IADAT-tcn2004 International Conference on Telecommunications and Computer Networks

# USE OF DS-CDMA BASED GOLD SEQUENCES FOR A LOCAL POSITION SYSTEM WITH ULTRASONIC BEACONS

**J. Manuel Villadangos, Jesús Ureña, Manuel Mazo, Álvaro Hernández, Fernando Álvarez*, J. Jesús García, Carlos De Marziani, Diego Alonso**
Electronics Dept., University of Alcalá. Polytechnics School, Ctra. Madrid-Barcelona, km 33,700. 28871. Alcalá de Henares, Madrid, Spain.
Tel: +34 918856564 / Fax: +34 918856591
* Dept. of Electronics and Electromechanical Eng., University of Extremadura. Spain
*villa@depeca.uah.es*

## Abstract

*The present work shows a Local Positioning System (LPS) of mobile robots (MR) using simultaneous emissions of the ultrasonic beacons. In order to solve the problem of the simultaneous emission of the ultrasonic beacons, the well-known technique called Direct Sequence Code Division Multiple Access (DS-CDMA) is used. This technique modulates the ultrasonic signal (50 kHz) with a 127-bit Gold code for every beacon. In this way, it is possible to detect the arrival time of the code, by carrying out the simultaneous correlations with the assigned codes to each beacon. For determining the absolute position, the technique of triangulation will be used from the Time-of-Flight Differences (DTOF) obtained between a reference beacon and the others. Using this method, certain errors, derived from the retardation in the firing of the beacons and the response times of the ultrasonic transducers, are avoided. The existence of a synchronism in the emission of the beacons, that guarantees a periodic and simultaneous emission in all of them, is required, not being necessary the determination of the emission instant in the mobile robot. This is particularly useful in environments where several robots can coexist.*

## Keywords
Local position system, ultrasonic beacon, Gold code, Direct Sequence CDMA.

## 1. INTRODUCTION

The 3D local positioning system of mobile robots based on a beacon system by ultrasounds is broadly well-known. It consists of using several beacons located at known positions in the environment, where the robot is moving, and of measuring the time-of-flight (TOF) of the ultrasonic signal from the emission instant. To synchronize the emission instant of every beacon, a radio-frequency or a coded infrared signal is often used to select which beacons is going to transmit [1]. This method implies that the robot should remain static until all the measurements have been captured. Also, it supposes that the maximum acquisition frequency of the position is reduced in a factor similar to the number of used beacons.

If the beacons work as receivers and the kM as an ultrasonic emitter, it is only necessary to transmit an ultrasonic pulse to obtain the TOF for every beacon. This method requires a centralized communication and process system, which, starting from the obtained TOF, computes the robot's position and communicates it to the robot [2].

The proposal of this work is the determination of the absolute position of a mobile robot using the measurement of the DTOF between a reference beacon and the rest, considering that all them emit simultaneously and in a continuous way. To solve the problem of the simultaneous emissions in beacons, the DS-CDMA technique is used, by modulating the ultrasonic signal (50 kHz) with a 127-bit Gold code different for every beacon, and by transmitting it in a periodic way. A receiver on board the robot would carry out the simultaneous correlations with the codes assigned to each beacon, in order to detect the DTOF's among a reference beacon (the nearest) and the rest. This method also avoids the robot to know the emission instant, because it is only necessary a common synchronism among all the beacons.

There exist several previous works that have used the codification of the ultrasonic signal to implement advanced sensors for the detection of obstacles in robotics, using pseudo-random sequences [3] [4], Barker codes [5], or Golay codes [6]. In absolute positioning with ultrasounds, Hazas [7] has been the first one in using Gold sequences of 511 bits. The triangulation technique will be used in order to obtain the absolute position of the RM, using the differences in times-of-flight (DTOF's) [8].

## 2. SYSTEM DESCRIPTION

Gold codes are a particular set of pseudo-random sequences (PN), which have high auto-correlation and low cross-correlation properties [9]. If different Gold codes are assigned to users in a *Direct-Sequence Spread Spectrum* (DSSS) system, their signals can be sent simultaneously and can be still separated at the receiver. The wide bandwidth provided by the PN code allows the signal power to drop below the noise threshold without loss of information.

In the proposed system, every beacon has assigned a 127-bit Gold sequence that identifies it (see figure 1). The symbol, formed in this case by a 50 kHz carrier cycle ($T_c$=20us), is modulated in BPSK by the Gold sequence, providing a signal whose duration is 127·20us=2.54ms (see figure 2). This signal is emitted by each beacon in a periodic and continuous way.

All the beacons are synchronized by a common clock ($f_{clk}$=500kHz) and they emit periodically every 40ms (see figure 2), avoiding in this way the necessity of carrying out a synchronism from the mobile robot by means of some wireless system (RF, infrareds, etc.).

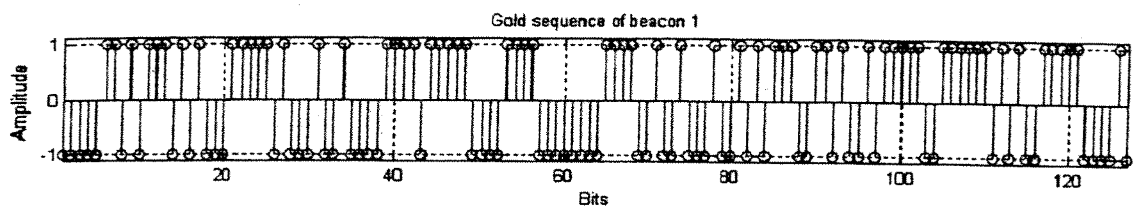


Fig 1. Example of a 127-bit Gold sequence.

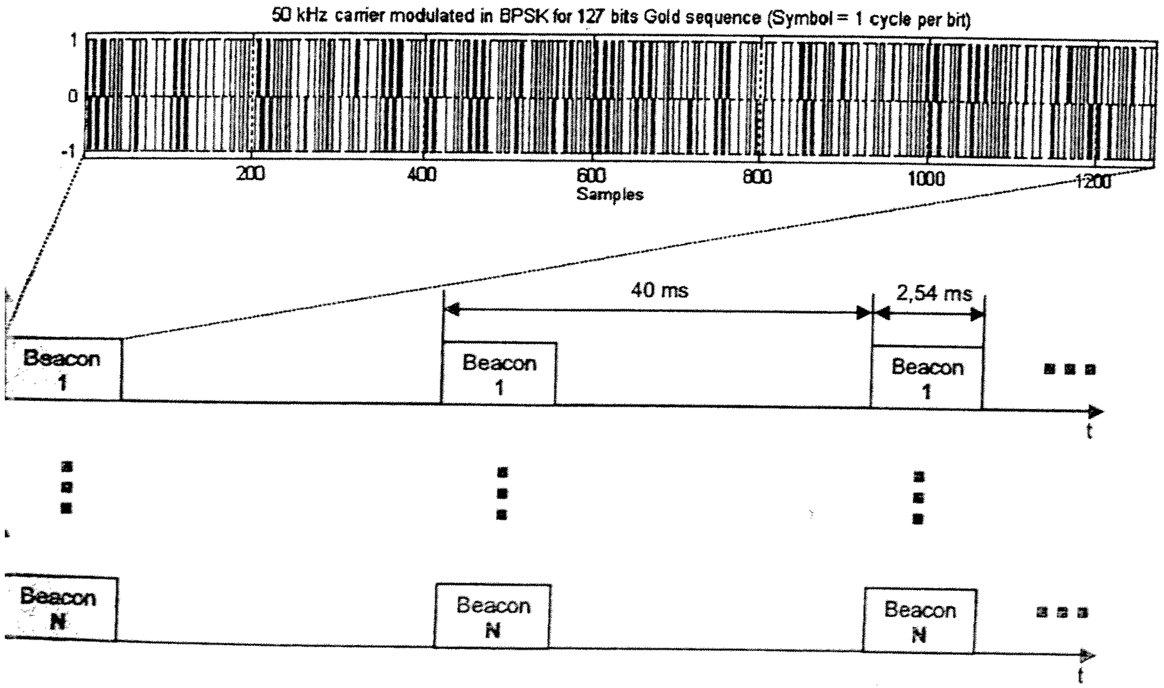


Fig. 2. Signal emitted by each beacon.

et us consider a beacon system formed by 5 beacons placed over the floor, with an approximated height of 3m, d into a 6x6m surface (figure 3). The nearest beacon to the robot is considered as reference beacon (beacon 3). he robot was located at the coordinates ($x$=3m, $y$=3.1m, $z$=1m). Figure 5 shows the captured signal orresponding to the simultaneous emission of the 5 beacons, having a signal-noise ratio of 0dB.

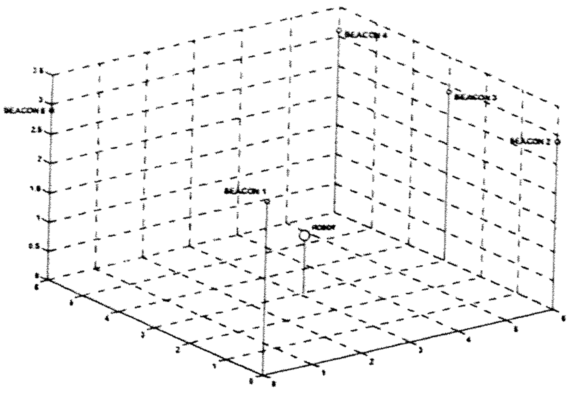

Fig. 3. Example of a beacon system.

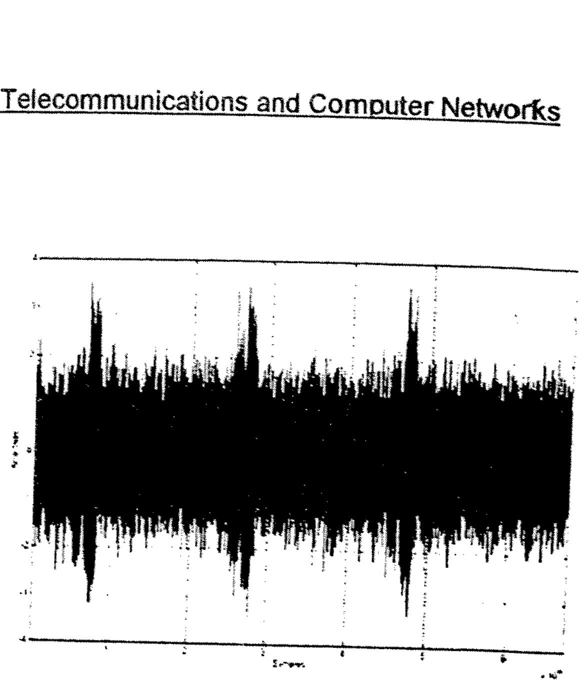

Fig. 4. Signal captured at the robot position.

Once the signal is captured, the correlations between the received signal and the Gold sequences from every beacon are carried out. The maximum values in the correlation function determined the arrival instant of the corresponding sequence (see figure 5). The nearest maximum to the time origin determines which is the reference beacon. It will be enough to compute the difference in samples among the other maximum values in the different correlation functions, and to multiply by the sampling frequency, in order to obtain the differences in times-of-flight between the reference beacon and the rest. These values will be used in the positioning algorithm to determine the robot's absolute position.

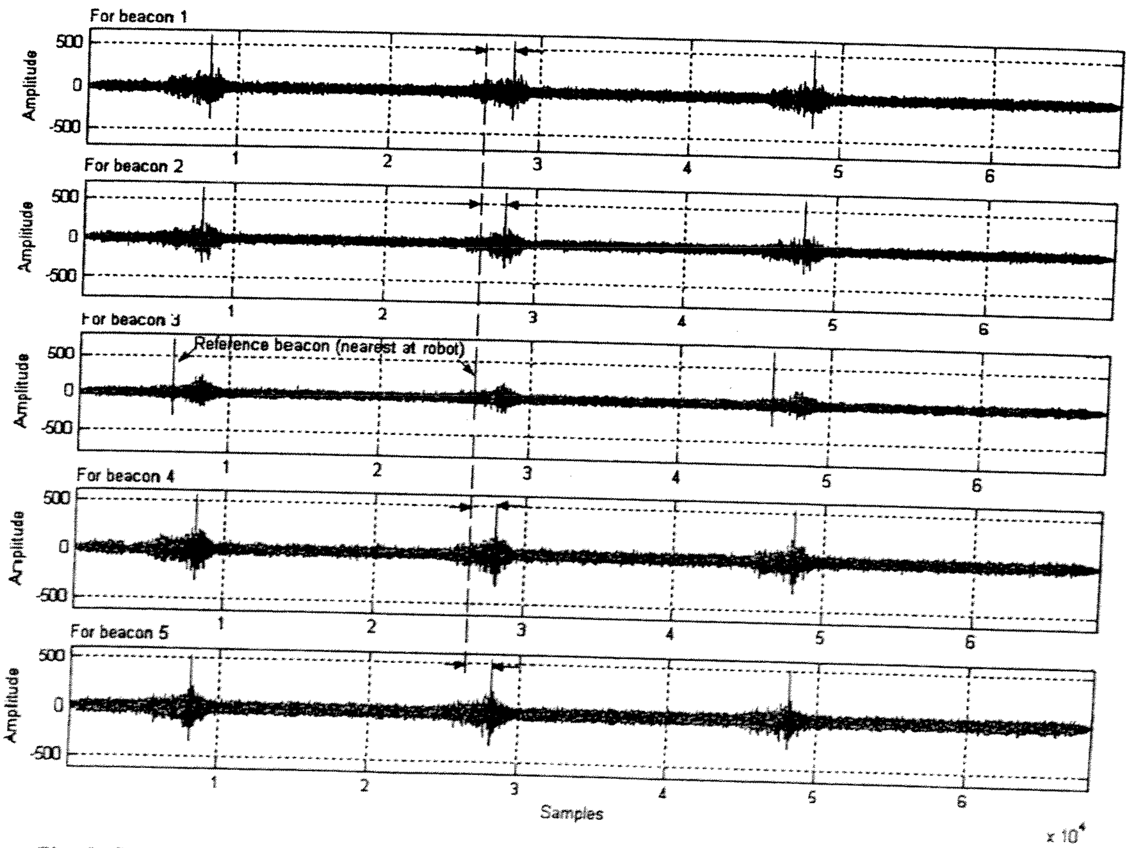


Fig. 5. Cross-correlations between the received signal and 127-bit Gold sequences for every beacon.

## 3. ABSOLUTE POSITION CALCULATION

Considering a group of $N$ beacons ($N$=5), a equation system can be proposed (1) to obtain the absolute position of the RM in 3D ($x$, $y$, $z$), using the positions where the beacons are located ($x_i$ ,$y_i$ ,$z_i$) and the differences in times-of-flight among a reference beacon (for example, beacon 1) and the rest, so:

$$\begin{array}{l} (x-x_1)^2+(y-y_1)^2+(z-z_1)^2=d_1^2 \\ (x-x_2)^2+(y-y_2)^2+(z-z_2)^2=(d_1+c\cdot\Delta T_{12})^2 \\ (x-x_3)^2+(y-y_3)^2+(z-z_3)^2=(d_1+c\cdot\Delta T_{13})^2 \\ \quad\cdots\qquad\cdots\qquad\cdots\quad=\quad\cdots \\ (x-x_N)^2+(y-y_N)^2+(z-z_N)^2=(d_1+c\cdot\Delta T_{1N})^2 \end{array} \qquad (1)$$

Where $d_1$ is the distance to beacon 1 (reference one), considered as a variable, and $\Delta T_{12}$, $\Delta T_{13}$... $\Delta T_{1N}$ are the differences in times-of-flight measurements, among the reference beacon and the rest. We assume the propagation speed $c$ of ultrasounds (c = 342 m/s). Developing the squared values, subtracting the first equation to the others and regrouping terms, a lineal equation system is achieved, which can be solved in a simple way, by the lineal minimum square method, shown in (2):

$$\mathbf{A}\vec{\mathbf{x}}=\vec{\mathbf{b}} \qquad (2)$$

Where,

$$\mathbf{A}=\begin{bmatrix} 2x_1-2x_2 & 2y_1-2y_2 & 2z_1-2z_2 & -2c\Delta T_{12} \\ 2x_1-2x_3 & 2y_1-2y_3 & 2z_1-2z_3 & -2c\Delta T_{13} \\ \cdots & \cdots & \cdots & \cdots \\ 2x_1-2x_N & 2y_1-2y_N & 2z_1-2z_N & -2c\Delta T_{1N} \end{bmatrix} \qquad (3)$$

$$\vec{\mathbf{x}}=\begin{bmatrix} x \\ y \\ z \\ d_1 \end{bmatrix} \qquad (4)$$

$$\vec{\mathbf{b}}=\begin{bmatrix} c^2\Delta T_{12}+x_1^2+y_1^2+z_1^2-x_2^2-y_2^2-z_2^2 \\ c^2\Delta T_{13}+x_1^2+y_1^2+z_1^2-x_3^2-y_3^2-z_3^2 \\ \cdots \\ c^2\Delta T_{1N}+x_1^2+y_1^2+z_1^2-x_N^2-y_N^2-z_N^2 \end{bmatrix} \qquad (5)$$

The solution is equal to (6):

$$\vec{\mathbf{x}}=(\mathbf{A}^{\mathrm{T}}\mathbf{A})^{-1}\mathbf{A}^{\mathrm{T}}\vec{\mathbf{b}} \qquad (6)$$

## 4. HARDWARE IMPLEMENTATION OF SYSTEM

Every beacon generates a Gold code using a FIFO serial memory, at which the samples of the ultrasonic signal modulated in BPSK are directly stored, followed by the suitable amount of null samples necessary to achieve the repetition period. The output of the FIFO memory is connected to the power driver that excites the ultrasonic transducer. The used transducer is *Murata* Super Tweeter Driver (ESTD01), which has a wide bandwidth (100kHz) and a large emission pattern (figure 6).

The receiver is based on an acquisition system formed by an 8-bit ADC ($f_s$=500kHz) connected to a 64 kbyte FIFO memory, enough to achieve the repetition period of the ultrasonic signal in the beacons. The FIFO memory is read by a FPGA device, that carries out the correlation between the acquired signal and the corresponding Gold code. The maximum value of the correlation is stored and, afterwards, sent to the CPU, where the positioning algorithm is performed.

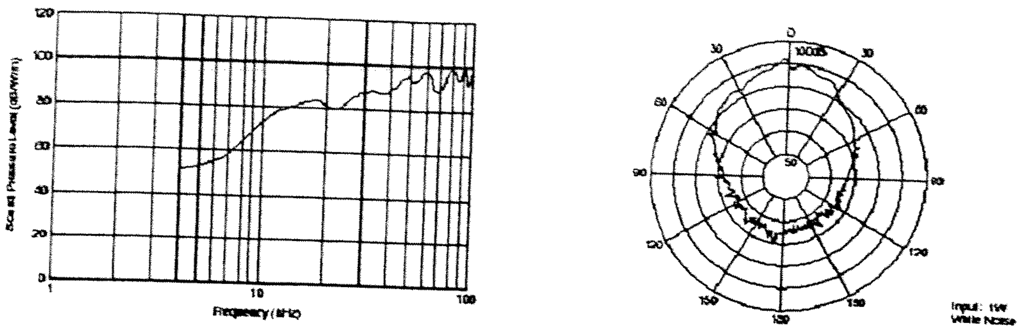


Fig. 6. Frequency characteristics and directivity of Super Tweeter Driver (Murata).

The size of the FIFO memory is determined by the dimension of the capturing window, fixed by the repetition period of sequences. At each emission, at least one maximum from the correlation function should be detected.

## 5. CONCLUSIONS

A Local Positioning System (LPS) for mobiles robots (MR) using emissions simultaneous from ultrasonic beacons has been presented. To solve the problem of the simultaneous emission of the ultrasonic beacons, the DS-CDMA technique has been used, by modulating the ultrasonic signal (50kHz) with a 127-bit Gold code in each beacon. The resulting signal is transmitted periodically and continuously. In this way, it is possible to detect the arrival time of codes, carrying out the simultaneous correlations with the assigned codes to each beacon. The determination of the absolute position is performed using the triangulation technique with the DTOF's obtained among one reference beacon and the others.

## 6. ACKNOWLEDGMENTS

This Work has been possible thanks to Spanish Ministry of Science and Technology through PARMEI Project (ref. DIP2003-08715-C02-01), and the University of Alcalá through the ISUAP project (ref. PI2004/033).

## References

[1] Seiji Aoyagi, Masaharu Takano, Hajime Noto. Development of Indoor Mobile Robot Navigation System Using Ultrasonic Sensors. Proc. ICV'98, 1998.3, pp345-349 6.

[2] Roy Want, Andy Hopper, Verónica Falcao, Jon Gibbons. The active Badge Location System. Olivetti Research Ltd (ORL). Cambrige. England. http://citeseer.nj.nec.com/want92active.html

[3] Klaus-Werner Jörg, Markus Berg. Using Pseudo-random Codes for Mobile Robot Sonar Sensing. IAV'98. Madrid, Spain; March 25-27, 1998, pp. 231-236.

[4] Anr .ew Heale and Lindsay Kleeman. A Sonar Sensing with Random Double Pulse Coding. Australian Conference on Robotics and Automation, Melbourne, August 30 - September 1, 2000, pp 81-86.

[5] Ureña Ureña, Jesús. Contribución al Diseño e Implementación de un Sistema Sonar para la Automatización de una Carretilla Industrial. PhD. Thesis, Electronics Department, University of Alcalá, 1998.

[6] A. Hernández, J. Ureña, J. J. García, V. Díaz, M. Mazo, D. Hernanz, J. P. Dérutin, J. Serot. Ultrasonic signal processing using configurable computing. 15th Triennial World Congress of the International Federation of Automatic Control (IFAC'02), Barcelona, 2002.

[7] M. Hazas and A. Ward. A novel broadband ultrasonic location system. In Proceedings of UbiComp 2002: Ubiquitous Computing, pages 264-280, Goteborg, Sweden, Sept. 2002.

[8] Ajay mahajan and Maurice Walworth. 3D Position Sensing Using the Differences in the Time-of-Flights from a Wave Source to Various Receivers. IEEE Transactions Robotics and Automation, volume 17 (2001) number 1, pp 91-94.

[9] R. Gold. Optimal binary sequences for spread spectrum multiplexing. IEEE Trans. On Information Theory, IT-13(4):619-621, 1967.

# PROCEEDINGS IADAT-tcn2004

## IADAT International Conference on Telecommunications and Computer Networks

*Focused on*

*Innovation, Technology and Research*

-3 December 2004
an Sebastian, SPAIN

Edited by
IADAT

Published by

International Association for the Development of

Advances in Technology

IADAT

ISBN : 84-933971-1-3

ISSN: 1698-1073

# IADAT-tcn2004

## Proceedings of the IADAT International Conference on Telecommunications and Computer Networks

## *Innovation, Technology and Research*

*San Sebastian, Basque Country. Spain*
*December 1th-3th, 2004*

## CONTENTS

### Information Theory and Coding Theory



### Networking Theory and Technologies