Determining the Physical Sequence of Sensors on a Serial Bus With Minimal Wiring

C. K. Harnett

***Abstract*—This report demonstrates a three-wire system for determining the physical sequence of addressable devices on a serial bus, enabling automated spatial mapping of sensors along a network. Small inductors between each chip are incorporated into an oscillator circuit, producing a different resonant frequency for each chip during the sequence detect function. Frequency-counting-based sequence detection is compatible with small microcontrollers such as those used in wireless environmental sensor networks. The sequence detection hardware does not interfere with normal use of the same three wires to supply power, data, and ground connections to the wired sensor network in this application.**

***Index Terms*—Intelligent sensors, multisensor systems, spatial mapping.**

I. Introduction

MUCH WIRELESS sensor network research focuses on automated node location [1], particularly for three-dimensional mapping of environmental conditions in situations where it is impractical for users to manually enter fixed node locations [2], or where the nodes move through the environment over time [3]. However, environments to be monitored often include freshwater, seawater, or moist soil—conductive media in which radio waves are severely attenuated. In this case, a practical solution is to install a local wired network that can communicate with sensors at different depths in the conductive medium, and bring the information out to the wireless node for broadcasting. Such wired networks must be low power, low-cost, and use few processor resources. The system should allow users to field-assemble sensors *in any order* on a cable attached to a wireless node, and immediately receive position-mapped data from within the conductive medium.

This report demonstrates a three-wire physical sequence determination method that is compatible with the power and computational resources of typical wireless nodes. In this system, distributed components form an oscillator with a resonant frequency that depends upon chip sequence. After the sequence detection function is complete, the same three wires are used for normal operation.

II. Existing Sequence Determination Methods

Common methods for obtaining the physical sequence of sensors along a serial bus include "chain mode" operation, chip-select lines, and sockets with fixed addresses.

Manuscript received October 10, 2007; revised November 11, 2007; accepted November 13, 2007. This work was supported in part by the National Science Foundation under Grant 0644511. The associate editor coordinating the review of this paper and approving it for publication was Dr. Subhas Mukhopadhyay.

The author is with the Department of Electrical and Computer Engineering, University of Louisville, Louisville, KY 40208 USA (e-mail: c0harn01@gwise.louisville.edu).

Digital Object Identifier 10.1109/JSEN.2008.917126

The "chain mode" function uses a direct connection between adjacent chips to determine which chip is next in line [4]. This method scales easily when new chips are added to the network. However, a chain "in" and chain "out" connection are needed at each chip, bringing the total number of connections to five in this application with its required power, data, and ground connections.

Chip-select methods commonly use an additional line each time the number of sensors on the network is doubled, requiring seven wires per chip for a ten-sensor network (four chip select lines plus a power, data, and ground line).

Addressable sockets, with a fixed addressable switch chip hardwired into each port, might use as few as three wires, with the data line enabling one sensor at a time. However, this method adds traffic to the network, and usually requires gate addresses be stored in the master microcontroller alongside a lookup table of their physical locations. Other socket-based methods, such as sockets with patterned contacts [5], require extra pin connections at each sensor.

These established sequencing methods are suitable for most applications, but the varied user backgrounds and harsh environment of the outdoor sensor network in this report make it important to minimize software complexity and wire count.

III. Design of Oscillator-Based Sequencing System

The wireless environmental sensor network discussed in this report consists of above-water wireless nodes, each connected to an array of underwater sensors based on 1-Wire communication chips (Maxim Integrated Products). While the 1-Wire chips enable only three wires to sequence and operate all sensors, other systems such as SPI or I^2C can be used.

Since all wire-to-sensor connections are made in parallel, the existing serial bus provides no information about physical sensor location. New sensors are discovered in a sequence determined by their serial numbers. However, it is possible to use the power line to construct an oscillator circuit with frequency dependent on the device's position in the network.

This method relies on inserting a small inductor of value ΔL in the power line between each sensor attachment point. These inductors are $\sim$50 μH and are the size of a $1/4$ watt resistor. Provided the inductors have low resistance ($<$5 ohms), normal DC operation is unaffected. Voltage spikes from switching on sensors are generally under 1 V due to small required currents ($<$10 mA) and small inductance values; such spikes can be further suppressed by capacitors for gradual sensor power-up in this low duty-cycle system (1 sample/s).

During sequence detection, the oscillator circuit is powered, and the data line grounds a capacitor on one of the chips, as illustrated in Fig. 1. If the Nth chip's capacitor is grounded, this puts N inductors in series with one capacitor, determining

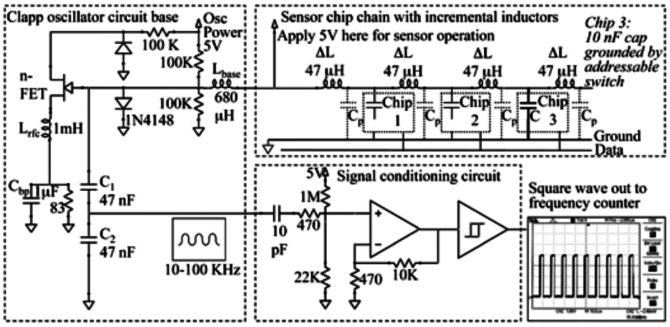

Fig. 1. Oscillator, sensors, and signal conditioning circuit.

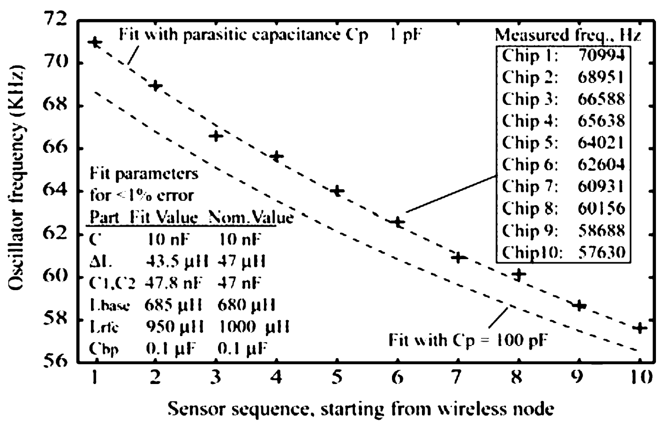

Fig. 2. Oscillator frequency *versus* sensor position along chain.

the frequency of a Clapp oscillator. The oscillator's resonant frequency decreases as the number of inductors between the switched capacitor and the main oscillator chip increases.

For capacitor switching, an addressable switch must be used that does not require 5 V power; fortunately, most 1-Wire chips with addressable switches can operate the switches in "parasite power" mode, even if other functions such as analog-to-digital conversion require power.

Fig. 1 also shows a signal conditioning subcircuit, consisting of an amplifier and Schmitt trigger, which converts the $\sim$100 mV, 10–100 KHz oscillator sinewave into a square pulse train of $\sim$4 V amplitude easily monitored by one input pin of a microcontroller. The microcontroller first searches for all sensor chips connected to the network and stores their ID numbers in a list. Then, it counts the oscillator frequency associated with each discovered sensor chip, sorting the IDs in order of decreasing frequency. The resulting list corresponds to physical sensor sequence. For normal operation, the oscillator circuit is powered off, and a 5 V DC is applied to provide power to the sensor chips.

IV. Results

Fig. 2 is a plot of recorded frequencies *versus* chip location for a ten-sensor network in which each chip's capacitor was sequentially grounded. The oscillator signal did not disturb the signal on the nearby 1-Wire data line, and the inline inductors did not interfere when using the 1-Wire switches to turn on LEDs connected to each chip in normal DC operation mode.

The impedance-*versus*-frequency function of the circuit in Fig. 1 was modeled in MATLAB, with the minimum impedance value corresponding to the circuit's resonant frequency. Circuit parameters were adjusted so that the model, shown as a dotted line on Fig. 2, fit the measured frequency values to within 1%. All parameters remained within the expected uncertainty range of each component. Parasitic capacitance was modeled by including C_p, a small capacitor in parallel with each sensor. As shown in Fig. 2, a C_p value of 100 pF decreased the predicted resonant frequency but maintained the decreasing frequency-*versus*-position relationship, indicating that the frequency-sorting method remains valid in longer networks with significant parasitic capacitance.

V. Conclusion

The proposed oscillator-based sequence detection method was demonstrated successfully on a ten-device network. Sensor cables may be swapped from one microcontroller to another, and more sensors added, without reprogramming. The number of chips is limited by decreasing frequency resolution for chips near the end of the line. For instance, in a 50-chip system the first two frequencies differ by 3%, while the last two differ by only 0.5%, requiring longer frequency counting and making results susceptible to component variation.

Automated sequence detection greatly increases the usability of an educational sensor networking system by adding "plug and play" operation. This new feature enables immediate mapping of sensor depth, and when combined with well-known wireless node location methods, will produce an intelligent sensor network capable of real-time three-dimensional display of environmental conditions.

References

[1] G. Q. Mao, B. Fidan, and B. D. O. Anderson, "Wireless sensor network localization techniques," *Comput. Netw.*, vol. 51, pp. 2529–2553, 2007.
[2] K. Pister, UCB/MLB 29 Palms UAV-dropped sensor network demo. 2001. [Online]. Available: http://robotics.eecs.berkeley.edu/~pister/29Palms0103
[3] P. Padhy, K. Martinez, A. Riddoch, H. L. R. Ong, and J. K. Hart, "Glacial environment monitoring using sensor networks," in *Proc. Real-World Wireless Sensor Netw. 2005*, pp. 10–14.
[4] DS28EA100 chain-mode thermometer data sheet. Maxim Integrated Products, Inc., Sunnyvale, CA, 2007. [Online]. Available: http://datasheets.maxim-ic.com/en/ds/DS28EA00.pdf
[5] DS28E04 EEPROM data sheet Maxim Integrated Products, Inc., Sunnyvale, CA, 2004. [Online]. Available: http://datasheets.maxim-ic.com/en/ds/DS28E04-100.pdf