CODIFICATION TECHNIQUES OF COMPLEMENTARY SEQUENCES FOR MULTIMODE SYNCHRONOUS SYSTEM FOR IR SENSORS

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Abstract

There are numerous applications that need to maintain periodic and continuous communication among emitters and receivers. One of the first problems to be solved is the identification of the origin of the information in the reception system, therefore the system should be multimode. In order to achieve this goal, it is necessary the use of codification techniques based on complementary sequences. The authors have developed an intelligent infrastructure, which allows obstacles to be detected in railways, based on IR emitter and receiver barriers, placed each one of them at each side of the railway. The codification techniques mentioned before are required by the emitters in the barrier for simultaneous transmission, and this work describes the technique used to code the emitters in the barrier in order to discriminate them in the reception system.

Keywords

Codification techniques, complementary sequences, multimode system, infrared barrier.

1. INTRODUCTION

In the current railway systems, it is becoming more and more necessary to have safety elements in order to avoid accidents, especially in high-speed lines.

One of the issues, that can cause serious accidents, is the existence of obstacles in railways, either fixed or mobiles. In railways, there are areas where an obstacle can likely appear, as overpasses with roads, or railway crossings. In the high-speed lines, zones close to overpasses are quite critical, since obstacles can fall. This can be caused by landslides, or simply by the fall of a vehicle or the transported material. The problem of landslides can also happen at entrances and exits of tunnels.

In these critical areas, systems are usually located to detect the presence of obstacles [1][2], so they can inform about them to the control system. In this way, the train circulation can be stalled, and possible accidents are avoided.

In order to solve this problem, we proposed the use of an infrared barrier, so that if a receiver does not receive the emitted signal, it can be concluded that there exists an obstacle between them. Nevertheless, to satisfy the reliability of the detection system, the use of codification techniques is necessary (i.e. complementary sequences). In this case, emitters and receivers are synchronized due to safety reason. We can take advantage of this situation to use new codification techniques derived from traditional ones for improving the performance of the system.

Regarding to this problem, the following aspects are analyzed in this work: the sensorial system and its geometry; the codification technique proposed and some conclusions.

2. SENSORIAL SYSTEM

Before analyzing the codification techniques, it is important to characterize the sensorial system where they are going to be applied, and also its requirements.

The initial requirements for the sensorial system are [2]: minimum size of the obstacle to be detected, 0.5x0.5x0.5m; system operation under extreme visibility conditions (no light or presence of fog); location of obstacles in the railway area under surveillance, on the rail lines or outside of the lines (vital and non-vital area).

In order to meet the mentioned requirements, optical emitters have been chosen (laser or diodes), whose emission beam can be considered as a very precise point (it will be necessary to use collimation techniques). These emitters are distributed in such a way that an infrared barrier is formed. Figure 1 shows a general view of the structure of the used sensorial system.

2.1. Geometrical distribution of the sensor array

The first approach for the infrared barrier, and maybe the simplest one, consists basically of placing emitters and receivers aligned in the axial axis. This allows to detect the presence of obstacles between both elements, but not their localization in the railway.

In order to detect obstacles in the railway, discriminating at least the vital area (into the rail lines) from the non-vital areas (outside the lines), another structure has been designed [3], different to the one mentioned before. In this case, every emitter provides three beams (multi-emission): one impacts on the receiver placed at the axial axis, and the other ones to both sides, as is shown in figure 2.

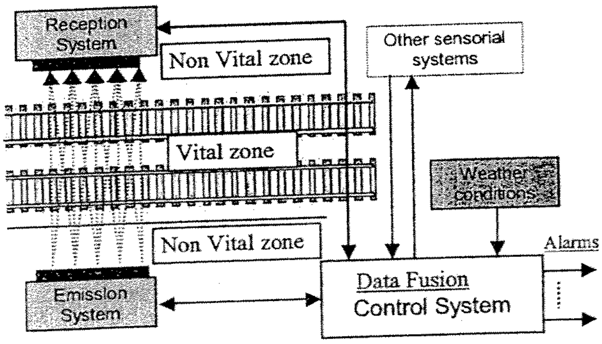

Fig. 1. Infrared barrier, placed in a rail sector.

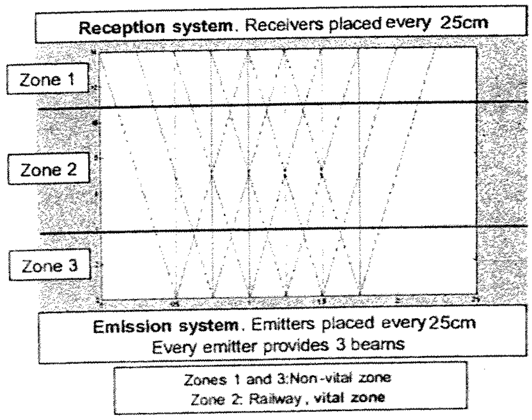

Fig. 2. Infrared barrier with multi-emission.

The distance among emitting sensors is 25 cm, in order to detect 0.5x0.5x0.5m objects successfully (size determined by rail regulations). The configured distance among emitters and receivers is 14 meters. Basically, the method of obstacle detection, and its location inside the railway, is based on the lack of reception in detectors.

3. CODIFICATION TECHNIQUE

In this system, the emission is carried out in a continuous way by the emitters; and when the receivers do not detect this emission, the presence of an obstacle can be concluded. According to the geometry of the system in figure 2, the radiation coming from three emitters is received by every receiver. In order to be able to discriminate the source of these emissions, it is necessary to carry out the codification of every emission. If interferences among the three codes are not desirable, they should be orthogonal. These codes, apart from discriminating the source of the emission, will provide high noise immunity to the system, as the obtained results show.

3.1. Complementary sequence set

A complementary sequence set [4] is a set consisting of p sequences with two kinds of elements $\{+1, -1\}$. They are characterized because the adition of their aperiodic autocorrelation functions is null for any shift different from zero. In this case, if $\{a_n\}$ $1 \le n \le p$ is a set of p complementary sequences with a length L, and $C_{a_n a_n}$ is the aperiodic autocorrelation function, then:

$$\sum_{n=1}^{p} C_{a_n a_n}(i) = \begin{cases} p \cdot L & si \;\; i = 0 \\ 0 & \forall \;\; i \neq 0 \end{cases} \quad (1)$$

Keeping in mind that at least three orthogonal sets of sequences are required (one per every received signal in the receiver), the minimum dimension of the set should be 3. Nevertheless, since this is not feasible, a set of 4 sequences is used. In this way the whole analysis will be carried out by supposing 4 sequences per set. So, if $p=4$, and every sequence in the set is denoted {a,b,c,d} then:

$$\begin{aligned} C_{aa}(n) + C_{bb}(n) + C_{cc}(n) + C_{dd}(n) &= 4L, \text{if n} = 0 \\ C_{aa}(n) + C_{bb}(n) + C_{cc}(n) + C_{dd}(n) &= 0, \text{otherwise} \end{aligned} \quad (2)$$

The code used in the emitter, not only discriminates the source of the emission, but also provides a high noise immunity to the system, as the obtained results show. The generation of the set is carried out from a seed W. The seeds should meet the relation shown in table 1, in order to obtain the orthogonal sets.

Set of length L	Seed
$\{a_1,b_1,c_1,d_1\}$	W
$\{a_2,b_2,c_2,d_2\}$	W+L/4
$\{a_3,b_3,c_3,d_3\}$	W+2*L/4
$\{a_4,b_4,c_4,d_4\}$	W+3*L/4

Tab. 1. Seeds for obtaining the orthogonal sets.

Figure 5 shows the mentioned situation, with four emitters and one receiver. As has been explained, the emitter and receiver units are synchronized, mainly because of safety reasons in the described application.

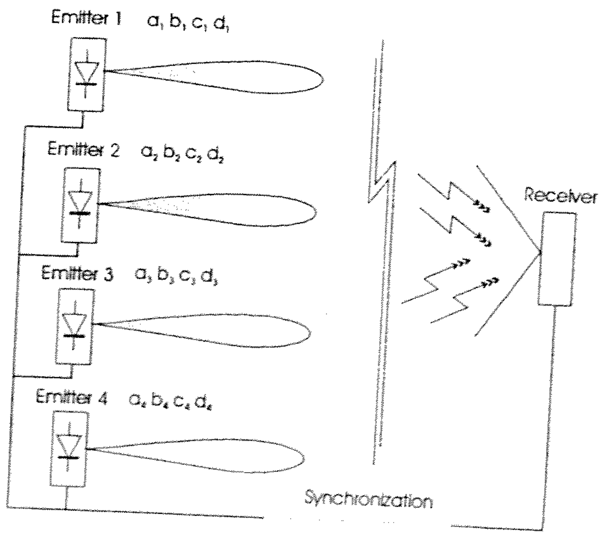

Fig. 5. Detail of the four emitters and the receiver.

Every emitter i transmits the set a_i, b_i, c_i, d_i continuously. Its continuous emission allows a signal to be obtained in the detector with period L with a maximum peak of $4 \cdot L$, showing that there is not an obstacle between the emitter and the receiver, according to (3). The index i means any emission in the system, $i=\{1, 2, 3, 4\}$.

$$Detector\_output = 4L\sum_{k=-\infty}^{k=\infty}\delta(n-k\cdot L) \quad (3)$$

It is remarkable that four correlators are implemented for every emission, one per each sequence in the set. Therefore it would be necessary to use 16 correlators in the whole system. Figure 6 shows the results when using 64-bit sequences, with a SNR of -12 dB. In figure 6 there is only one emission, and the detection has been carried out in the L instant.

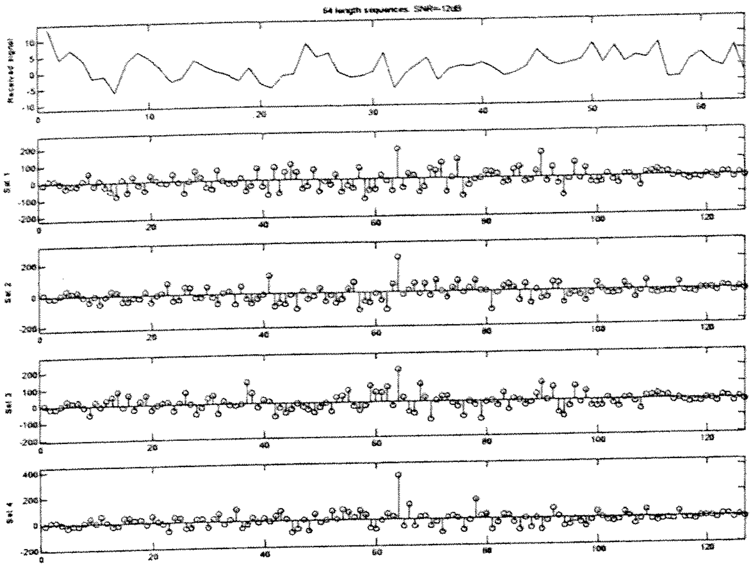

Fig. 6. Detector output for every emission. L=64, SNR=-12dB

3.2. New codification of complementary sequence sets

Taking to account that both, emitters and receivers, are synchronized, it is proposed to transmit only one sequence in the set, recovering the rest of the set in the receiver. Assuming that only $\{a_i\}$ are transmitted, the received signal, $r[k]=r^k$, is shown in (4) (introducing a noise n^k).

$$r^k = a_1^k + a_2^k + a_3^k + a_4^k + n^k \quad (4)$$

The process proposed for the reception consists of computing the correlation between the received signal and the components $\{a_i\}$ (only 4 correlations are necessary), and after adding the effects from the rest of the components $\{b_i, c_i, d_i\}$. If the four emitters work simultaneously, the correction component F_i is constant for every emitter, as shown in (5), assuming * as the correlation operator.

$$F_i^k = \left(b_1^k + b_2^k + b_3^k + b_4^k\right) * b_i^k + \left(c_1^k + c_2^k + c_3^k + c_4^k\right) * c_i^k + \left(d_1^k + d_2^k + d_3^k + d_4^k\right) * d_i^k \quad (5)$$

The length of F_i is the correlation's one, $2\cdot L-1$. Be S_i the correlation output for an emission i, depicted in (6).

$$S_i^k = r^k * a_i^k + F_i^k \quad (6)$$

Figure 7 shows the same situation as figure 6, but with the correction describes. As can be seen this technique increases the noise immunity.

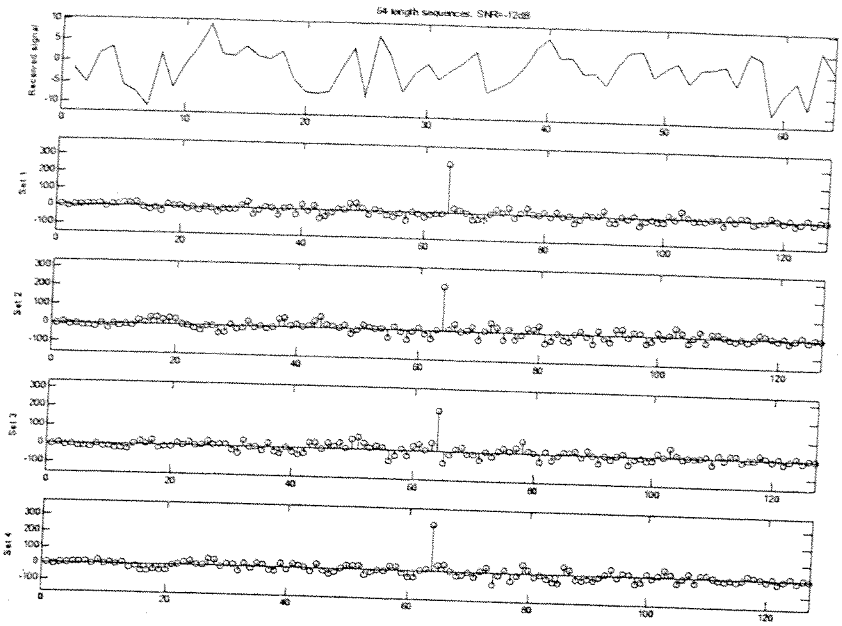

Fig. 8. Detector output for every emission using the proposed correction. L=64, SNR=-12dB.

4. CONCLUSIONS

A novel codification technique has been developed, in order to improve the performance of infrared sensorial system. This technique provides the following advantages, compare to others: 1) the emission interval is reduced four times because only one complementary sequence is emitted; 2) only one complementary sequence is degraded by the environment, so the noise immunity increases considerably. If the emission interval is kept, the length of the sequence can be increased four times, improving four times the signal to noise ratio (SNR). This reduction of noise is very important, taking account the barrier works under conditions of high degradation of the channel (it is an outdoor system). Furthermore, the proposed implementation reduces the computational load of the codification process, making easier and more feasible future implementations in real time solutions typically based on FPGAs.

5. ACKNOWLEDGEMENTS

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