A New Video Based Guideway Intrusion Detection System
for Public Transportation Infrastructures

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Abstract

During the last years, a new video based guideway intrusion detection system had been developed and
tested in several German rail transportation networks. The system is based on artificial intelligence
analysis of video images of critical areas including object class identification and appropriate automatic
alarm response. The system architecture is outlined as well as the integration into the operational
environment of transport systems. Experiences show that the algorithms detect various object classes like
human beings, trains or baggage. The tested image processing approaches include difference image and
single picture image evaluation. The classification process of the extracted feature vectors is supported
by artificial neural networks and support vector machines. The system is optimized to cost efficiency by
possibly integrating it into existing video camera networks.

1 Introduction

Since more and more urban guided transportation systems, especially metro networks face an increasing
demand in system renewal or retrofitting, many of these systems consider a migration strategy to fully-
automated operation as one possibility to improve efficiency, increase passenger service and cut costs [7,
8]. The protection of the passengers, who are waiting at the platform for incoming trains, must be
considered one of the most critical sub-systems no matter whether the operation is fully automated or
manual with drivers onboard the trains. Unless a reliably, available and safe protection of passengers
from running trains is guaranteed, a real AGT (Automated Guideway Transit) operation is impossible.

Apart from the safety point of view another aspect is of major importance for highly attractive urban rail
transit. The passengers' security has moved into the focus of the transport operator as an important
quality feature. The use of video based surveillance systems in combination with an intelligent technical
(semi-) automated image processing system to alert the operator’s service staff must be considered a
viable and promising technology for both purposes. Therefore innovative system solutions which make
use of state-of-the-art image processing technology have moved into the focus. Today computing power
and memory capacities of modern hardware technology enables such video-based solutions in a wide
field of applications.

The subsequent section will introduce the existing approaches for platform track supervision and outline
the usefulness of video technology. In section 3 the typical system structure of Guideway Intrusion
Detection System (GIDS) is introduced. A video-based approach is described and the different image
analyses methods and classification approaches are compared. Section 4 deals with the various systems
test which need to be performed to demonstrate the functional correctness of the system. Finally future
research work is discussed.

2 Guideway Intrusion Detection/ Prevention Systems

2.1 Existing technologies

Different technical solutions to supervise the station guideway have been developed and tested since the
first fully-automated public transport systems evolved in France and Japan about 25 years ago [4].
Physical barriers that separate the platform from the guideway as well as supervision methods are known (cf. Table 1).

**Table 1: Characteristics of platform protection systems**

<table>
<thead>
<tr>
<th>selectivity between persons and objects</th>
<th>platform doors</th>
<th>contact sensors</th>
<th>optical system (light, RADAR, LASER)</th>
<th>video image processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>not necessary, (physical barrier)</td>
<td>not possible</td>
<td>not possible</td>
<td>possible; recognize and differentiate objects, persons, trains</td>
<td></td>
</tr>
</tbody>
</table>

| availability and maintainability       | high, proven equipment difficult to retrofit | availability limited by high number of components and false alarms (vandalism), requires extensive maintenance requires service interruption | limited by many components in dirty environment; false alarms (vandalism) electro-magnetic components critical in dirty environment requires service interruption | high availability, proven cameras, personnel intervention possible, standard cameras with high MTBF easy to repair, no interruption necessary |

<table>
<thead>
<tr>
<th>cost structures per platform edge</th>
<th>high</th>
<th>mean</th>
<th>mean</th>
<th>expected low</th>
</tr>
</thead>
</table>

| extendibility                          | no extended functions | no extended function | no extended function | additional functions for security |

For fully automated metro systems the complete physical separation of the platform from the guideway can be considered the most rigid measure. Due to doors which open automatically and synchronized with the train stop in the station it is impossible to intrude the guideway from the platform. Although it is a proven technology, the high investments cost and intensive maintenance of the door movement and lock mechanics are a disadvantage. It is, however, quite difficult to retrofit and it does not offer any additional functions. Furthermore, the installation of platform doors is hardly possible under certain conditions. Especially the track geometry with curved tracks makes installation difficult. This aspect is of major importance regarding the modernisation of older systems (with out-dated track geometry) and the subsequent introduction of AGT operation.

Therefore, active technical systems which are installed above the tracks are also in use. The stations of the metro line D in Lyon, France, for example, are equipped with infrared beams over the track. If two or more of the beams are interrupted the station track is considered intruded by a person or object, which has to be protected from the trains. An electro-mechanical system based on the gravity of persons and objects is used in Vancouver (SkyTrain system) and Kuala Lumpur (PUTRA line). If persons fall onto a mat with piezo-electrical elements that mat will be deformed triggering an electrical current. Many components require multiple maintenance action and due to that high number of elements the system availability is limited. Furthermore all the previous systems require a service break for maintenance and repair. The less expensive cost structure is superior to platform door systems.

A video-based guideway intrusion detection system is likely to be more flexible and cost effective. Well proven and state-of-the-art camera technology assures high availability and requires low maintenance. The costs per platform edge are significantly lower than for the other systems. Due to an intelligent image processing software it is even possible to differentiate between person and objects falling onto the track. The recorded video sequence can be analysed afterwards and it may be used as legal prove in exceptional cases. It is even possible to use the camera system for additional services such as for security issues. The intelligence of the image processing algorithms need not be limited to the detection
of dangerous situations with running trains and people. Furthermore, all active systems require an additional video observation system anyway to assess the situation on the platform/track in case of an alarm situation. These installations may be used also for automatic intelligent image processing reducing investment costs.

2.2 Operational integration and requirements

The basic operational requirements on a guideway intrusion detection system (GIDS) are derived from its integration into the overall transportation system (cf. Fig. 1). The GIDS must be connected to the ATS level (Automatic Train Supervision) in order to enable the staff in the central control room or at the station to handle the alarm message, check operation status and logging messages or to perform the system’s parameterization. Apart from the connection to the control centre a direct link to the ATP/ATO (Automatic Train Protection) equipment is mandatory. The alarm message must be automatically transmitted to the ATP in order to send a stopping signal to approaching trains.

Fig. 1: Integration of GIDS into ATP/ATO and ATS infrastructure

The following basic safety principles apply to guideway intrusion detection systems [9]: The level of safety must be equivalent to that of conventional train operation with driver. The system surroundings must not influence the GIDS functionality. Only events in front of the train or between coupled trains (with significant gap) must be recognized by the supervision system. The system itself must react to the safe side in case of any system failures or disturbances that produce an unclear situation.

In case of an alert situation, the operational procedures are taken with respect to the position of approaching trains and the current situation inside the station. Four different cases must be distinguished (cf. Table 2 and Fig. 2). As a consequence the trains must either be stopped with operational braking or with the emergency brake. Standing trains in the intruded or any adjacent station must be prevented from departing.

Fig. 2: Operation status of trains
Table 2: Operational procedures in case of intruded platform track

<table>
<thead>
<tr>
<th>train position</th>
<th>train status</th>
<th>reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>station A</td>
<td>standing train</td>
<td>no departure</td>
</tr>
<tr>
<td>between station A and station B</td>
<td>approaching train</td>
<td>operational braking</td>
</tr>
<tr>
<td>station B</td>
<td>approaching train</td>
<td>emergency braking (if head of train in protected area)</td>
</tr>
<tr>
<td>station B</td>
<td>standing train</td>
<td>no departure</td>
</tr>
<tr>
<td>station B</td>
<td>departing train</td>
<td>emergency braking (while head of train in protected area)</td>
</tr>
</tbody>
</table>

3 Video based Guideway supervision

3.1 Object categorisation and geometry

Two major aspects that pose an exceptional challenge to a video-based supervision system must be considered. Whereas conventional supervision system (cf. section 2) can hardly distinguish between different objects or objects and people an intelligent image processing algorithm could achieve this. Therefore a detailed object model is required which categorises the different objects and their status of criticality (cf. Fig. 3).

The presence of certain objects, such as trains, shall be accepted. Other objects which exceed a certain size must not be accepted. First of all, people must be identified as critical objects because they need to be protected from incoming trains. Furthermore even non-living objects such as piles of paper, suitcases or trolleys must be identified as critical, because they are large and heavy enough to endanger incoming trains and can even cause a derailment. Such accidents could even harm people onboard the train.

Fig. 3: Categorisation of critical and noncritical objects
In accordance with this classification of critical and non-critical objects the supervision system must issues different status messages:

1. Detection of movements of persons from the platform into the track area or the intrusion area. The system outputs the signal “Track Obstacle Alarm”.

2. In case of no “Track Obstacle Alarm” the system outputs the signal “No Track Obstacle Alarm”.

3. Additionally the system signals its normal operational status by the signal “System Health Status”.

The object model also needs to incorporate further attributes of the objects which describe the dynamic and static characteristics. These attributes include the x- and y-coordinates of the objects inside the image and the number of pixels for each dimension (width, height). The real size of typical objects such as trains or people can be described by their minimum, maximum and average height and width. The correspondence between the real and the image dimension data of objects is the second important issue.

This second problem is closely related to the image processing task itself. Due to the 2-dimensional nature of an image an adequate geometrical model must be build in order to assign a certain image coordinate a real world position (cf. Fig. 4). This information is necessary to allow a correct estimation of the objects' size and position on the platform track.

![Diagram showing correspondence between 2-dimensional image data and real platform geometry](image_url)

**Fig. 4:** Correspondence between 2-dimensional image data and real platform geometry

By using an approach from Projective Geometry the real depth can be measured inside a 2-dimensional camera image [5]. The correspondence between the real length of the platform as well as the width and height of a train can be calculated with a standard transformation of the image coordinates taking into account the perspective deformation of the objects’ size and position.

### 3.2 System structure

For a typical installation two cameras are mounted in an approximately central position above the track area at a distance of 5 m to 10 m from each end of the platform. Two cameras supervise an area of about 100 m (cf. Fig. 5).
The captured video signals are transmitted over a 2-wire cable to the image processing unit. The image processing unit is situated in a standard industrial rack in the central control room of the station. Consequently, one platform edge has to be equipped with the following devices (cf. Fig. 6): cameras with lenses, housings, power supplies and mounting parts, 1 image processing unit, two-wire video receivers (one receiver for two video channels), 1 power supply for the two-wire video receiver (mounted in 19" rack), cable and cable mounting parts for the power supply of devices and video signal transmission. Furthermore an interruptible power supply unit should be used in addition in order to compensate minor voltage fluctuations or short term power failures.

The computer unit also communicates with the cameras over standard control interface. Camera parameters such as shutter time, automatic image saturation control or aperture adjustment can be set through this interface. Furthermore, the computer unit is connected to the control centre in order to transmit the video signal of the track for manual inspection in case of a reported incident. Besides, a
connection to the signalling equipment (ATP) must be installed to transmit the stopping signal to the train in case of emergency. A prototype installation of this configuration is shown in Fig. 7.

![Prototype installation of the proposed video supervision system](image)

The overall track surface area is continuously supervised for people and objects that fall from the platform onto the track. The transversal supervision area is defined by the platform edge and the wall of the tunnel facing to the platform edge.

### 3.3 Intelligent image analyses

Two different image processing approaches have been examined. On the one hand, a difference picture method [3] was used and on the other hand a single picture method was tested [6]. The difference picture method is based on the evaluation of the dynamic aspect of a sequence of pictures. The movement of persons and objects is tracked over several images. The whole algorithm is split into four steps: The image grapping process is followed by the image processing, the object generation and classification step. Within the image processing difference and reference images are created. The reference images are used to train a knowledge base on specific typical objects (train, persons etc.). The raw image resulting from the grabbing process is segmented into typical parts that represent the actual track, the platform, the area above the track. During the object generation step the features of each image segment are extracted and standardized. The objects are represented by a characteristic vector of the detected envelope (cf. Fig. 8). The motion of an object through a sequence of images can be tracked.

![Image analysis and representation of train objects](image)
Another approach was tested with the single image method [6], only using a single and therefore static image for the evaluation of the station track. Each scene (single picture) is represented by a feature vector extracted from the image’s pixels. The station guideway is segmented into a virtual tunnel and this tunnel is divided into several logical segments (cf. Fig. 9).

Each of these segments represents a detection cluster which is logically linked to an image. The feature vectors of these images describe the position and dimension data of the train. The classification is treated as a binary decision problem for two possible states: train in cluster area (yes/no) and object in cluster area (yes/no). For vector classification as support vector machine approach was tested instead of an artificial neural network.

The practical implementation of both methods can be realized in a real-time system. By using a standard PC (2 GB RAM, 3 GHz) the image sequences can be processed with 100 ms time step. Both analyses approaches proved their viability and can be considered successful. They had been extensively tested in three German urban rail systems and proven to work satisfactorily. Therefore, a combination of both methods combining the advantages of both (cf. Table 3) would be even superior to the existing algorithm.

![Image of track area and situation classification](image)

**Table 3**: Comparison of tested image processing approaches

<table>
<thead>
<tr>
<th>Different image method with ANN</th>
<th>Single image method with SVM</th>
</tr>
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<tbody>
<tr>
<td>- object dynamics estimation possible</td>
<td>- easy and relatively fast parameterization</td>
</tr>
<tr>
<td>- ANN well proven tool for classification and decision making</td>
<td>- SVM well proven tool for classification problems</td>
</tr>
<tr>
<td>- use of relative measured values (differences)</td>
<td>- easy to handle for technical staff, more suitable for automatic configuration (system restart)</td>
</tr>
<tr>
<td>- suppression of slow changes in brightness, shadow etc.</td>
<td>- static objects detection possible; recognition of lying/static objects (fallen person behind train)</td>
</tr>
<tr>
<td>- segmentation of image/motion of two small objects</td>
<td>- very fast and robust feature generation from single image</td>
</tr>
<tr>
<td>- explicit object size estimation possible</td>
<td></td>
</tr>
</tbody>
</table>

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### 3.4 System Acceptance and qualification tests

Preliminary system qualification tests have been performed in cooperation with a German transport operator [3]. The general feasibility and correct functionality have been proven. Currently an extensive and generic safety certification procedure has been developed which is based on the requirements of VDV standard 399 (cf. section 2) and the life cycle concept of EN 50126/50129.

Several testing scenarios (cf. Fig. 10) including event test as well as permanent test have to be passed and the correct interpretation of the platform track situation has to been demonstrated with positive tests.
(correct identification of intrusion) and negative tests (correct interpretation of empty track or noncritical objects). Furthermore, formal availability and safety models will be defined using FMECA (Fault Tree+) in order to allow a quantified system validation and positive acceptance.

4 Conclusion

The potential of video-based guideway intrusion detection systems is very powerful due to significantly reduced cost structures compared to existing systems (doors, electro-mechanical or optical devices) and a much wider field of application of the camera system. Successful image processing algorithm based on difference and single pictures methods have been tested and proved its viability for recognition and differentiation of critical and uncritical objects in a railway station environment. Major advantages of the proposed methods indicate that an improved processing version should combine the existing approaches within a hybrid method to further optimise performance and robustness.

Most of the rail operators make use of separate camera installations for security issues only. The video-based track surveillance system can be extended observing also the platform and provide additional services for security matters [1]. The object and person classification approach may be enhanced to describe the content of an image in a contextual point of view.

References

[7] UITP: Automation in Metro Networks. UITP Metropolitan Railways Division, 2004
[9] VDV: VDV standard 399. Standard no. 399: Requirements on technical equipment to assure passenger safety in stations for fully automated (unattended) train operation (in German). issued by Verband Deutscher Verkehrsunternehmen (German Association of Transport Operators), 1999

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