IR SENSOR ARRAY CONFIGURATION AND SIGNAL PROCESSING FOR DETECTING OBSTACLES IN RAILWAYS

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ABSTRACT

This work describes a sensor array based on optical emitters, which allows to detect obstacles in railways. The sensorial system consists of a barrier of emitters and another of receivers, placed at opposite sides of the railway. Apart from the disposition of the sensorial system, it is necessary a codification method for the emission in order to detect the reception or the non-reception of transmissions between an emitter and a receiver. The 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.

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.

In this work, one of the issues, that can cause serious accidents, is analyzed: 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], so they can inform about them 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 proposed sensorial system and its geometry; the emission codification; the designed prototype and the obtained results.

2. SENSORIAL SYSTEM

The proposed goal for this sensor array is to detect the presence of obstacles in railways with high reliability. This can be achieved using different sensorial elements [1][2][3]: radar, laser, artificial vision, ultrasounds, etc.

The selection of the transducer depends on several aspects, as: economics, immunity to the meteorological conditions, size of the obstacles to be detected, etc. The initial requirements for the sensorial system are: 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.

3. GEOMETRICAL DISTRIBUTION OF THE SENSOR ARRAY

The first approach for the infrared barrier, and maybe the simplest one [4], 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, different to the 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 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

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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.

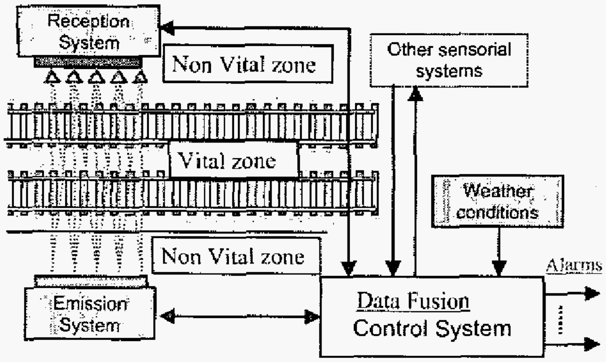

Figure 1. Infrared barrier, placed in a rail sector.

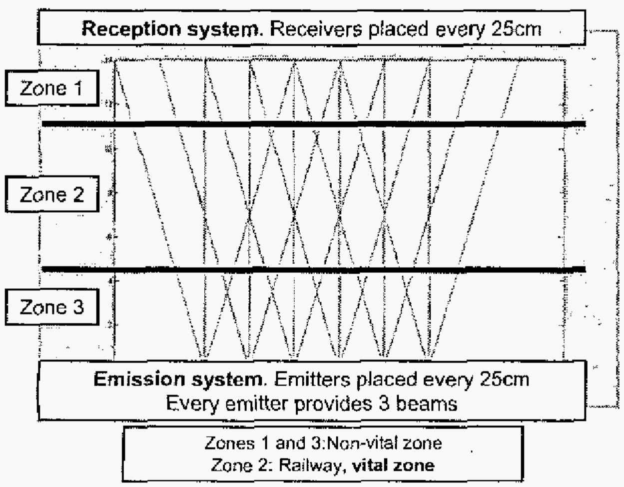

Figure 2. Infrared barrier with multi-emission.

Figure 3 shows the detection of one obstacle in a non-vital area (green area). The remarked area shows the possible obstacle location, according to its dimensions and the non-received beams.

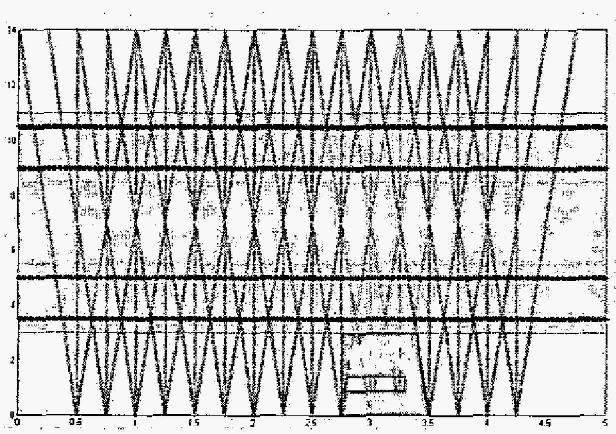

Figure 3. Obstacle detection in a non-vital area.

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 anything on the railways, not considering its accurate position.

4. SIGNAL PROCESSING

As it has been already 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 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 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[5]. 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. Golay complementary sequence pairs [6] (sequences *a* and *b*) are used for this application, due to their special characteristics of noise immunity and orthogonality between pairs. If sequences are N-bit long, and they are composed by values {1,-1}, it is met that:

$$\begin{aligned} C_{aa}(n)+C_{bb}(n) &= 2N, \text{if n} = 0 \\ C_{aa}(n)+C_{bb}(n) &= 0, \text{otherwise} \end{aligned} \tag{1}$$

In (1), C_{aa} and C_{bb} are auto-correlation functions for each one of the complementary sequences. 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 (2) explain this situation.

$$\begin{aligned} A(n) &= \sum_{k=-\infty}^{k=\infty} a(n-k\cdot N/2) \\ B(n) &= \sum_{k=-\infty}^{k=\infty} b(n-k\cdot N/2) \end{aligned} \tag{2}$$

Taking advantage of this feature, a new usage is proposed for the Golay complementary sequences with a length of N bits (being N a power of 2) [4]. During one period, the half of values in *A(n)* and *B(n)* are null, and this property is used to transmit both signals as has been described in [4]. Their continuous emission allows to obtain a signal with period N/2 in the detector, showing that there is not an obstacle between emitter and receiver, according to (3). All this is possible if an Efficient Golay Correlator [9] has been implemented in the detector.

$$Detector\_output = 2N\sum_{k=-\infty}^{k=\infty}\delta(n-k\cdot N/2) \quad (3)$$

If there exists an obstacle temporarily, the detector output will not be periodical; and if the obstacle is permanent, it will be null. Figure 4 shows an example of the emitted and received signal, as well as the output provided by the detector due to the obstacle absence. Because the symbols of sequences are {1,-1}, it is necessary to carry out a previous ppm modulation to be applied to an optical emitter. In this case, just as it is described in [4], the code assignment shown in figure 5 is carried out, being T the symbol period. In [8] the process of the sequence detection is described in detail.

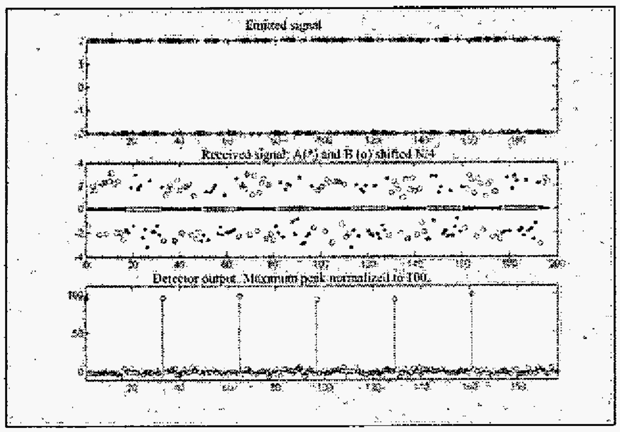

Figure 4. Emitted and received signals, and detector output without obstacles, for a signal-to-noise ratio of +6dB.

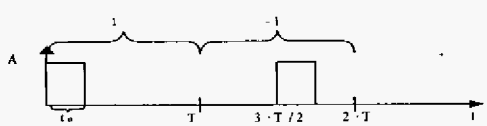

Figure 5. Pulsed excitation for an IRED and code assignation.

5. SYSTEM IMPLEMENTATION

In figure 6, the block diagram of the described system is shown, for three emitters and one receiver, able to discriminate among three emissions. The system in figure 6 can be considered as a basic unit, repeating it in order to build the infrared barrier explained in section 3.

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

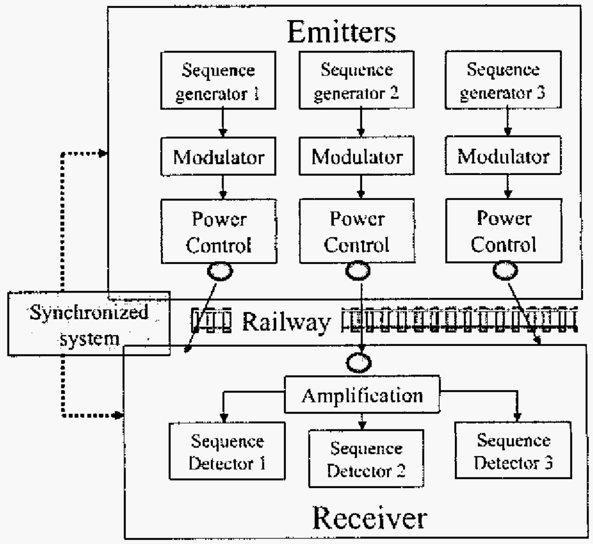

Figure 6. Block diagram of the basic unit.

- Control unit. This block is based on a Spartan II FPGA based development platform. On one hand, it generates the pulsed sequence used (and the modulation) to excite each emitter, as has been described previously. 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 Efficient Golay Generator into the FPGA [9], with the suitable modifications to obtain the signal to emit, as 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 Golay sequences, there is only one orthogonal pair [6], so the third one is pseudo-orthogonal, verifying that interferences are minimum. The developed prototype generates 1024-bit long sequences, with a chip duration of 10 microseconds. This implies that a delta is generated (a peak in the detection system) every 5.12 ms when there is not any obstacle. This results enough for the application of the system. Figure 7 shows the FPGA-based development platform used.
- Emitter-receiver system. This stage processes the coded signal; it carries out the optical link between 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 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. Figure 8 shows the designed emitter-receiver system. The infrared emitter is shown in figure 9.

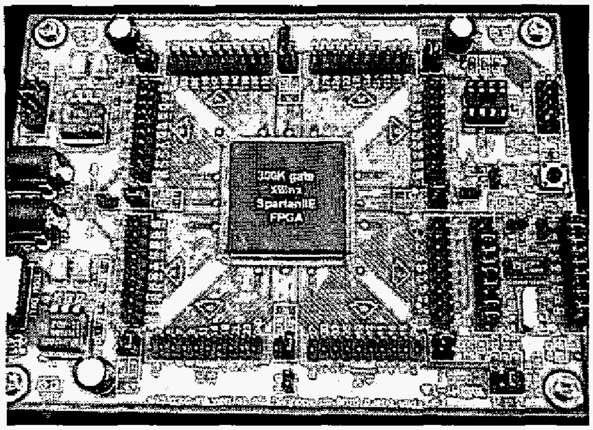

Figure 7. FPGA-based development platform.

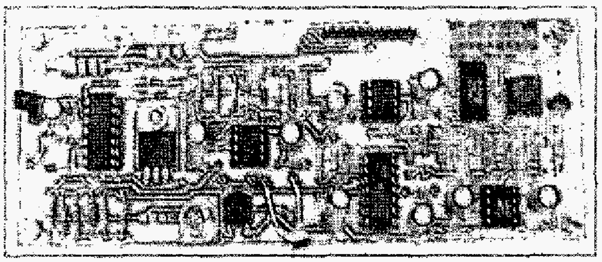

Figure 8. Designed reception system.

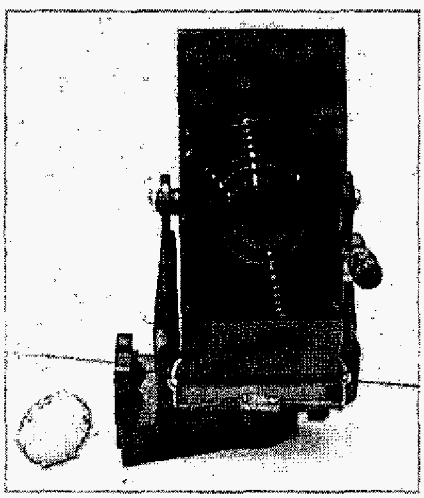

Figure 9. Used infrared emitter.

6. RESULTS AND CONCLUSIONS

In figure 10 a similar situation to the one in figure 4 is observed, but with a signal-to-noise ratio of -6dB, and also showing the system immunity before this degradation.

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 Efficient Golay 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).

The design of a sensor array for obstacle detection in railways has been achieved. Its geometry allows, not only to detect the presence of obstacles, but also to locate them inside the analysis region, discriminating between a vital area and a non-vital one.

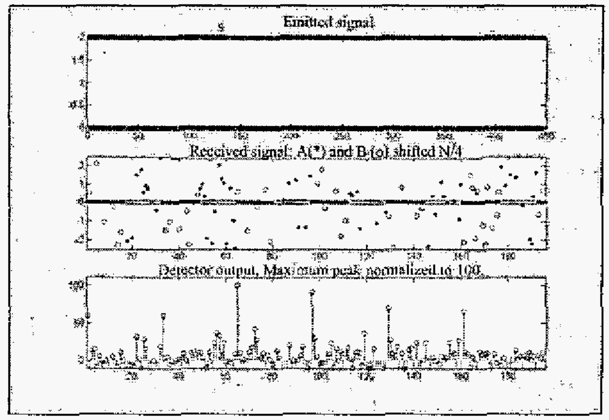

Figure 10. Emission of 64-bit sequences, for S/N=-6dB.

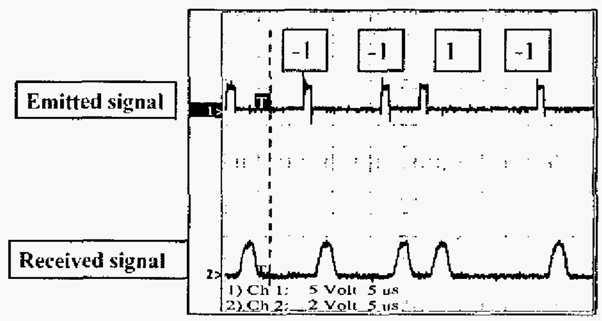

Figure 11. Real emission of the sequence {-1, -1, 1, -1}

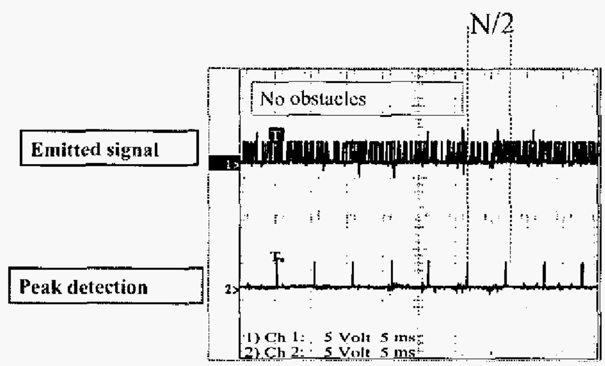

Figure 12- Real detection every N/2 (5.12 ms) without obstacles.

The emission and detection processes have been implemented in a prototype with three emitters and a receiver, constituting the basic element of an infrared barrier. The real tests carried out are successful.

7. ACKNOWLEDGEMENTS

The work described in this paper was made possible by funding from the Ministry of Science and Technology: Projects SILPAR (reference DPI2003-5067) and PARMEI (reference DIP2003-08715-C02-01).

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