the FPGA and then fabricated as an ASIC though the IBM 130 nm process (see Fig. 2). Through these progressively more customized implementations, the size and power requirements can be significantly reduced compared to an implementation that is based on a general-purpose microprocessor or microcontroller.

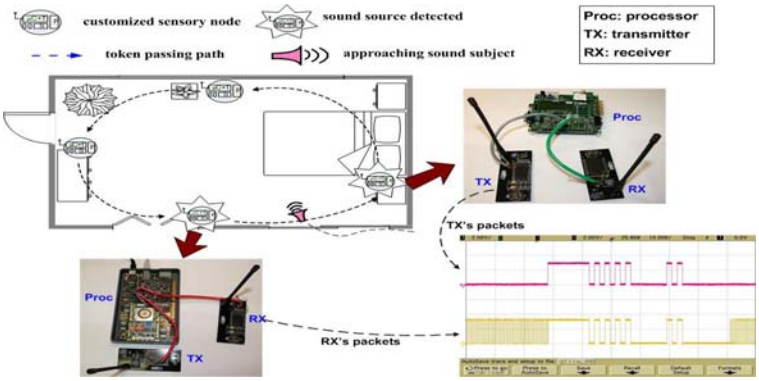
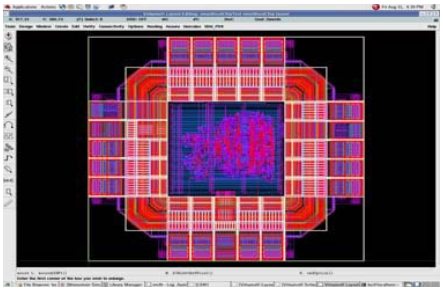


Fig. 1. System prototype with off-the-shelf microcontrollers, wireless communication devices and an FPGA.



Process: IBM 0.13 µm
Voltage: 1.32 V
Target Freq: 20MHz
Dynamic Power: 13.7 µW
Leakage Power: 754 nW
Core Size: 9.0e+4 µm2
Gates: 6598

Fig. 2. Digital design layout for the LCR ASIC chip.

References

[1] C. Shen, R. Kupershtok, B. Yang, F. M. Vanin, X. Shao, D. Sheth, N. Goldsman, Q. Balzano, and S. S. Bhattacharyya. "Compact, low power wireless sensor network system for line crossing recognition," ***Proceedings of the International Symposium on Circuits and Systems*****, pages 2506-2509, New Orleans, Louisiana, May 2007.**

[2] C. Shen, R. Kupershtok, S. S. Bhattacharyya, and N. Goldsman. "Design techniques for streamlined integration and fault tolerance in a distributed sensor system for line-crossing recognition," ***Proceedings of the International Workshop on Distributed Sensor Systems*****, Honolulu, Hawaii, August 2007.**