Developing an identification system for museums using ultrasound technology

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***Abstract* — This work presents the design of a low cost electronic system that uses PSK modulated ultrasound signals to perform location and identification in indoor environments. The target application is the identification of works of art in museums. In this paper we describe the design, implementation and testing of the system prototype. This system (composed by three emitters and one receiver) can correctly identify each emitter at distances from 20cm up to 500cm with a BER (Bit Error Rate) below 7%. In the presence of three emitters separated 200cm from each other the system can correctly identify the emitter at distances from 20cm up to 400cm. The system's probability of false detection is below 10^{-6}.**

I. INTRODUCTION

The need to locate, identify and provide information in ubiquitous computing, is the motivation for developing low cost identification and location indoor systems. In outdoor environments it is possible to obtain precise location information from GPS (Global Position System). However, this system does not present accurate readings in an indoor ambient. To get accurate localization in indoor environments several systems have been developed using different technologies, such as ultrasound, infrared and radio frequency. In this work we describe a prototype system designed to be used in the identification and location of art works in museums. When a visitor approaches an art work, the system should provide its identification (id) and an estimate of the distance. The latter feature may be used by the system to provide an immersive experience to the user by, for example, reducing the loudness of the audio description when the user goes away from the art work being observed. RFID tags do not allow this type of features because RF signals, unlike ultrasound signals, may be detected from the other side of a wall, leading to possible mismatches in art work identification.

II. RELATED WORK

The Parrot system [1] uses a mixture of RF (radio frequency) and US (ultrasound) signals. The nodes, called the *parrots*, transmit a RF signal followed by an ultrasonic pulse. These signals are captured by other nodes that calculate the distance between them based on the time of flight of the signals. One of the advantages of this system is that it creates a wireless network where it stores the positions of all the remaining nodes. This network can be accessed in each node, providing knowledge of all the nodes to each other, such as their position and the nearest node available.

The Cricket [2,3,4] and Active Bat [4,8] systems, also use both types of signals. The RF signal is used as a trigger to the transmission of the ultrasonic pulses. The ultrasonic pulses enable 3D high precision location in indoor environments. Although these ultrasonic systems require additional hardware and complex manual pre-configuration, they provide 3D location of indoor objects with an accuracy of centimeters. One of the most significant differences between these two systems is that the Cricket is a support system for localization similar to the GPS (users use the system to obtain information), therefore there is no central processing unit as in Bat (the system obtains information from the users to a central processing unit).

The Active Badge [4,5,6] is a system that relies on infrared signals to provide location of staff, patients or objects in a hospital setting. Each badge sends a 15sec code using infrared light, that is captured by receivers placed on the building structure. These receivers are connected to a central station to provide room location. The infrared signals can work up to 6 meters but its behavior is severally affected by the presence of florescent light.

The Dolphin [12] system was designed to solve the problems presented by the Active Bat and Cricket systems. The main focus is in the configuration needed in large scale implementations. This system is based on wireless sensors distributed on the location area. Each one has the ability to send RF and ultrasonic pulses but fixed positions of some sensors are needed to provide an accurate reading.

There are other systems with features of location and information but do not use ultrasonic pulses. The RADAR [4,10] is a RF based system that uses the power of the RF signals to triangulate the position of the object. The greater advantage of this system is the ability to use a preexistent wireless network.

The Floor location system [4,9] is a system that locates users by their footprint. The system makes use of the GRF (Ground Reaction Force) to characterize the users and stores all the data on a central processing unit. The system can identify the type of user, the exact footprint of a user and even the type of shoe the user is wearing. Although this system is innovator it presents an important disadvantage: if the number of users becomes large, due to the large amount of information that is stored for each user, the database becomes difficult to manage.

III. LOCATION AND IDENTIFICATION BY PSK MODULATED ULTRASOUND SIGNALS

We intend to develop a system prototype of an identification system for museums using ultrasonic technology. The object of identification is the displayed art work and not the users of the system. The dimensions of the museum and art galleries are diverse as well as the number of objects and their relative position, therefore the system needs to work by influence areas (meaning that each emitter has an area where the receiver can correctly identify it) as shown in figure 1.

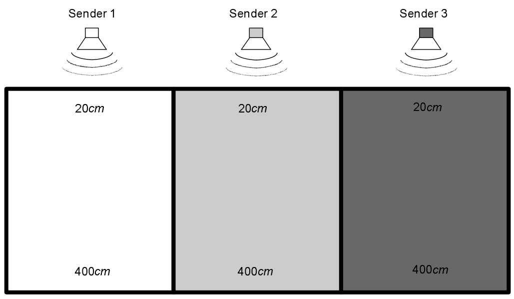

Figure 1 – Influence areas of the emitters.

The receiver must be able to correctly identify the emitter between distances of 1 to 4 meters and also be capable of working correctly in the presence of other emitters that are also active. The solutions proposed are quite simple in order to get a system with the desired functionality but at a reduced cost.

First of all we need to choose the type of modulation [13,14] to code the ultrasonic pulse. Several modulation schemes were evaluated: ASK (Amplitude-Shift Keying); PSK (Phase-Shift Keying) and FSK (Frequency-Shift Keying). PSK modulation was chosen due to its easy implementation and simplicity. This type of modulation only needs to make phase shifts of the carrier wave, and with the use of only two symbols (BPSK – Binary Phase-Shift Keying) the shift of π radians is obtained by simple carrier inversion.

BPSK [13] is a phase modulation that uses two distinct phases (0 and π radians). The signals s_0 and s_1 may be represented by [13]:

$$s_0(t) = \sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t) \quad (1)$$

$$s_1(t) = \sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t + \pi) = \sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t) \quad (2)$$

Where $0 \le t \le T_b$, and T_b is the duration of the bit, f_c the carrier frequency and E_b the bit energy. Then, the BPSK signal may be defined as:

$$s(t) = Am(t)\cos(2\pi f_c t + \theta) \quad (3)$$

where $A = \sqrt{\frac{2E_b}{T_b}}$ is the amplitude, $m(t)$ is the ±1 bipolar signal, ω is the frequency and θ is the initial offset phase of the carrier. Considering an initial offset phase $\theta = 0^o$ and $\omega = 2\pi f_c$ we have:

$$s(t) = Am(t)\cos(\omega t) \quad (4)$$

The signal bandwidth, B, relates the bit rate r with the carrier frequency f_c, as shown in the following two equations

$$B = 2r \quad (5)$$

$$B = \frac{2 f_c}{N_{per}} \quad (6)$$

where N_{per} is the number of the carrier periods per bit.

The demodulation used in the system was the DBPSK (Differential Bipolar Phase-Shift Keying). This type of demodulation eliminates the necessity of carrier recovering at the receiver and provides a good immunity to changes of the carrier frequency. An example of this immunity may be observed in figure 2, where the carriers of two demodulated signals are affected by frequency shifts.

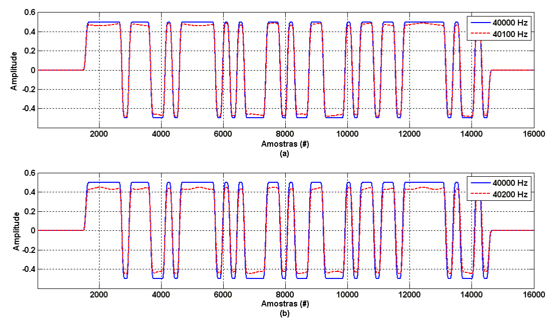

Figure 2 – Effect of the variation on the carrier in the DBPSK. **(a)** Variation of 100*Hz*, **(b)** Variation of 200*Hz*

Each emitter sends a unique modulated sequence in random time slots. Therefore, the emitters rarely start transmitting at the same time, but collisions may occur.

The DBPSK demodulation also provides some immunity to the Doppler Effect. This effect causes a variation in the observed frequency at the receptor when the receiver and emitter are moving in relation to each other. Therefore, it has basically the same effect as a shift on the carrier frequency. Due to the relative immunity of the DBPSK demodulation to frequency shifts, the relative speed necessary to cause a failure of the system would have to be greater than the average velocity of a moving person. Since we are developing a system to work in indoor museums, fast movements of the visitors are unlikely.

IV. SYSTEM IMPLEMENTATION

The prototype consists of three emitters and one receiver. The emitters are coded with three different sequences modulated using PSK. To explore the maximum bandwidth provided by the transducers used (40 kHz± 1 kHz*)* the number of periods of the carrier wave per bit for a transmission rate of $r = \frac{1\text{kbit}}{s}$ is 40.

$$N_{per} = \frac{2 \times 40\text{k}}{2\text{k}} = 40 \qquad (7)$$

Each sequence is modulated by a sinusoidal carrier of 40 kHz with a sample frequency of 160 kHz well above the Nyquist minimum sampling frequency.

The sender module [15] (figure 3) uses the supply voltage (12Vpp) to generate a square wave that is sent to the ultrasonic transducer which converts it into a sinusoidal wave due to the band pass properties of the transducer. The algorithm implemented in this module consists into loading the sequence to the microcontroller module, waiting for the correct time slot and generating the correct square wave using CMOS logical ports. A micro controller from MicroChip, the 18F452, was used to control this process. The developed board is shown in figure 3. All the programming was done in assembly language to ensure real time operation of the system.

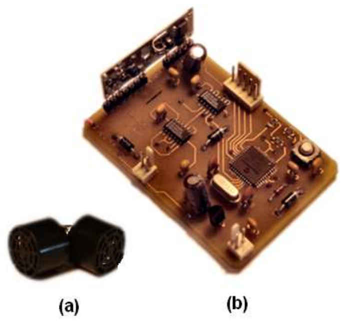

Figure 3 – Hardware of the sender module. **(a)** Transducers, **(b)** Processor and logical ports

The receiver module is composed by one ultrasonic receiver, a pre-amplifier, a DSP board from Texas Instruments named eZdsp 2812 and a board ("*Locus Board*") with an eight channel DAC and variable gain preamplifiers. The receiver module is shown in figure 4.

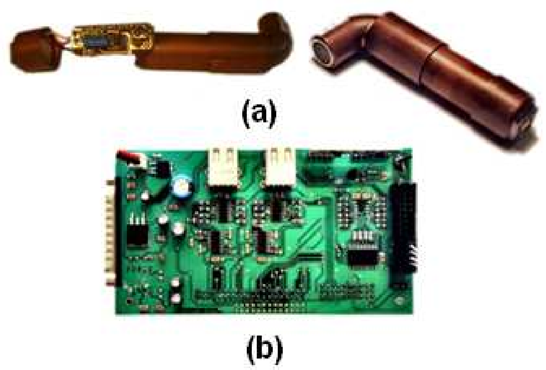

Figure 4 – Hardware of the receiver module. (a) Transducer and pre-amplifier, (b) "*locus Board*"

The demodulation and the filtering of the received signals are performed continuously on the receiver processor so that the system can provide identification in real time. After the identification of the received sequence is carried out, the system communicates with the PC using the RS-232 serial port. The system only provides the received sequence and the amplitude of the signal which can be used to estimate the distance to the emitter.

V. TESTS AND RESULTS

In order to gauge the system, two types of field tests were made. The objective of the first one is to test the maximum range at which the system correctly decodes the emitter sequence. The second test estimates the probability of detection of each emitter for different positions. Although, the receiver has 4 programmable discrete gains only two of those were sufficient to cover the area of influence.

Distance (cm)	BER	Amplitude
20	0.0052	1248.5
40	0.0047	1103.1
60	0.0046	619.5
80	0.0082	442.1
100	0.0044	344.8
120	0.0044	272.1
140	0.0049	235.2
160	0.0047	199.3
180	0.0044	168.1
200	0.0047	140.6
220	0.0048	122.5
240	0.0050	115.4
260	0.0050	93.7
280	0.0056	86.3
300	0.0710	78.9
320	0.4789	72.7

Table 1 – BER and amplitude of the sequences (Minimum Gain)

In the first test a 9 bit sequence was used and the distance between the sender and the receiver changed from 20*cm* up to 320*cm* (for a minimum gain and jumps of 20*cm*).

For each position 10000 sequences were acquired so that we can compute the system BER accurately. The results are shown in table 1.

Of the 150000 acquired sequences (the data for the 320*cm* distance was discarded due to the high BER) 2535 presented errors. The histogram with the number of errors per sequence is shown in figure 5.

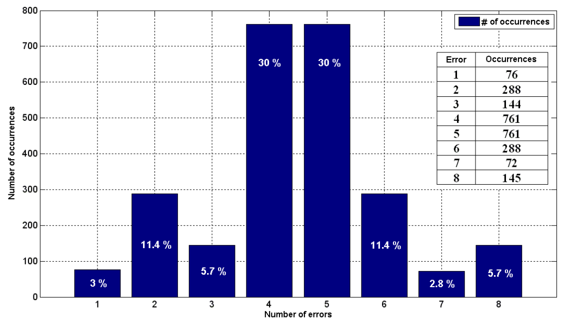

Figure 5 – Error histogram (Minimum Gain)

A similar procedure was carried out using a higher gain. In this new test the difference between positions (resolution) changed from 20cm to 50cm and the distance between the emitter and the receiver started at 200cm. The results are shown in Table 2 and figure 6. Of the 70000 acquired sequences (the data for the 550cm position was discarded due to the high BER) 648 presented errors.

Distance (cm)	BER	Amplitude
200	0.0047	367.2
250	0.0055	274.2
300	0.0049	209.6
350	0.0047	160.0
400	0.0051	118.0
450	0.0055	104.0
500	0.0054	80.8
550	0.6174	48.5

Table 2 – BER and amplitude of the sequences (Elevated Gain)

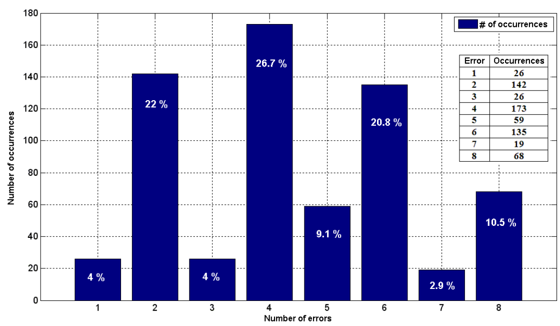

Figure 6 – Error histogram (Elevated Gain)

For the second set of tests all the three senders were used simultaneously. The senders were separated from each other by 200cm and the position of the receiver was varied from 100cm to 400cm and the maximum gain was used. The results are shown in figure 7 (in this figure the minimum gain is referred by Gain 0 and the higher gain as Gain 1). The figure is divided in three and in each one the receiver is pointed directly to one of the emitters. Each rectangle represents the percentage of sequences received from each emitter. For example, when the receiver is in front of the sender 2 at 400cm but pointing to sender 3, .most of the sequences come from sender 3, a few from sender 2 and we also get about 30% with errors.

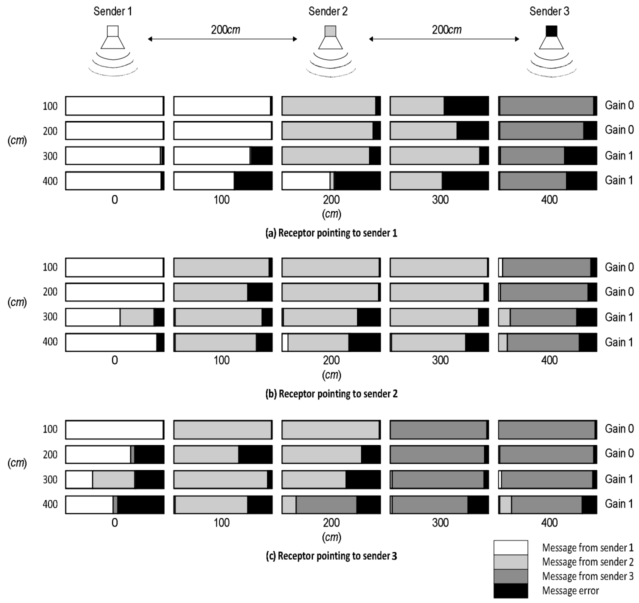

Figure 7 – Probability of detection using 3 senders

VI. RESULT ANALYSIS AND CONCLUSIONS

In the first tests (maximum range of the system) it is clear that the system works reasonably well up to 500*cm* using two discrete gains (minimum and maximum gain). For the minimum gain the system stops working correctly for a distance of about 320cm, because the BER rises dramatically. For the higher gain the system stops working correctly at 550cm. It is obvious that the system breaks for this large distance, amplitude of the signal is significantly reduced and the BER increases significantly.

From the observation of figure 7 we can clearly see the areas of influence of each sender. The percentage of the black bars (sequences with errors) increases with the distance because as the distance between the sender and the receiver increases the signal to noise ratio degrades significantly. It is also notorious the symmetry between the results when the receiver is pointing to sender 1 and sender 3 and the areas of influence proposed in figure 1.

The algorithms used in this work are simple and provide a good basis to build upon.

The main objectives of this work were achieved and a similar solution may be incorporated, in the future, in a real location and identification system for museums.

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