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A LOCAL POSITIONING SYSTEM BASED ON PSEUDO-RANDOM SEQUENCE EMISSION

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Abstract: A Local Positioning System for Autonomous Robot guidance aid is proposed, based on the principles of GPS, but being the emitter placed on the Robot(s) and the detectors placed in the environment. The emitted signal is an infrared laser signal ASK-modulated with a Pseudo-Random Sequence. Auto-correlation is performed at a central node. Distances to the reference points are computed in terms of differential phase shift measurements. Using m-sequence-codes makes multiemission-working conditions possible. High precision is achieved as it is shown in a final table. *Copyright © 2002 IFAC.*

Key words: Autonomous Robot, infrared detector, pseudo-random sequences.

1. INTRODUCTION

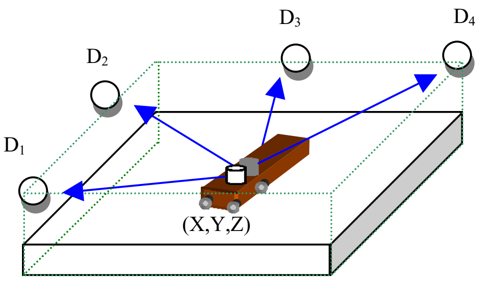
There has always been much effort devoted to know the position of an objet referred to a certain coordinate-system. With independence of the scope in which that object is or moves, the problem of positioning is an important point to be solved in many situations. Navigation systems based on having position co-ordinates referred to a constellation of satellites is the task of the well known GPS (Global Positioning System). It can provide a necessary localization for a civil or military plane, a boat in the sea, a single person carrying a portable GPS receiver set or, as it is getting more and more common in our society, a navigation aid for a conventional car, bus, etc. A similar positioning system restricted to a local environment is often known as LPS (Local Positioning System), by analogy to GPS. It follows essentially the same goal: knowing the position coordinates of an object restricted to a certain moving-area. A very common way to work in an infrared-based system is emitting a pulsed infrared signal. It is a continuous sin-wave signal modulated by a pulse train, at a frequency depending on power considerations and standard regulations. Another possible technique is to use a digital code emitted by the robot and make a correlation with a copy of that code stored at the reception unit. This technique is similar to those ones used in radar applications, GPS or some ultrasonic-based position and navigation systems (Ureña, 1998). A pseudo-random sequence can be sent from the emitter(s) to each detector(s) and be auto-correlated at the signal-processing unit.

When working with a pulsed sin-wave, the distance can be calculated by phase-increments computation between emission and detection. If a binary sequence is used and further correlation is performed, distance may be calculated computing the various time of flight (TOF). Nevertheless the concepts of TOF or wave phase difference are quite close, as they are tightly connected each other through the speed and frequency of signal transmission.

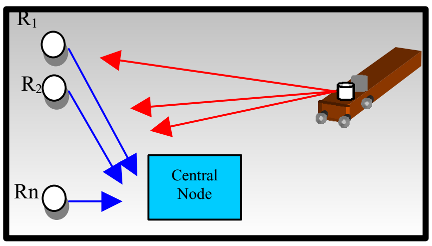
There is a big challenge when working under the presence of sun light as it can affect seriously the quality of the detected signal. This problem can be solved, for instance, by using interferential filters together with the photodetectors. If the emitted signal is a binary sequence (ie: a pseudo-random sequence), auto-correlation provides high noise immunity when working not only in presence of severe sun light conditions but under electrical noise disturbance as well.

2. GENERAL DESCRIPTION

In the case of this work the object to be positioned is an autonomous robot moving inside a building with known dimensions and shape (see figure 1). Its position is referred at any time to a cell of detectors placed at the ceiling of the building. This cell is formed by a minimum number of four detectors and is designed to cover a certain region of the moving space so that the robot does not get lost. The signal is an infrared signal emitted from the robot and it is collected at the passive detection points. It is then carried to a central node that performs control and calculation tasks, devoted to detector-synchronism and position results. The detection module, placed in the central node has a photodetector matricial structure, showing great modularity and facility to be modified if necessary. Another important point to deal with in this system is the question of the emitted signal. As it has been already mentioned, it is an infrared signal, emitted by an Ired placed on board the mobile robot.



(a)



(b)

Fig. 1. General LPS configuration. (a) 3D configuration; (b) Communication between elements: the receivers R_i and central node are communicated via optic fiber.

In previous works, a LPS was proposed in which the signal used was a sin-wave pulsed signal. Distance was obtained by means of phase measurements. Calculations were performed in a very similar way than in the case of operating with a single telemeter for obstacle-distance measurement (Ferrero, 1996). But an incremental method was proposed so that many problems dealing with emitter-detector synchronism were avoided. In this work an adapted GPS for local positioning is proposed. It works in similar way, as a pseudo-random sequence-modulated sine-carrier wave (ASK) is sent. In these way, good noise immunity is achieved and, at the same time, multi-emission mode of operation is successfully performed.

3. POSITION IN GPS

In the GPS, the position, discarding in principle any other effects that must be taken into account to obtain proper results, can be theoretically obtained from three satellites emitting a special code, one different from each other. Due to a synchronization drift error it becomes necessary to include a fourth measurement; this means considering an additional satellite emitting a code. In real performance, a much higher number of satellites is used to obtain the position. There are also a lot of error sources that must be taken into account and corrected to achieve an accurate result. The set of equations that must be solved to obtain the position are the following (Bryan and Van Dierendonck. 1996)

$$\begin{aligned} r_1 &= \sqrt{(x-x_1)^2+(y-y_1)^2+(z-z_1)^2}+c\Delta t \\ r_2 &= \sqrt{(x-x_2)^2+(y-y_2)^2+(z-z_2)^2}+c\Delta t \\ r_3 &= \sqrt{(x-x_3)^2+(y-y_3)^2+(z-z_3)^2}+c\Delta t \\ r_4 &= \sqrt{(x-x_4)^2+(y-y_4)^2+(z-z_4)^2}+c\Delta t \end{aligned} \qquad (1)$$

Where a fourth equation is included so that the undesirable term 'Δt' is eliminated. The 'r_i' are the distances to each of the satellites and x_i, y_i, z_i are the coordinates of them. These equations lead to a geometrical problem whose solution is the position to be obtained.

4. POSITION IN LPS

A general description of the system is presented before analyzing the question of the type of emitted signal. As it has been said, the system is a LPS based on infrared emission. A detection cell is placed in the moving area of the robot, consisting of 'D_1', 'D_2', 'D_3' and 'D_4'. The signal is different depending on whether it is emitted in pulsed shape or as a pseudo-random digital code, as it is the case of GPS. This question will be discussed in next points. The main difference from the GPS is that the roles of emitter(s) and detector(s) are inverted. In the LPS, as it can be seen in the figure 1. The emitter is placed on board the robot and a signal is collected at each detector and carried to a central processing node. Unlike the case of the GPS they are passive. The similarity yields in the way of solving the problem to know the position. (Lázaro, *et al.*, 2000). Another set of similar equations is held and a geometrical problem is solved to have the position calculated.

4.1 The differential LPS

This LPS works with differential phase-measurements (Martín, *et al.*, 2001). Every detector, or more correctly, every single detecting (passive) point will send its signal to the central processing unit with the information about its phase. The phases of the signals collected at the detecting points are considered in pairs to obtain differential distances from them. The set of equations, obtained from this, is:

$$\begin{aligned} d_1 &= \sqrt{(x-x_1)^2+(y-y_1)^2+(z-z_1)^2} \\ d_2 &= \sqrt{(x-x_2)^2+(y-y_2)^2+(z-z_2)^2} \\ d_3 &= \sqrt{(x-x_3)^2+(y-y_3)^2+(z-z_3)^2} \end{aligned} \qquad (2)$$

Where x_i, y_i and z_i are the coordinates of the detectors, considering a minimum of three, and the incremental distances defined, used to solve the geometrical problem are:

$$d_{21} = d_2 - d_1 = C_1$$
$$d_{31} = d_3 - d_1 = C_2 \qquad (3)$$

4.2 The GPS-based LPS

The LPS works in a very similar way to GPS in the sense of the signal emission and treatment, rather than in the aspects concerning physical emitter-detector configuration. Anyway, the conditions are quite different in this case, what makes the system much easier to be designed concerning certain aspects. In GPS there are many effects that must be corrected when working with a signal coming from the satellites.

Trajectory and signal-speed corrections when it is transmitted through ionosphere, or satellite-mechanics must be considered. These questions do not need to be taken into account when dealing with an indoor LPS. But on the other hand, as distances are so small compared to the large distances covered by the signal in GPS the system has to be very accurately designed and any clocks used must be compulsorily extremely exact. Otherwise it will give unacceptable imprecise values for distances.

Working in the way described a set of equations with the same form than (1) is used, but being the emitter and receiver permuted in this case.

Using a ASK modulated signal two tasks are performed. First, a two-step-correlation provides a peak value if a valid code is detected. At the same time, cross-correlation with the copies of all the possible emission-codes informs which emitter sent the signal, providing thus, identification. And secondly, carrier signal recovering is performed so that distance information is obtained by differential phase computations.

For the first of the tasks, good cross-correlation performance must be assured. This means working with high orthogonal-properties sequences. For the second task, a stable-phase system and accurate phase measurement methods must be developed.

5. PHYSICAL SYSTEM OF THE PROPOSED LPS DESCRIPTION

A block-scheme of the whole system is shown in figure 2. The signal used for the purpose described is an ASK modulated one, at a 100KHz carrier-frequency. A Pseudo Random digital code (PN code) is used for modulation. This code is a 31 bit-m-sequence, and the system has been designed so that eight different codes can be emitted simultaneously. Auto-correlation and cross-correlations are performed at the central node for valid code and emitter identification.

The distance is obtained from carrier phase shift computation between the signals detected. Low frequency conversion is made before phase measurement so that accuracy is improved.

The emitter is an infrared conventional emitter and the receiver is a conventional infrared led as well, with an optical band-pass filtering stage so that noise immunity is improved.

Distances are calculated in a central processing node, which is designed based on a FPGA, by means of differential phase shifts, as it has been mentioned. In this way, spheres of geometrical problem associated to classical GPS are substituted by hyperboloids in 3-D space.

Another important aspect to be noted, is that when working with more than one robot simultaneously, It means sending different codes for each emitter. This is performed by sending eight different 31-bit m-sequences. They can be sent whether in parallel, simultaneously, or temporally multiplexed.

6. RESULTS AND DISCUSSION

In table 1, results, in terms of distances and precisions achieved are shown. In figure 3 correlation results are shown. Reliable correlation response is obtained. Tests were made under artificial lamps optical contamination, and presence of sun light. Multi-emission has been tested as well. The system recognizes successfully one emitter out of a set of eight possible ones. Code identification is

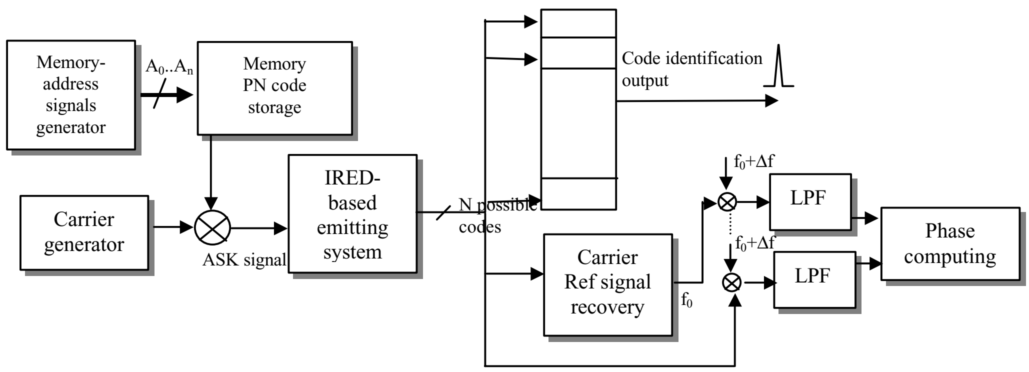


Fig. 1. System description. ASK signal generation and detection tasks: code identification and phase measurement.

carried out by a peak detection software algorithm. As it can be seen in the figure, sequences show good orthogonal response by cross-correlation operation. It can also be seen that effective code-identification is achieved when overlapping two sequences, also under severe noisy conditions.

Table 1. Spatial-precision results for LPS.

Detectors configuration	***Time measuring precision***	***Spatial positioning precision achieved***
4 in each detection cell	ns. Digital time counters	Milimetric
Phase measurement-LPS Distances range: 2-10m		

7. CONCLUSIONS

A LPS has been proposed in which the strategy developed for usual GPS is used to know the position of a mobile robot in a local environment. The precision obtained for position is quite acceptable. The possibility of coexistence of several mobiles emitting simultaneously has been explained. ASK modulated signal is used to emit 31 bit m-sequences codes, which provide good orthogonality properties, so that successful emitter identification is achieved.

8. ACKNOWLEDGEMENTS

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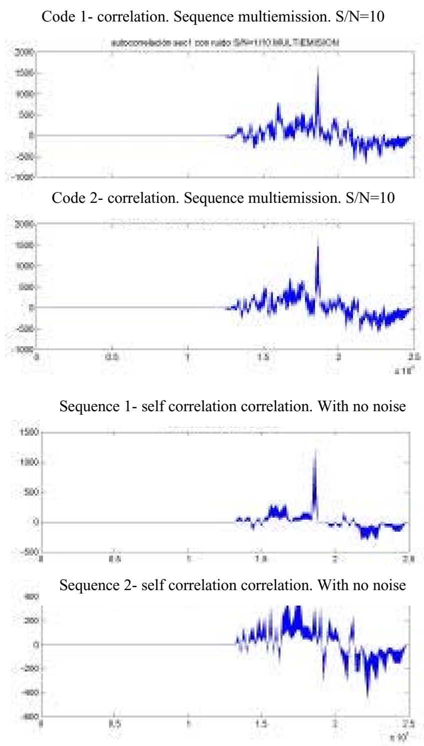

Fig. 2. Correlation results for code recognition. Distances: 2-10m.

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