TELIAMADE ULTRASONIC INDOOR LOCATION SYSTEM: APPLICATION AS A TEACHING TOOL

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ABSTRACT

This paper proposes TELIAMADE (an indoor location system based on ultrasonic and radiofrequency signals) to be used as a teaching tool in the context of Telecommunication Engineering. Due to its simple design, the versatility of its configuration and the characteristics of the involved signals, TELIAMADE is an appropriate tool for teaching basic aspects in location systems, digital communication systems, encoded signalling, microcontroller programming, radio protocols or advanced signal processing techniques. The TELIAMADE design allows students to sample, store and analyze signals at different points of the circuits by using conventional oscilloscopes. Furthermore, some parameters can be configured, allowing students to assess the advantages and inconveniences of each specific configuration with respect to features such as bit-rate, range, robustness against noise or updating period. Our system presents advantages in the field of teaching for understanding commercial systems for location (like GPS) or communication (like wireless digital communication systems).

Index Terms— education, teaching, indoor, ultrasonic, location

1. INTRODUCTION

In recent years, several research papers focus on development and improvement of location systems have been published. Improvements have taken place in both outdoor and indoor locations systems. Among the most widespread outdoor location systems GPS (Global Positioning System) highlights. However, from an educational point of view, some GPS features (such as those relating to the volume of data or the range of frequencies used) make this system difficult to be studied in school laboratories, due to the specialized instrumentation necessary for recording and signal processing [1, 2].

A similar situation is found in the learning of commercial digital communication systems. In this case, the high frequency of the transmitted signals complicates the study of issues such as transmission bit rate, range, noise immunity, dependence of attenuation on both distance and signal frequency, etc.

Scaling features (such as frequency, bandwith, transmission rate, etc.) would be of great use to address the study of these systems in an educational context. Since ultrasonic-based location systems allow such scaling, this work proposes TELIAMADE system (an ultrasonic- and radiofrequency-based indoor location system) [3, 4] to be used as a teaching tool in the context of Telecommunication Engineering studies.

2. DESCRIPTION OF TELIAMADE

2.1. Architecture of the system

TELIAMADE is an indoor location system based on ultrasonic and radio-frequency signals. The system has a star topology in which a master node (network coordinator) handles the rest of network nodes by using the ZigBee radio protocol. The network coordinator is connected to a PC using a standard RS232 interface and acts as a gateway. Thus, the network administrator can send control information to all network nodes changing their configurations or requesting information to monitor the system. Network nodes (except the coordinator) have a module for the transmission and reception of ultrasonics signals. These nodes can be set up to operate as transmitters or receivers of ultrasonic signals.

Figure 1 shows the TELIAMADE architecture. The system typically consists of a set of transmitting nodes, one receiving node (mobile target) and one coordinating node. This node (denoted by C) is connected to a PC via the serial port and synchronizes in time all network nodes by using the Zigbee radio protocol. Nodes placed on the ceiling (denoted by Tx) and the mobile node (denoted by Rx) are set up to operate as transmitters and receivers, respectively. Transmitters are located at known coordinates inside the indoor environment. These nodes are usually placed on the ceiling to avoid obstacles in the signal propagation path to the receiver, since a direct ray between the transmitting node and the receiving node is required. The distance between a transmitting node and the mobile node is calculated by measuring the time of flight (TOF) of the ultrasonic signal. The measure of the TOF

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is sent to the coordinating node using the Zigbee radio protocol. Using the distance to three transmitting nodes the position of the mobile node can be estimated by triangulation.

The TOF measurement requires precise synchronization of the ultrasound transmission and reception. A TDMA scheme is implemented for providing synchronization from the coordinator to all nodes (using the ZigBee radio transmission) and to assign a time slot to each node for the ultrasound transmission in order to avoid ultrasound interferences [4].

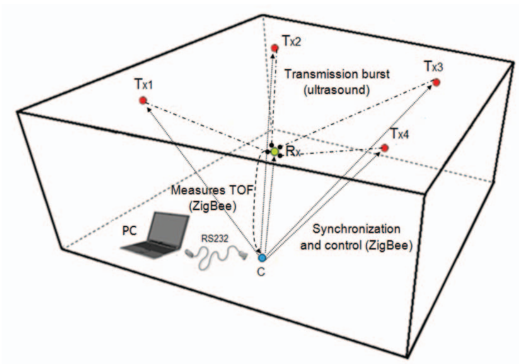

Fig. 1. Architecture of the TELIAMADE system. (C) coordinating node connected to a PC via the serial port. (Tx) node set up as ultrasonic transmitter. (Rx) mobile node set up as ultrasonic receiver.

2.2. Network nodes design

Every network node has a radio-frequency module consisting of a radio chip (CC2420) based on the standard IEEE 802.15.4 [5] and a dipole antenna. This module allows sending and receiving ZigBee messages in the 2.4 GHz band. The radio chip includes a baseband modem implementing the direct sequence spread spectrum technique (DSSS), with a maximum data rate of 250 kbps. This chip is connected to a microcontroller (PIC18F4620) via a SPI interface. The program loaded into the microcontroller allows the node to be configured and controlled by sending, receiving and processing the ZigBee messages.

Figure 2a and 2b show the block diagram of the ultrasonic transmitting and receiving module, respectively. For the transmission and reception of the ultrasonic signal, the nodes have a dual pair of transducers of 40 kHz frequency (Kobitone, 255-400ST12/255-400SR12). Since both generation and signal acquisition are digitally performed using the microcontroller, the system provides great flexibility to implement different modulation and signal processing techniques. For instance, the BPSK modulation scheme is implemented for transmission using encoded signalling to increase robustness against noise and multipath effects. The system allows the transmitting burst to be specified, from a single pulse signal to pseudo codes of different lengths used to modulate a 40

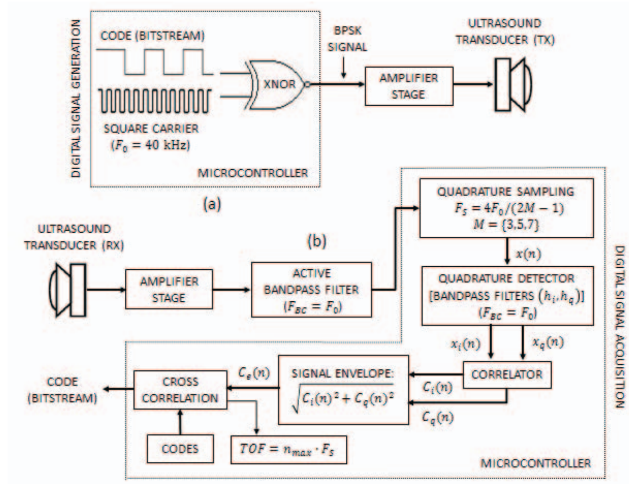

Fig. 2. Block diagram of the ultrasonic transmitting (a) and receiving (b) module.

kHz square carrier using BPSK. The frequency of the carrier signal is determined by the resonant frequency of the transducers. The narrow bandwidth of the transducers (∼2kHz) also influences the signal bit period, selected in this case as 1 ms. In order to increase the signal power and therefore improve the reach of the system the signal is amplified before being transmitted by the transducer.

In the reception module the signal is sampled after two analog amplification stages. The first stage provides an amplification of 20 dB. A 40 kHz second-order bandpass filter is implemented in the second stage to reduce signal noise. This stage has a gain factor of 29 dB. The TOF measurement is performed by applying a quadrature detector that uses a bandpass sampling scheme [6] with low sampling frequencies (32 kHz, 18 kHz or even 12 kHz) [4]. Figure 3 shows the transmission and reception of an ultrasonic pulse using a sampling frequency of ∼18kHz for a distance of 2 meters between nodes. The red line indicates the in-phase component (C_i), the green line the quadrature component (C_q) and the blue line the envelope (C_e). The TOF is estimated as the temporal instant where the maximum of the envelope is reached, using an interpolation algorithm [7].

3. TELIAMADE AS A DIDACTIC TOOL

3.1. Communication systems learning

In the field of education, the study of commercial communication systems is hard to address since these systems are based on signal transmissions in the range of MHz to GHz. In this frequency range we find some limitations if we use school laboratories. For instance: (i) the very high sampling frequency required is not commonly available in conventional oscilloscopes; (ii) non-negligible parasitic capacities; (iii) the

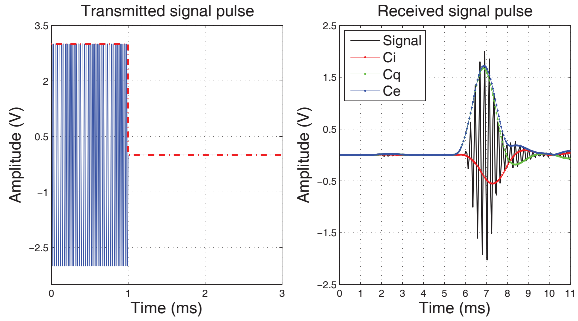

Fig. 3. Transmission and reception of an ultrasound pulse (simplest case) using a sampling frequency of ∼18kHz for a 2m distance. The red line indicates the in-phase component (C_i), the green line the quadrature component (C_q) and the blue line the envelope (C_e).

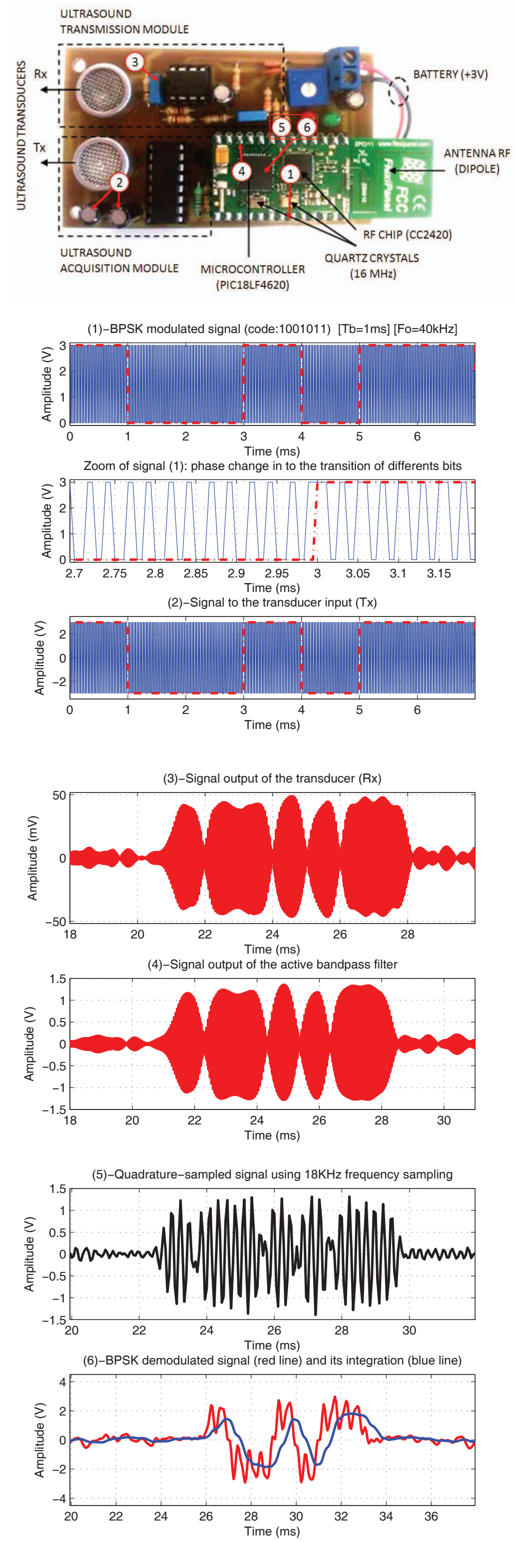

Fig. 4. Picture of a network node and some of the signals that can be observed using a conventional oscilloscope.

great volume of data complicates the storage and subsequent processing; and (iv) basic features (such as the relationship between attenuation and distance or the relationship between bit error probability and signal-to-noise ratio) may not be studied in school laboratories. On the other hand, working with low-frequency systems in school laboratories is not possible given the large size of antennas that would be needed for signal transmission and reception.

TELIAMADE system is proposed to overcome these limitations. Since the ultrasound-based physical layer allows to work with low carrier frequencies (∼40 kHz), the signals can be sampled in school laboratories using conventional oscilloscopes. For example, figure 4 shows a picture of a network node and some interesting signals. Thus, students can observe the signals at any point in the circuit and analyze the channel coding, the modulation and demodulation scheme, the amplification and filtering stage to reduce noise in the receiver, etc.

Since ultrasonic signals are used, it is also easy to generate noise and multi-path effects to check some features such as the bit error probability of the encoded signaling technique as a function of the signal-to-noise ratio. Furthermore, the flexibility of our system in placing the network nodes at different locations (distance, angle) and configuring some parameters (such as the size of the frame sent, the signaling burst, the chips duration of the encoded signaling or the sampling frequency) allows students to analyze the system under different conditions and assess the advantages and disadvantages of each particular configuration in terms of bit rate, robustness against noise, radiation diagram, bit error probability or scope as a function of both distance and angle. TELIAMADE system also allows students to acquire some knowledge of medium access techniques (like TDMA), advanced signal processing (like quadrature bandpass sampling), radio protocols (like Zigbee) and microcontroller programming.

3.2. Location systems learning

Since the Global Positioning System (GPS) is one of the most used location systems, it has been considered as a reference for assessment the skills of TELIAMADE system as a teaching tool. GPS has a number of limitations that make it inappropriate for a teaching environment. For instance: (i) GPS uses Gold codes of 1023 bits with a bit length of 1/50 seconds and a chip duration of $\sim 1\mu$s. The study of the received signals would therefore require storing some tenths of second to analyze various received bits; (ii) Commercial GPS receivers are not suitable as a teaching tool. They are closed systems (encapsulated and shielded), in which only the antenna input and output data (usually a digital output of 9600 bps via RS-232) are available. The signal processing is performed without the possibility for the student to understand the internal behavior of the system by analyzing signals at different points; (iii) Measuring instruments with a high sampling rate would be needed due to the high frequency of carriers (1.2276 GHz and 1.5754 GHz). This limitation persists even with the conversion to intermediate frequency signals (several MHz depending on model); and (iv) even if it were possible to have appropriate instrumentation to sample GPS signals in school laboratories, the large volume of data would greatly complicate both storage and signal processing. For example, after conversion to intermediate frequency, a 1-sec GPS trace would have a size of hundreds of megabytes.

TELIAMADE system is proposed as a teaching tool for the study of location systems. This system overcomes the disadvantages of conventional systems like GPS. One of the great advantages of our system is the possibility offered to the student to analyze the signals in each block of both transmitter and receiver, thus helping to understand how each module works. In addition, the frequency scaling performed by TELIAMADE makes possible to work with conventional oscilloscopes. The quadrature band-pass sampling implemented in our location system allows to use sampling frequencies as low as 18kHz or even 12kHz [4], facilitating both storage and data processing. Finally, since the system has an open and flexible software, students can set up different parameters to analyze the strength, reach and precision of the location system. Thus, students can perform experiments as shown in Table 1, where the root-mean-square errors (RMSE) in the distance measure between one transmitting and one receiving node are shown. 500 measures were taken with the distance varying from 2 to 6 meters (step of 1m). The TOF-based distance was estimated using approximate sampling frequencies of 32, 18 and 12kHz.

	RMSE (mm)		
d (mm)	$\sim$32kHz	$\sim$18kHz	$\sim$12kHz
2000	0.196	0.217	0.234
3000	0.312	0.348	0.300
4000	0.344	0.318	0.400
5000	0.492	0.425	0.464
6000	0.609	0.520	0.623

Table 1. Root-mean-square error ($RMSE$) for a pair of transmitter and receiver nodes separated by a distance d, using sampling frequencies of about 32, 18 and 12KHz.

4. CONCLUSIONS

Given the complexity of commercial systems in educational environments, this work proposes TELIAMADE system to be used as teaching tool for the study of both digital communication and location systems. The advantages of TELIAMADE related to the frequency range used, the signals involved, the configurable software and the ability to analyze the circuitry of both transmitter and receiver, allow students to study relevant features of communication and location systems such as bit error probability, range, noise immunity, signaling technique, modulation scheme, location accuracy and performance under different configurations (burst size, angle and distance between devices, etc.). In addition, students may acquire knowledge related to advanced signal processing (like quadrature bandpass sampling), medium access techniques (like TDMA), radio protocols (like Zigbee) or microcontroller programming.

5. REFERENCES

[1] E. Kaplan and G. Hegarty, *Understanding GPS: Principles and Applications*, Artech House Publishers.

[2] P. Misra and P. Enge, *Global Positioning System: Signals, Measurements and Performance*, Ganga-Jamuna Press, Massachusetts.

[3] C. Medina, J.C. Segura, and A. De la Torre, "Teliamade: sistema de localización en interiores basado en ultrasonidos y rf," in *Simposium Nacional de la Unión Científica Internacional de Radio (URSI)*, 2010.

[4] C. Medina, J.C. Segura, and A. De la Torre, "Una red inalámbrica de sensores orientada a localización con precisión sub-centimétrica," in *Simposium Nacional de la Unión Científica Internacional de Radio (URSI)*, 2011.

[5] IEEE std. 802.15.4-2003: Wireless Medium Access Control (MAC) and Physical Layer (PHY) specifications for Low Rate Wire-less Personal Area Networks (LR-WPANs).

[6] R.G. Vaughan, N.L. Scott, and D.R. White, "The theory of bandpass sampling," *IEEE Transactions on signal processing*, vol. 39, pp. 1973–1984, September 1991.

[7] F.E. Gueuning, M. Varlan, C.E. Eugene, and P. Dupuis, "Accurate distance measurement by an auton-omous ultrasonic system combining time-of-flight and phase-shift methods," *IEEE Transactions on signal processing*, vol. 46, pp. 1236–1240, December 1997.