AN INTELLIGENT LEVEL CROSSING: TECHNICAL SOLUTIONS FOR IMPROVED SAFETY AND SECURITY

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ABSTRACT

The level crossings have been identified as particularly weak point in the rail transport infrastructure, seriously affecting the safety of both transport operators and users. In this paper we propose an Intelligent Level-Crossing model with an intention to set a standard for the future research in the area of the level-crossing safety. Furthermore, we provide an overview and discuss advantages and drawbacks of existing and new technologies most likely to improve safety of the road and rail users at level-crossings.[1]

Key words: level-crossing safety, sensing, obstacle detection

1 INTRODUCTION

In recent years, the safety in the rail and road sector has attracted lots of public attention. On the European level, numerous research networks have been established with the aim to provide an environment for partners to join their efforts for improved safety on roads and rail: SAFETRAM, SAMRAIL, SAMNET, EURNEX, to mention but a few.

Level-crossings have been identified as particularly weak points in the rail transport infrastructure, seriously affecting the safety of both transport operators and rail and road users. The level-crossing accidents contribute to as much as 50% of all fatalities caused by railway operations. The great majority of these accidents are caused by inappropriate human behaviour rather than malfunctioning of the technical equipment. Although the probability of occurrence of rail accidents is relatively low in comparison with road accidents, when they do happen they may potentially cause at once large numbers of fatalities and huge economic costs. For this reason, various projects have been commissioned by rail authorities in many different countries in order to asses the present risk at level-crossings and to review and evaluate existing technologies applied or potentially applicable to level-crossing environment [1,2,3,4,5,6].

Traditionally, safety equipment at level-crossings include automatic barriers and various types of visual and audio warning signs. These vary largely across different countries as their safety policies and regulations vary. More

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[1] This work has been carried out as part of activities of the European project SELCAT. For more details see http://www.levelcrossing.net/

advanced safety measures, developed in recent years, typically involve use of variety of sensors for monitoring the level-crossing area.

In this paper, we discuss advantages and drawbacks of various technical solutions, which deploy modern sensor technologies most likely to improve safety of the road and rail users at level-crossings. The Section 2 presents the concept of the Intelligent Level-Crossing. The Section 3 describes technologies capable of detecting obstacles or activity at level-crossings. Sections 3-7 discuss these technologies in more detail. The Section 8 illustrates benefits of integration of different technologies into a single system and fusion of the obtained data of various types. Finally, the Section 9 concludes the discussion.

2 INTELLIGENT LEVEL-CROSSINGS

An Intelligent Level-Crossing is a system which integrates functions of modern sensors, communications and information technologies in order to improve safety and operational efficiency at rail-road crossings.

The main benefits offered by a well designed Intelligent Level-Crossing system are (i) increased security and safety of the road users, train passengers and rail staff, (ii) improved efficiency of the rail and road traffic management by provision of real-time information to rail and road users on the status of the traffic network (for example, possible route alterations due to traffic jams at level-crossings).

Such system has the capability to detect the conditions at the level-crossing, identify potentially hazardous situations, notify the local traffic management system, trigger the system response accordingly, and provide advanced warnings to the vehicle users and train drivers.

Figure 1 illustrates the main components and functionalities of an Intelligent Level-Crossing system. The two main functional modules of the model are the Level Crossing Zone (LCZ) and the Control Unit (CU).

The LCZ module covers the physical area of the level-crossing and contains signalisation devices, barriers and sensors. In general, the sensors may be either the ground sensors - fixed at the appropriate points in the level crossing area, or the on-board sensors - on board of the incoming train. The sensors perform monitoring and event detection in the level crossing zone. For best performance, a variety of sensors may be deployed: audio, video, radars, lidars, loops, etc. The utilisation of diverse types of sensors allows for the complementary functioning of the sensors (in the case of sensor failure or limited coverage) and the data fusion. The data collated by sensors are transmitted to the CU module for further processing.

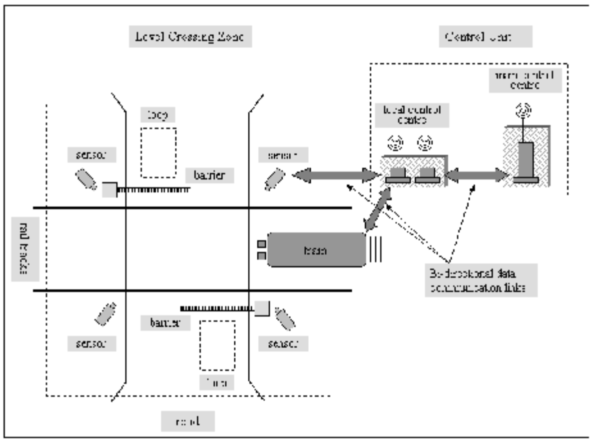

Figure 1: Functional model of an Intelligent Level-Crossing

The CU module consist of two separate control systems, namely the Local Control Centre (LCC) situated at the level crossing and the remote Main Control Centre (MCC). According to the information supplied by the ground and on-board sensors, the detected event is identified and the decision of taking an appropriate action is made by the LCC at the site or by the remote MCC.

The LCC module is situated at the level crossing site. It gathers all the data produced by the sensors, performs the initial data processing, and makes immediate decisions accordingly (for example lowering or lifting the barriers, switching the signalisation on or off, etc).

The remote MCC module, in accordance with information received form LCC, deals with making decisions and taking actions on a higher level. For example, the MCC decides whether it is required to perform a temporary redirection or a partial closure of the rail and/or road traffic elsewhere on the network due to an accident at a level crossing.

The train, the LCC and the MCC are interconnected by bi-directional data communication links, which may be wired or wireless. These links provide a fast channel for the exchange of information within the system. The regular updates are sent back and forth between all the system components. The seamless information flow provides for the high resposnivity of the whole system and smooth operation of the rail/road traffic.

At the local level, the communication is twofold: between the level crossing equipment and the LCC, and between the incoming train and the LCC. The sensors send collected data to the LCC module, which in return may send signals to activate or deactivate safety equipment at the crossing (signalization and the barriers) or adjust the sensors settings (position, sensitivity, coverage etc). The train may inform the LCC of its location, the speed, or any potential technical problems that may occur on board; it also acquires information from the LCC about the current state at the level-crossing.

At a higher level, the LCC and MCC have a dedicated communication channel. At any time the MCC is aware of the current status at all the crossings. It performs the information management in agreement with the safety rules and regulations and notifies the LCC of the necessary actions to be taken, such as a temporary closure of the level crossing due to interruptions elsewhere on the rail/road network, etc.

An Intelligent Level-Crossing makes use of those technologies most likely to provide improved safety and security while maintaining seamless functioning of the system, with no or very little disruptions to the traffic network operation, at an acceptable installation and maintenance cost.

The following section describes technologies potentially offering such capabilities, applied to obstacle/activity detection at level-crossings.

3 OBSTACLE/ACTIVITY DETECTION AT LEVEL CROSSINGS

The purpose of obstacle detection systems is to prevent vehicle and train collisions at level-crossings. They allow for the timely detection of objects caught within the level-crossing area and provide means for automated alert notification and activation of an appropriate network response (such as setting off the warning signs, lifting/closing the barriers, train route alterations, or partial closing down of the rail network). The main benefit of these systems is that they are potentially capable of fully automated performance, remote control and system failure diagnostic.

Technologies deployed for obstacle detection at level-crossings generally fall into two broad categories: intrusive and non-intrusive [4]. Intrusive technologies typically require installation below the ground surface and hence cause traffic distractions during installation and maintenance; in general, they cost less to purchase but incur higher installation and maintenance costs. The intrusive technologies include inductive loops, pneumatic road tubes, magnetometers and piezoelectric cables. The non-intrusive technologies are typically installed above the road/rail surface, they are in general more expensive but easier to install and maintain. Typical non-intrusive technologies are radar, infrared, acoustic, ultrasonic and video.

The selection of the most appropriate technology for obstacle/activity detection depends on various factors and the final choice will inevitably be a result of a tradeoff between the cost and performance. The findings reported in the relevant literature so far, rely on different evaluation conditions and criteria. Hence, it is not surprising that the conclusions of their performance evaluation vary. Some researchers recommend video image processing and active infrared methods [5], whereas others find that video surveillance and inductive loops [6] offer best performance.

Although a reliable methodology for evaluation of obstacle/activity detection in the level-crossing context is yet to be established, most of the researchers find fusion of the video processing and another complementary technology as most promising. The inherent limitations of the video techniques, such as inability to perform under reduced visibility due to averse weather conditions and time of the day, may be overcome by integration with another type of technology such as radar or active infrared. The following sections discuss these technologies in more detail.

4 INFRARED BASED SYSTEMS

There are two types of optical infrared obstacle detection systems used in traffic applications: *passive* and *active* ones [5]. Passive infrared systems only detect energy emitted by all objects whose temperature is above the absolute zero. When an object enters the field of view of a passive infrared device, the change in the energy emitted by the road surface and the energy emitted by the object indicates the presence of an object within the monitored area. Although the passive detectors can operate at any frequency, the long-wavelength infrared band (8-14 µm) can be used to eliminate or minimize the effect of environmental light changes. The main weakness of passive infrared systems is their sensitivity to certain weather conditions, such as snow, fog, rain, but also dust and smoke, where the energy emitted by the objects can be scattered and absorbed by the atmospheric particles. Active infrared systems use the low power infrared diodes to illuminate the monitored area. The diode energy is then reflected by objects and detected by infrared sensitive detectors which convert it into electrical signals. The change in detected energy indicates the presence of objects. The undesirable effects of weather conditions on the accuracy of detection can be eliminated by signal processing. Both types of infrared systems may be used for detection of the objects' presence and speed. The advantage of the active type is that this technology provides an image information which can be used for the object classification.

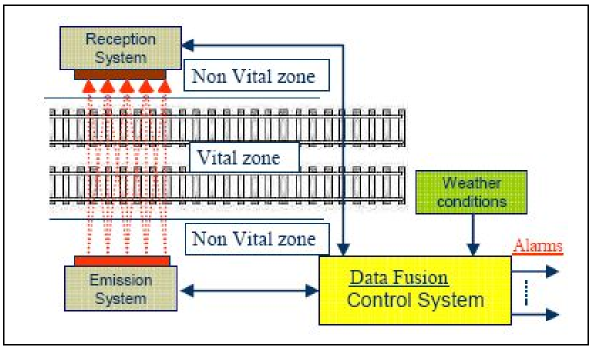

Fig. 2: Infrared object detection system

An active infrared based system for railway applications proposed by Garcia *et al* [7] is shown in Figure 2. It consists of an infrared-sensitive array of multi-emitting emitter-detector pairs. It is capable of successfully detecting objects of the minimum size 0.5x0.5x0.5m. This system accounts for the signal degradation due to atmospheric attenuation and solar interference by means of an interpolation algorithm which dynamically models the threshold for detection of the peak signal. This technique allows for efficient reduction in the number false detections.

5 MICROWAVE RADAR BASED SYSTEMS

The basic principle of radar operation is transmission of the electromagnetic waves across the monitored area. When an object enters the zone of interest it interrupts the radiation the portion of which is reflected back to the antenna. Depending on the type of emitted waves, there are two types of radar systems: a constant frequency continuous wave radar (CW) and the frequency modulated continuous wave radar (FMCW) [5].

The advantage of radar based technology is that its operation, in general, is not affected by weather and lighting conditions. The main disadvantage is that the CW microwave radars, which rely on Doppler effect, cannot detect static objects. Also, this type of technology does not determine the size of objects accurately; hence, it is not ideal choice for pedestrian and bicycle classification.

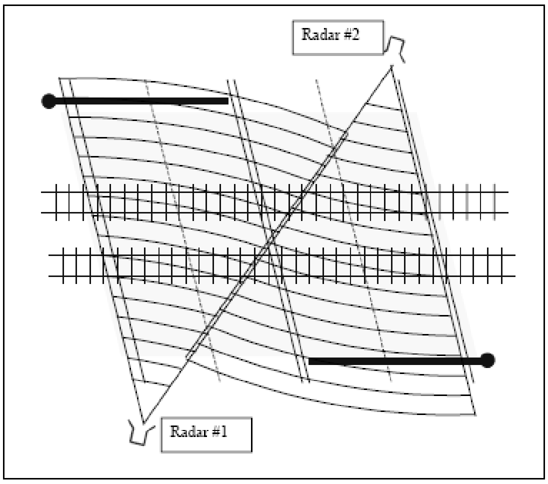

Fig. 3: Radar object detection system

Lohmeier et al [8] describe an ultra-wideband pulse radar system for vehicle detection at level-crossings, Figure 3. In this application two radar devices are used, each with the beam width of 50 ° in the horizontal plane. These characteristics allow for full coverage of the monitored area without decrease in the sensitivity at longer distance ranges. The delay between the successive pulse emissions is generated by a pseudo-random number generator to enable the simultaneous operation of the two radars without interference.

6 LASER BASED DETECTION SYSTEMS

As in radar systems, the area of interest is scanned with electromagnetic waves – near infrared pulses which are reflected off the objects caught within the range. Typically, laser based systems use multiple laser scanners. The advantages of this type of sensors are wide viewing angle, high scanning rate, and long-distance range. This technology can be used to determine the presence, location, direction and speed of the object. It is fairly accurate in detection of the size of the objects and suitable for object classification, but at the same time sensitive to small size objects such as fog vapour droplets. This weakness however, may be overcome by signal processing of the reflected waves. Another issue with laser scanners is their inability to correctly detect low reflectance objects (for example, vehicles of a dark colour). Iwata *et al* [9] propose an efficient solution for this problem based on background occlusion information rather than the appearance of the detected object.

7 VIDEO BASED OBSTACLE DETECTION

Video image processing is the most recent technology to be applied in rail transport safety applications. Although it suffers form significant drawbacks, such as relatively high purchase cost and susceptibility to weather and lighting conditions, its performance in obstacle detection applications may be significantly improved by using novel image processing and scene understanding algorithms. Furthermore, the integration of multiple cameras allows for wide area coverage and recovering of the three-dimensional data. The multiple-view installations together with scene understanding algorithms and powerful processors create an intelligent system capable of detecting small size objects, accurate object classification and tracking. This technology allows for the capture and storage of large amounts of data and real-time processing. The data collected by video cameras may be stored and used for further research in the area of safety and security, such as human behaviour modeling and traffic flow modeling in the level-crossing context.

In Japan, a system of stereo cameras is used to achieve a large coverage area without the need for mechanical scanning [11]. Stereo cameras enable the system to obtain the three-dimensional shape information which significantly reduces the number of false detections due to shadows and vehicle headlights. The principle of the stereo camera method is illustrated in Figure 4. The effect caused by the direct sunlight may be minimized by using four stereo camera sets.

8 DATA FUSION

The benefits offered by video systems may be further enhanced by fusion of the video data with the information collected by another type of sensors.

Alessandretti *et al* propose the radar and vision data fusion for vehicle detection [12]. The radar output is used to provide the location for video search. The combination of the two data types provides high accuracy in vehicle detection. The advantage of this method is that it uses very simple computational techniques to speed up the processing. Instead of model matching, which is often used in vehicle detection applications, only the low level image features are considered, such as vertical and horizontal edges in a binary image. The edges are examined for vertical symmetry and the centroid and a precise bounding box of a vehicle are computed. Only one vehicle is associated with a single radar point. However, localization errors may occur which causes detection of multiple objects, i.e. false positives, in a single area. The number of false positives can be reduced by discarding bounding boxes unlikely to represent a vehicle, ones that are either too large or too small. The high-level fusion of the radar and video data enables the validation of the radar targets by establishing a correspondence with vision targets.

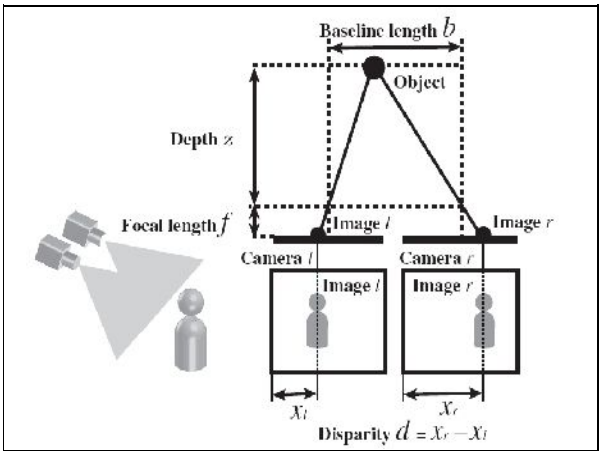

Figure 4: The stereo camera system

9 CONCLUSION

A half of all rail accidents occur at level-crossings. The great majority of them are caused by human factors rather than technology failure. Therefore, functionalities of traditional safety measures, such as barriers and warning signs, need to be reinforced by modern technical solutions.

In order to minimize the operational cost and maximize the safety and security, an Intelligent Level-Crossing system has been presented. This system integrates functionalities of traditional safety measures with modern sensors, communication links and information processing. This system offers capabilities of automated management of monitored area, system failure diagnostic and remote control.

The fusion of the video data with another type of sensors, such as radars, proved to be the most promising solution for the problem of the obstacle/activity detection at level-crossings. However, more tests in real life situations need to be done. An universal, reliable methodology for performance evaluation of obstacle/activity detection in the context of level-crossing is yet to be established.

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