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Low cost obstacle detection for smart railway infrastructures

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***Abstract*— In this work an intelligent infrastructure is shown, which allows to detect obstacles in railways, based on optical emitters. The sensorial system is based on a barrier of emitters and another of receivers, placed each one of them at one side of the railway. Apart from the disposition of the sensorial system, is also presented a codification method of the emission in order to detect the reception or the non-reception of transmissions between an emitter and a receiver. The presented method is based on a signal codification using complementary sequence pairs, suitably adapted for their simultaneous emission through the transmission channel. A high reliability under adverse conditions is achieved with the developed system, being possible to detect the presence of obstacles, and to inform about their situation.**

I. Introduction

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

In this work, one of the causes, that can provoke serious accidents, is analysed: the existence in railways of obstacles, 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 it to the control system. In this way, the train circulation can be stalled, and possible accidents are avoided.

Regarding to this problem, the following aspects are analysed in this work: the sensorial system to use, and its geometric disposition; the emission codification of the selected sensor to provide the system with a high immunity to noise; the designed prototype and the obtained results

II. Sensorial System and Geometrical Distribution

Different references in literature deal about what type of sensorial system to use for the detection of obstacles in railways [1][2] [3]. From the point of view of the weather conditions, a system radar [4] would be the most immune, but it presents a drawback with the detection of small obstacles on the line.

Cameras could also be used to control the areas of risk [3] [5], but the weather conditions (fog, hard rain, etc) and the economic aspects can discard their usage.

On the other hand, for the application described in the previous section, the trend is the use of optical sensors, either infrared or laser [1]. No matter the sensor type chosen, all the details, that will be discussed next, can be applied to both types. The selection between one of them will depend strongly on economic aspects. In this case, the shown results will be obtained using infrared emitters.

Infrared barriers usually consist of emitter-receiver pairs, located each one at a different side of the line, so it is only possible to detect the presence of an obstacle, but not its position.

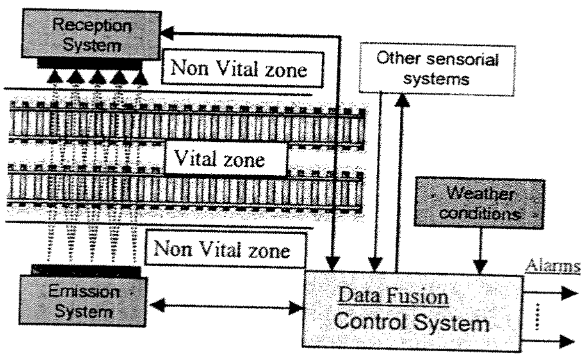

Fig. 1. Infrared barrier, placed in a rail sector.

The topology of the proposed system is similar to one in figure 1, using three individual emitters in every emitting sensor. 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), a special structure has been designed. 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 it is shown in figure 2.

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.

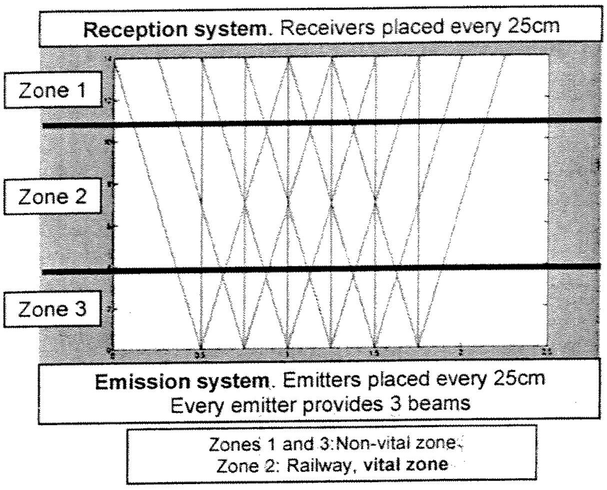

Fig. 2. Infrared barrier with multi-emission.

Obviously, if more emitting transducers were used for every emitting sensor, the position of obstacles could be discriminated with more precision. This aspect, not only makes more expensive the sensorial system, but also does not provide any additional interest to this application, where the main goal is only to determine if there is any on the railways, not considering its accurate position.

III. Emission codification

As it has already been commented, the main problem to be solved is to detect with reliability the existence of obstacles. In this system, emission is carried out in a continuous way by emitters, and when this emission is not detected by receivers, the presence of an obstacle can be concluded.

According to the geometry of the system in figure 1, the radiation coming from three emitters is received by each receiver. In order to be able to discriminate the source of these emissions, it is necessary to carry out the codification of every emission [6]. This code, apart from discriminating the source of the emission, will provide a high noise immunity to the system, as the obtained results show.

Golay complementary sequence pairs (sequences *a* and *b*) are used for this application [7] [8], due to their special characteristics of noise immunity. If sequences are N-bit long, and they are composed by values {1,-1}, it is met that:

$$C_{aa}(n) + C_{bb}(n) = 2N, \text{if n} = 0$$
$$C_{aa}(n) + C_{bb}(n) = 0, \text{otherwise} \qquad (1)$$

In (1), C_{aa} and C_{bb} are auto-correlation functions for each one of the complementary sequences. Figure 3 shows the result of the correlation sum if the sequences are shifted in time.

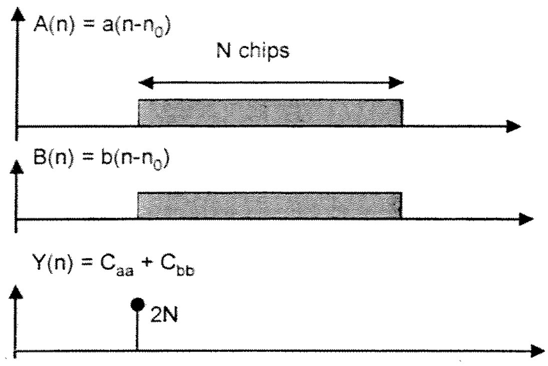

Fig. 3. Schematisation of the ideal result of the autocorrelation sum of a complementary pair.

This is fulfilled even if the sequences are superimposed. In other words, if the following signals are generated:

$$A(n) = a(n-n_1) + a(n-n_2)$$
$$B(n) = b(n-n_1) + b(n-n_2) \qquad (2)$$

Thus:

$$Y(n) = A(n) * a(n) + B(n) * b(n) = 2N\delta(n-n_1) + 2N\delta(n-n_2) \qquad (3)$$

Where the symbol * represents the cross-correlation between both signals. In the aforementioned case, the separation between superimposed sequences have to fulfil $(n_2 - n_1) > 0$, in other words, there must be at least one separation chip in the sequence superimposition. Figure 4 exemplifies this case.

Since it is necessary to carry out the detection of objects, the emitting element should emit continuously. With continuous emission, these sequences provide special characteristic when they are emitted overlapped and delayed N/2, being N the sequence length. Signals A and B in equation (4) explain this situation.

$$A(n) = \sum_{k=-\infty}^{k=\infty} a(n - k \cdot N/2)$$
$$B(n) = \sum_{k=-\infty}^{k=\infty} b(n - k \cdot N/2) \qquad (4)$$

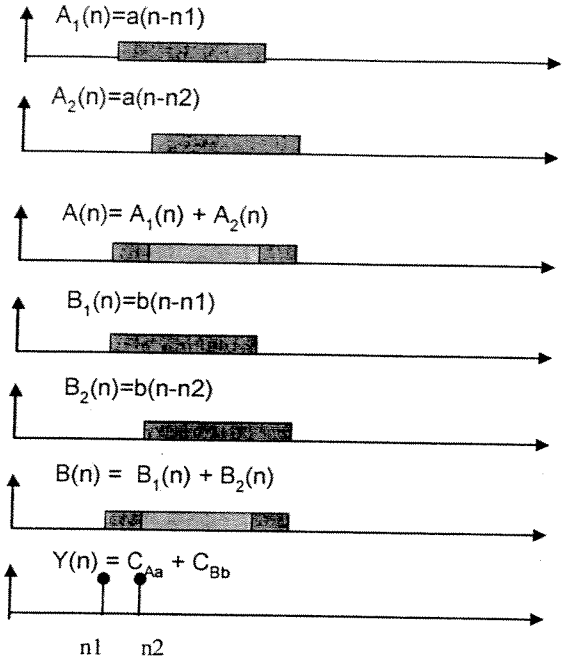

Fig. 4. Correlator output in the case of complementary sequence superimposition.

In this case, an Efficient Golay Correlator [9] provides as output the expression shown in (5).

$$C_{Aa} + C_{Bb} = 2N \sum_{k=-\infty}^{k=\infty} \delta(n - k \cdot N/2) \quad (5)$$

Being δ the Kronecker delta function; and, C_{Aa} and C_{Bb} the auto-correlation functions determined by subindex.

The particularity of this situation resides in the special characteristics of the Golay sequence pairs with length N, (being N a power of two). They present the following properties:

- A(n) y B(n) are periodic signals with N/2 period.
- During one period, the half of values in A(n) and B(n) are null, and the rest present values of -2 or 2. If sequences have been generated with the EGG algorithm (Efficient Golay Generator) [9] [10] [11], then the null values are:
    - $1 \leq n \leq N/4$ for EGG seeds from 0 to N/2-1.
    - $N/4 \leq n \leq N/2-1$ for EGG seeds from N/2-1 to N.

In figure 5 the values of A(n) and B(n) generated in this way can be observed, for the case of Golay sequence pairs with N=64 bits and using a 0 seed.

Anyway, this property can be used to multiplex both signals in the time domain: it is necessary to delay N/4 bits one of the sequences, just before emitting it and to undo the delay just when receiving it. This delay is shown in figure 5. This situation can be observed in figure 6 for N=64 bits (in this case, a signal-to-noise ratio of +6 dB is supposed). Under these conditions, the resulting delta train from the correlator can be observed (a delta every N/2: every 32 samples in this example). Obviously, the great advantage of this method resides in the possibility of emitting simultaneously through the same channel both sequences of a Golay pair, not being required multi-phase modulations or similar techniques.

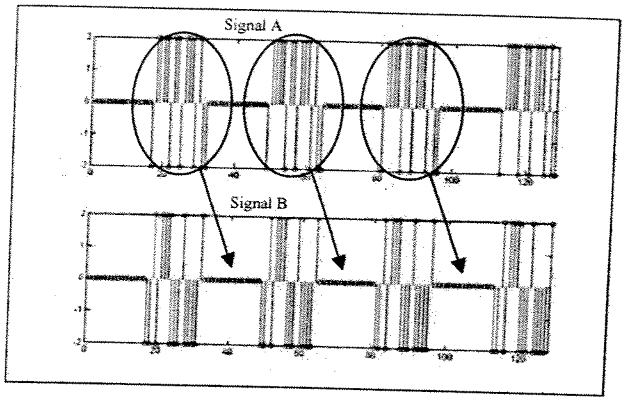

Fig. 5. Emitted signals A(n) and B(n) with a separation between sequences of N/2.

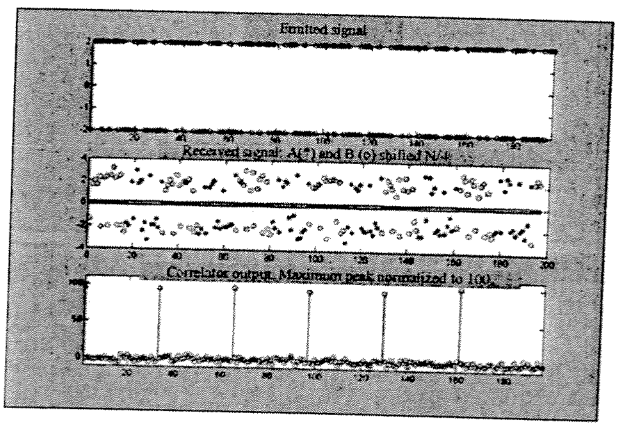

Fig. 6. Example of multiplexing the sequences of a Golay pair in time domain (N=64 bits). S/N=+6dB.

IV. Application to the Infrared Emission

Taking into account that the maximum efficiency of the infrared emitters is achieved for pulsed emissions, in order to carry out the emission of both symbols {-1,1} a code is assigned to every emitter. This allows to keep the mentioned characteristics, and also to discriminate them. In figure 7, the code assignment is shown, considering that the symbol duration is T seconds.

In the reception block, firstly it is necessary to detect the symbols {-1,1}. Afterwards, using an EGC Efficient Golay

Correlator, a delta is obtained every N/2 chips, whenever there is not any obstacle between emitter and receiver.

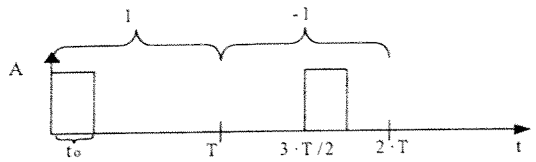

Fig. 7. Pulsed excitation for a IRED and code assignation.

In [12] the process of sequence detection is described in detail.

V. HARDWARE IMPLEMENTATION OF THE SYSTEM

In figure 8, the block diagram of the described system is shown, for three emitters and a receiver, able to discriminate among three emissions. The system in figure 8 can be considered as a basic unit, repeating it in order to build the infrared barrier explained in section 2.

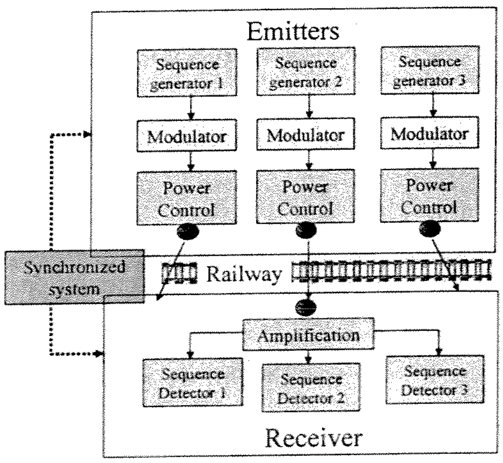

Fig. 8. Block diagram of the basic unit.

To emulate the real system, has been implemented a prototype with three emitters and a receiver. This prototype has two main blocks: the control unit and the emitter-receiver system.

- Control unit. This block is based on a FPGA system [10]. On one hand, it generates the pulsed sequence used (and the modulation) to excite every emitter, as it has been described previously (sections 3 and 4). On the other hand, it carries out the detection with the samples acquired by the reception system. Also, it is in charge of synchronizing the emitter and receiver systems. It has been necessary to implement the EGC into the FPGA, with the suitable modifications to obtain the signal to emit, as it was described in section 3. Since it is possible to receive up to 3 emissions in the receiver, orthogonal sequences have been used, so that interferences are avoided among them. With the Golay sequences, there is only one orthogonal pair [7] [11], so the third one is pseudo-orthogonal, verifying that interferences are minimum. The developed prototype generates 1024-bits long sequences, with chip duration of 10 microseconds. This implies that a delta is generated (a pick in the detection system) every 5.12 ms when there is not any obstacle. This results enough for the application of the system.
- Emitter-receiver system. This stage processes the coded signal, it carries out the optical link among the two ending points of the infrared barrier, and it adapts the received signal to carry out the data correlation under the best possible conditions. The infrared emitter and the receiver are separated, in such a way that the beam of the optical link is propagated from one side to the other one of the railways.

VI. OBTAINED RESULTS

Some simulated and real results are shown next, taking into account the code assignment carried out in the infrared emission, as it has been described in section 4. Nevertheless, in [13] the efficiency of the use of these sequences is demonstrated in situations with very low signal-to-noise ratio.

In figure 9 it is observed a similar situation to the one in figure 6, but with a signal-to-noise ratio of -6dB, also showing the immunity of the system before this degradation. Again an optimal output is obtained in the correlator every N/2 chips. Figure 10 shows the results obtained when signal loss is produced, in addition to a low signal-to-noise ratio. Figure 11 shows the emission of the sequence {-1, -1, 1, -1}, carried out by the implemented system. Figure 12 shows the output of the correlator implemented in the FPGA with no obstacles. It can be observed how a peak is obtained in the detector every N/2 (equal to 5.12 ms in this case).

VII. CONCLUSIONS

A proposal of a system for obstacle detection in railways has been carried out. Its geometry allows, not only to detect the presence of obstacles, but also to locate it inside the analysis region, discriminating between a vital area and a non-vital one.

Although it could be considered that similar results could be obtained with periodic sequences (pseudo-random, Gold, etc.), the method proposed in this work provides two significant advantages:

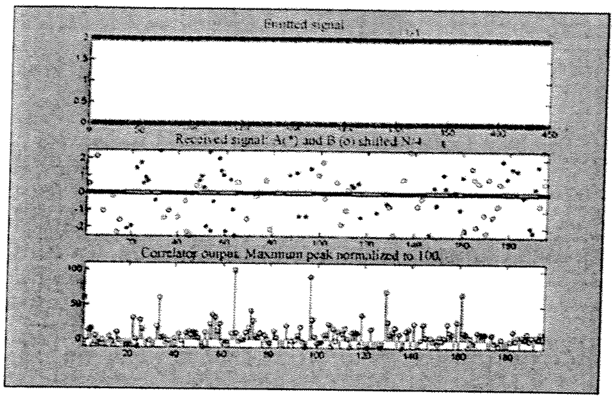

Fig. 9. Emission of sequences with length of 64, and S/N=-6dB

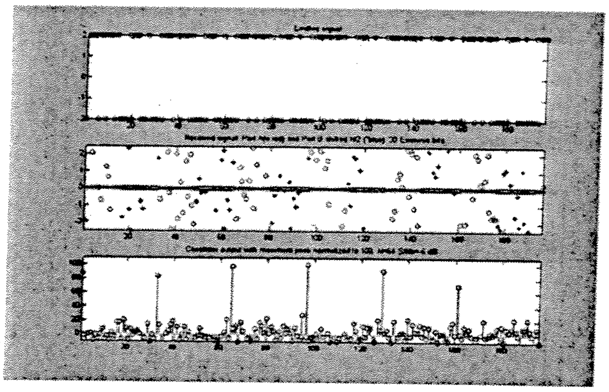

Fig. 10. Random signal cancellation with a signal-to-noise ratio of -6 dB.

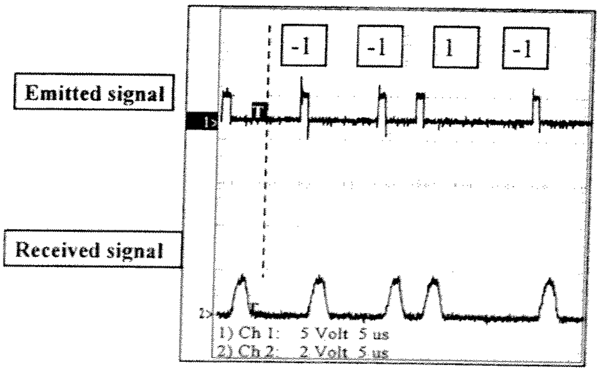

Fig. 11. Real emission of the sequence {-1, -1, 1, -1}

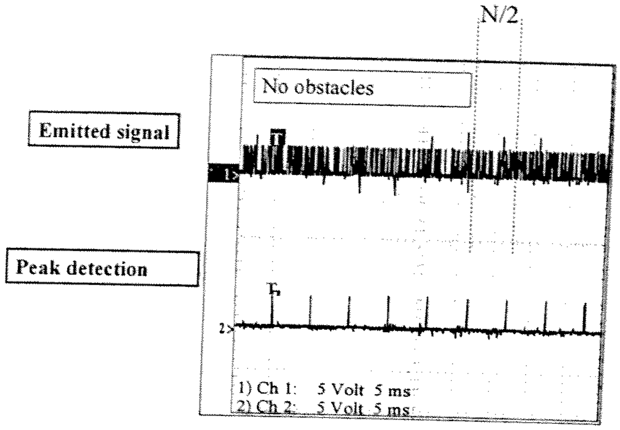

Fig. 12. Real detection every N/2 (5.12 ms) without obstacles.

- Although N-bit sequences are used, the output deltas are obtained every N/2.
- The correlation can be implemented using efficient techniques (EGC [9]), so that the operation number increases according to log2N, what allows to use sequences with enough length without using a so expensive hardware (for example FPGA's [10]).

All the process described in sections 3 and 4 has been implemented in a prototype with three emitters and a receiver, constituting the basic element of an infrared barrier. It has been necessary to modify the EGC [9] in order to work with this particular case of Golay sequences. The real tests carried out with it are successful, as it is shown in figures 8 and 9.

The feasibility of the used code method confirms the simulated and real results obtained, even under conditions of high degradation of the channel (typical in rail systems). The location of the obstacle will be obtained using the infrared barrier, if the geometry in figures 1 and 2 is considered.

VIII. Acknowledgment

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