IR SENSOR ARRAY FOR DETECTING OBSTACLES IN RAILWAYS

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ABSTRACT

This work describes an infrared sensor array, which allows obstacles to be detected on railways. The sensorial system consists of an emitting barrier and a receiving one, placed at both opposite sides of the railway. The method of obstacle detection is based on the lack of reception in detectors. 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. In this case complementary sequence pairs are used, 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, according to the geometrical distribution of the sensor array.

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 analysed: the existence of obstacles in railways, either fixed or mobiles. In the high-speed lines, zones close to overpasses are quite critical, since obstacles can fall down. 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.

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: radar [3], laser [1], artificial vision [4], 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 nor 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, 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 on the railway.

In order to detect obstacles on 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 on the axial axis, and the other ones to both sides, as 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) [5]. The configured distance among emitters and receivers is 14 meters. If the system is used at entrances and exits of a tunnel, or near bridges, it is mandatory to cover at least a distance of 9 meters along the track [5]. It will be necessary at least 36 emitters and their corresponding receivers, in one side of the bridge or tunnel. Basically, the method of obstacle detection, and its location inside the railway, is based on the lack of reception in detectors.

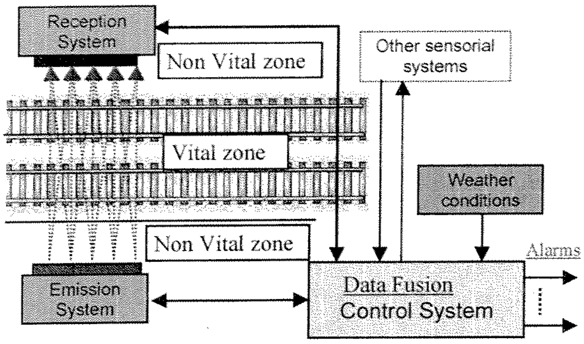

Figure 1. Infrared barrier, placed in a rail sector.

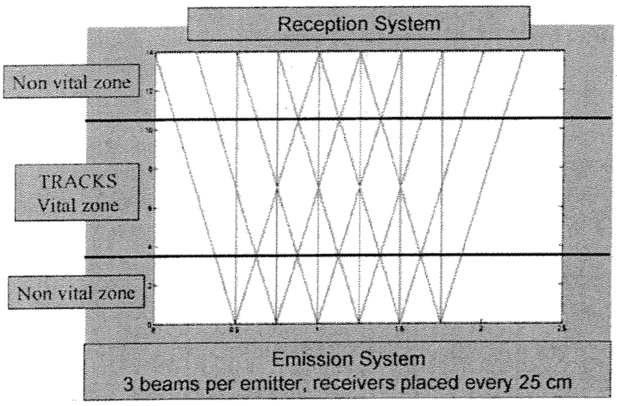

Figure 2. Infrared barrier with multi-emission.

Figure 3 shows the detection of one obstacle in the vital area (yellow area). The remarked area shows the possible obstacle location, according to its dimensions and the non-received beams. Figure 4 shows the detection of one obstacle, but in this case in the non-vital area. In both cases, if the obstacle is bigger than 0.5 m, at least 6 beams are not received, being the system highly redundant. This is an advantage to discriminate false alarms due to small animals, rain, or simply sensor failures. In figures 3 and 4, the horizontal axis represents the distance among sensors, and the vertical one the distance among emitters and receivers.

4. SIGNAL PROCESSING

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 3, 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.

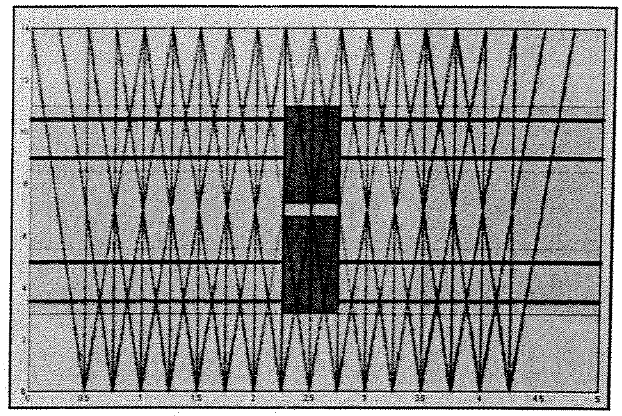

Figure 3. Obstacle detection in the vital-area.

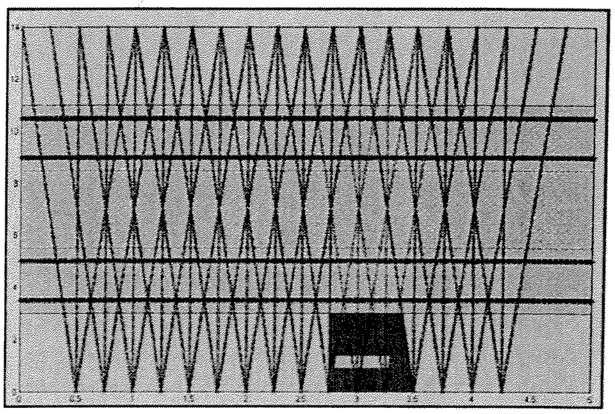

Figure 4. Obstacle detection in a non vital-area.

Golay complementary sequence pairs (sequences a and b) are used for this application [6], 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:

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

In (1), C_{aa} and C_{bb} are auto-correlation functions for every complementary sequence. 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) [7]. Their continuous emission allows a signal to be obtained in the detector with period $N/2$, showing that there is not an obstacle between the emitter and the receiver, according to (2).

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

If there exists an obstacle temporarily, the detector output will not be periodical; and if the obstacle is permanent, it will be null. Figure 5 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 [7]. In [8] the process of the sequence detection is described in detail.

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, based on a FPGA, has been implemented with three emitters and a receiver. This prototype has two main blocks: the control unit and the emitter-receiver system. The control unit based on a FPGA system [7]. On one hand, it generates the pulsed sequence used (and the modulation) to excite every emitter, as 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 Efficient Golay Correlator into the FPGA, with the suitable modifications to obtain the signal to be emitted, as was described in section 3. The developed prototype generates 1024-bits long sequences, with a chip duration of 10 µs. 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.

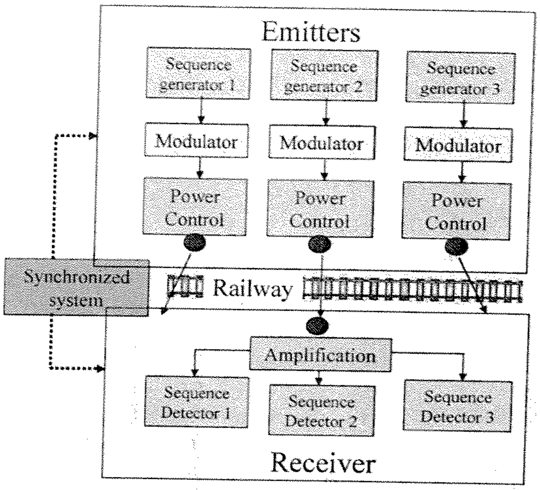

Figure 6. Block diagram of the basic unit.

6. RESULTS

Some real results are shown next, taking into account the code assignment carried out in the infrared emission, as has been described in section 4. Nevertheless, in [8] the efficiency of the use of these sequences is demonstrated in situations with very low signal-to-noise ratio.

Figure 7 shows the emission of the sequence {-1, -1, 1, -1}, carried out by the implemented system. Figure 8 shows the output of the correlator implemented in the FPGA with no obstacles. In figure 8a it can be observed how a peak is obtained in the detector every $N/2$ (equal to 5.12 ms in this case) without obstacles. Figure 8b shows as the peak disappears when there is an obstacle between the emitter and the receiver.

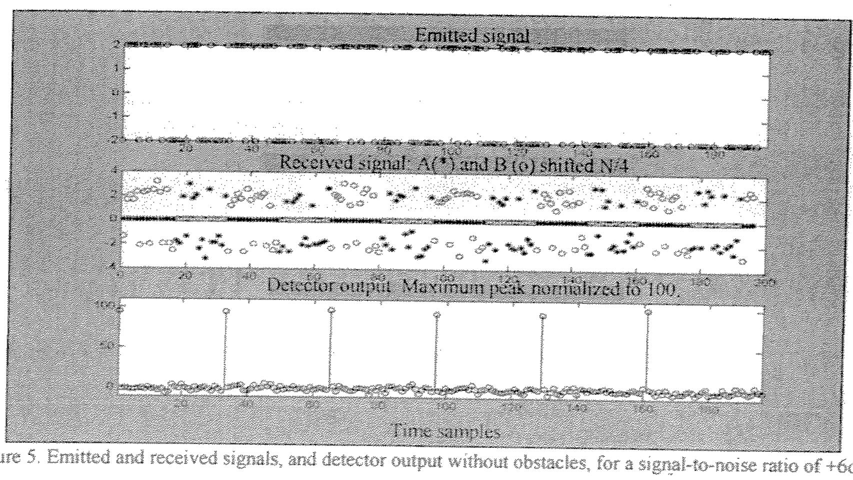

Figure 5. Emitted and received signals, and detector output without obstacles, for a signal-to-noise ratio of +6dB.

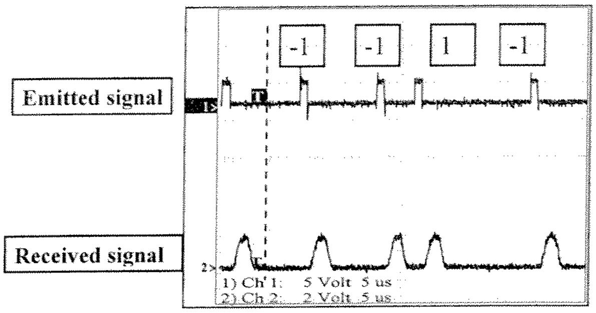

Figure 7. Real emission of the sequence {-1, -1, 1, -1}.

7. CONCLUSIONS

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.

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 Efficient Golay Correlator [8] in order to work with this particular case of Golay sequences. The real tests carried out are successful, as is shown in figures 7 and 8. The feasibility of the used code method confirms the simulated and real results obtained.

8. FUTURE WORKS

As has been shown, experimental results are satisfactory. Simulated results show that the system can work even under conditions of high degradation of the channel (typical in rail systems). It is necessary to obtain an outdoor channel model, in order to equalize the system when the weather conditions are extreme, and to know how large the system robustness is.

9. ACKNOWLEDGMENT

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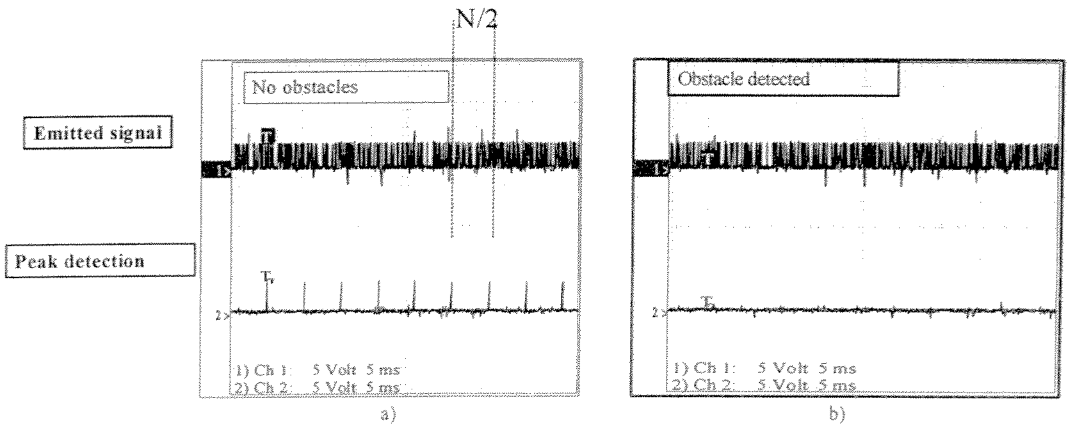

Figure 8. Real detection every $N/2$ (5.12 ms). a) without obstacles; b) obstacle detected.

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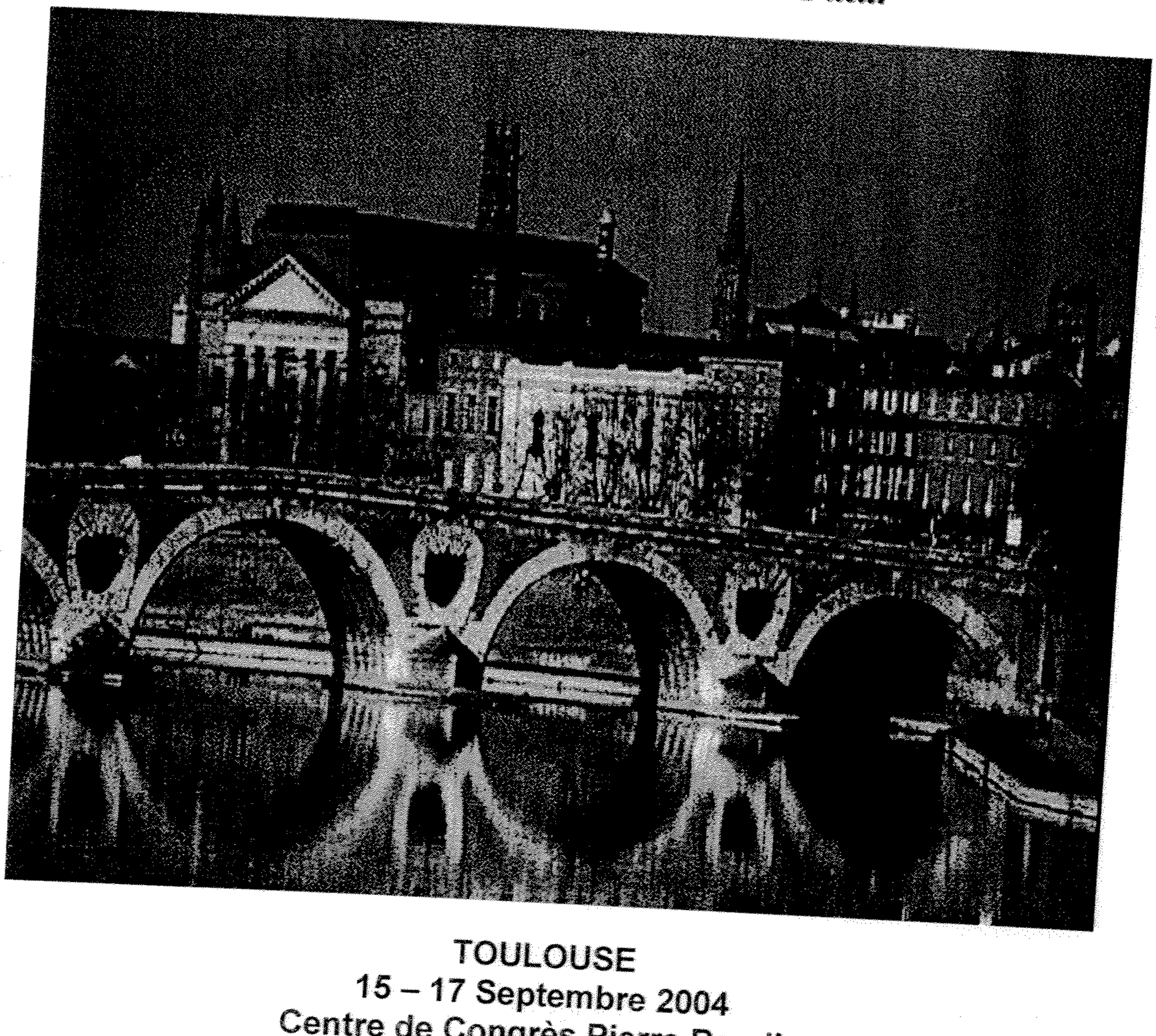

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