Image fusion for obstacle detection optimization

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***Abstract*—This paper presents a new approach for optimization of obstacle detection in railway infrastructure. The approach is oriented at the fusion of IR and night vision images, captured by the SMART obstacle detection system in real world scenarios. Those sensors can operate in low-light and at night conditions. However, due to different light and environmental conditions, object that is not visible on IR image may be visible on image from Night vision system. The fusion process includes artificial intelligence powered extraction and fusing data and features from IR image and image from Night vision system, as well as distance estimation between obstacle detection system and detected obstacles on railway infrastructure. Use of this approach can compensate hardware flaws of sensors and increase accuracy in obstacle detection in different conditions, and those increase safety and reliability of obstacle detection system.**

I. Introduction

Timely and accurate object detection in traffic can have great effect on significant reducing of accident's number, especially those with fatal outcome. On the other side, as railway represents an important type of transport, its interruption due accident or malfunction of infrastructure and vehicles can have a significant economic impact on the industry and people's everyday life.

From the safety point of view, the existence of any object on the rail track and/or in its vicinity, represents a potential obstacle to the safe railway traffic. Level crossing is an intersection of rail tracks and a road or path. and this is conflict place with frequent traffic accidents. Those crossings are mostly good illuminated, marked and equipped with appropriate equipment in the prescribed manner. However, disordered crossings are often formed, which are caused by different people's needs. Such crossings are not designed, marked, and equipped with appropriate equipment or devices for safe traffic. Also, they can be formed at unsecured places of railway infrastructure i.e., part of the rail track, so they represent dangerous places.

Visibility has a very important role in the accurate and timely detection of obstacles on railway infrastructure. However, the visibility of the objects is good at day and night conditions, but only on the part of the infrastructure where there is enough lighting. In conditions of reduced visibility on the part of the infrastructure, where there is no lighting at all or there is not enough lighting, the detection of the object is significantly difficult. In addition, bad weather conditions (rain, snow, fog, etc.) have a significant impact on reducing visibility. In such conditions, the correct and timely object detection and actions by the driver is uncertain, and there may be a delayed reaction and the inability to stop the train in a timely manner or traffic accident.

However, in addition to object detection, decision is detected object obstacle or not, as well as estimation of distance between train and obstacle, depends on train driver. Time and accuracy of those action are closely related with health status and experience of train driver, as well other circumstances as train speed, construction of the train, length of driving composition, etc. All this have influence on train stopping distance, and whether there an accident will happen or not.

Further development and improvement of railway traffic is conditioned by increasing efficiency, capacity, and quality of services. The quality and cost competitiveness of railway freight transportation can be considerably improved through following the trend of automation, in order to achieve cost-effective, flexible and attractive service. The development of autonomous systems in the railway is present mainly in the field of public transport services (driverless metro lines, light rail transit (LRT)) and automated guided transit (AGT). At the beginning of 2018, 996 km of automated metro is in operation with 62 lines that together serve 41 cities in 19 countries. Current forecasts, based on projects approved for implementation, show that by 2025 over 2300 km of fully automated lines will be in operation subway [1]. The initiatives proposed by the European Transport Strategy 2011-2021 (Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system) aim to 30% of the road transport freight transport over 300 km to other modes of transport, such as rail or water transport by 2030, and more than 50% by 2050 [2]. Achieving such a vision certainly requires the development of new infrastructure, as well as increasing the efficiency and throughput of existing infrastructure. For the fully autonomous train operation (ATO) all the activities and responsibilities of train operators need to be taken over by several systems that can sense the environment and to overlook the scene, detect potentially dangerous objects on the train's path and react accordingly and in the right way [3]. The key element for safe railway traffic is safe and reliable Obstacle Detection System (ODS), and it must work in a challenging environment and in a hard visibility conditions, in order to fulfill strict railway standards and regulation.

In this paper, the new approach of image fusion obstacle detection optimization is presented. The key element for safe and reliable railway traffic is obstacle detection system. However, the use of sensors that cannot operate in low-light conditions will affect the great detection error, as well as increasing the chances of causing a traffic accident. Because of that, IR camera and Night vision system can be used in low-light and at night conditions. However, those sensors also have its limitations, due to different weather conditions. The main idea of image fusion approach is to optimize obstacle detection through artificial intelligence powered extraction and fusing data and features from IR image and image from Night vision system, as well as distance estimation between obstacle detection system and detected obstacles on railway infrastructure.

II. SMART On-board ATO Obstacle Detection System

Obstacle Detection System (ODS) system represents machine vision system with hardware and software solutions, in order to provide reliable information of obstacle existence on railway and/or in its close vicinity, and to estimate distance from the system to the detected obstacle. System needs to operate in real time and in different light conditions (day, low-light and at night), detect obstacles at a very long ranges e.g., up to 2 km, work reliable in bad weather conditions, including heavy winter and desert-like situations, and keep the reliability while train moves with speed ranges from 0 km/h up to 180 km/h [4].

During realization of HORIZON 2020 S2R-OC-IP5-01-2015 project “SMart Automation of Railway Transport - SMART” an on-board obstacle detection system for ATO was developed. The SMART ODS consists of three monocular RGB cameras (RGB), one IR camera (TH), one Night vision system (NS), one laser scanner (LS), and additional devices for connecting (Fig. 1). All the sensors were mounted on specially designed vibration resistant metal housing, which surface is powder coated and designed taking into account its use in different weather conditions [5, 6].

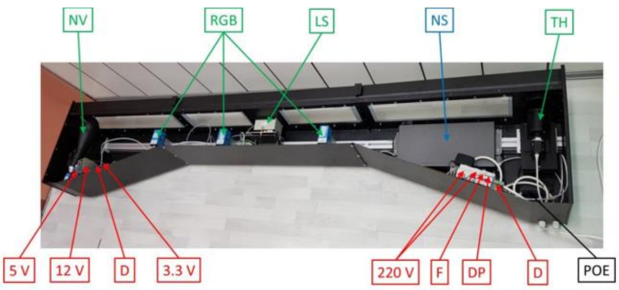

Figure 1. On-board obstacle detection system [7]

In framework of project, static and dynamic tests were obtained on Serbia railways. During static test, ODS was mounted on two holders (Fig.2), while during dynamic tests system was mounted on Serbia Cargo ŽS series 444 locomotive (Fig. 3) [6].


Figure 2. On-board obstacle detection system during static tests [7]


Figure 3. On-board obstacle detection system during dynamic tests

Since the system should work in different challenging environment and visibility conditions, RGB cameras and Laser scanner were used during the daylight operation. However, those sensors were unusable at night conditions, so IR camera and Night vision system were used.

IR camera operates in infrared range of spectrum, that its use in conditions of reduced visibility such as at night [8]. Working principle of Night vision system is based on collecting of tiny amounts of light, that are present in environment and mostly imperceptible for human eye [9]. Night vision system used in presented researched is ICCD (Intensified CCD) camera consist of optical lens system, image intensifier tube and CMOS camera sensor coupled on image intensifier tube output screen (Fig 4).

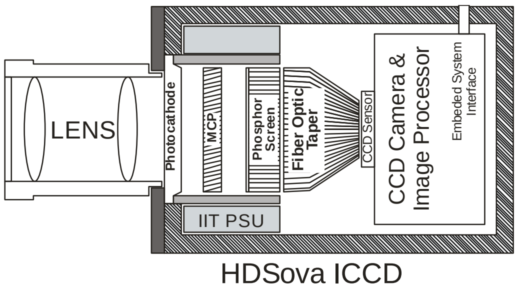

Figure 4. ICCD camera scheme [9]

One of the most important part of Night vision system is image intensifier. This part has task to multiple tiny amounts of light from environment, that user can easily observe the image. In order to collect and multiple the more light, Image intensifier consists of three functional units (Fig. 5) [9]:

- photocathode, that converts the incoming photons to photo electrons,
- micro channel plate (MCP) that strongly multiplies these photo electrons,
- phosphor screen that converts the multiplied photo electrons back to photons.

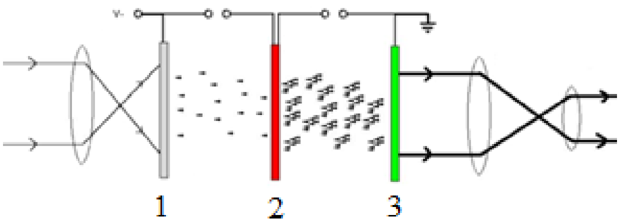

Figure 5. Three functional units of an image intensifier: the photocathode (1), the micro channel plate (2) and the phosphor screen (3) [9]

III. SMART Obstacle Detection System Software

During realization of SMART project, two approaches were used for obstacle detection. The first approach was based on traditional region-based segmentation and edge detection, while various soft computing methods were implemented for segmentation improvement. Another approach was based on a state-of-the-art computer vision object detector YOLO (You Only Look Once) trained with COCO dataset. YOLO is a fast and accurate object detector based on Convolution Neural Network (CNN) and its outputs are bounding boxes of detected objects in the image and labels of the classes detected objects belong to.

For obstacle detection at night conditions, the first approach was used with IR camera and Night vision system. Safe and reliable obstacle detection requires using of appropriate intelligent image processing algorithm. On the other side, not every object in the scene is an obstacle, but only the one that is on rail tracks and/or in close vicinity. Because of that, after image capturing, region-of-interest (ROI) was determined. As the ROI represents rail tracks and its close vicinity, the first step is to detect rail tracks on IR image. For that purpose, different edge detectors were used on variety of scenarios, in order to determine one that give detection results as good as possible, with small noise, or completely without it. [8, 10]. One of the tested scenarios captured at night conditions in Babin Potok near city of Prokuplje, Serbia, without external illumination is shown in Fig. 6 (left) [8], while other is shown in Fig. 7 [10]. Those scenarios are the most complex because include rail tracks, humans, and the environment, as three completely different kinds of objects for potential detection. Five different edge detectors (Roberts, Sobel, Prewitt, Canny and LoG) were tested on set of scenarios with set thresholds. The best rail track detection results gave Canny edge detector [11, 8, 10] (Figures 6 and 7 (right)). Results showed that other detectors cannot be used in further analysis, because rail tracks were not detected, or results have noise.

Figure 6. Tested scenario No.1 captured with IR camera at night conditions (left), Rail track detection using Canny edge detector (right) [10]

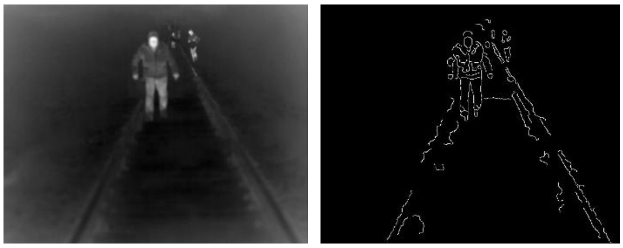

Figure 7. Tested scenario No.2 captured with IR camera at night conditions, Rail track detection using Canny edge detector (right) [8]

Based on rail track detection results, ROI was determined (Figure 8 (left)). In further obstacle detection process, objects in ROI were detected using of region-based segmentation method with set threshold [12]. Since these detected objects are in the ROI, that means that they are on rail tracks and/or in close vicinity. Based on first assumption, they represent obstacles, so they are marked as such (Figure 8 (right)) [6].

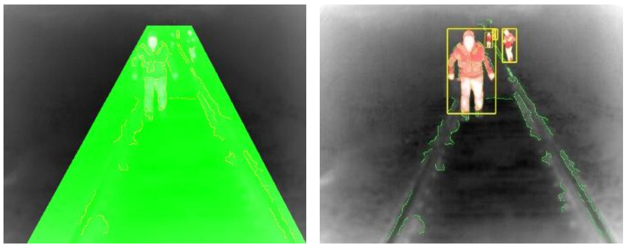

Figure 8. Determined ROI (left), Objects marked as obstacles (right) [6]

Another system that was used for obstacle detection on railway infrastructure in night and low-light conditions is Night vision system. This system is dependent only on amount of light in environment. As in case with IR camera, night vision system is coupled with intelligent image processing algorithm that includes rail track detection, determining of ROI, and object detection in ROI. In order to improve quality of input images, increasing of image contrast was done with histogram equalization. One of the tested scenarios captured near village Žitorađa, Serbia, is shown in Figure 9.

Figure 9. One of the tested scenarios with night vision system (left) [7], Image after histogram equalization (right)

Rail track detection was obtained using of region-based segmentation process with set threshold [12]. Based on detected rail tracks, ROI was determined, and object detection was performed using of region-based image segmentation method with set threshold (Fig. 10) [12]. Detected object in ROI was marked as obstacle, as was in case of using IR camera [9].

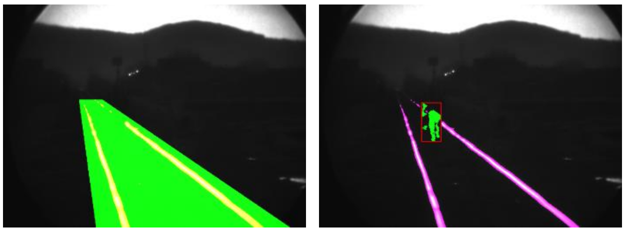

Figure 10. Determined ROI (left), Object marked as obstacles (right) [7]

A set of test scenarios was realized in Babin Potok near city of Prokuplje, Serbia, in night conditions. One of the tested scenarios was random walking of two objects zigzag along the railway infrastructure. This scenario can happen on every unprotected railway.

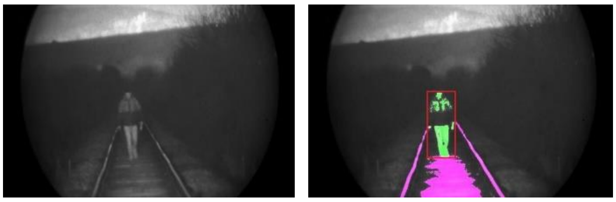

Figure 11. Object in ROI (left), Object marked as obstacle (right) [7]

In the first moment, object was between rail tracks and detected as an obstacle because it was in previously determined ROI (Fig. 11). However, in next moment, same object was out of ROI and was not detected as an obstacle, while another object on right rail track was detected as an obstacle (Fig. 12).

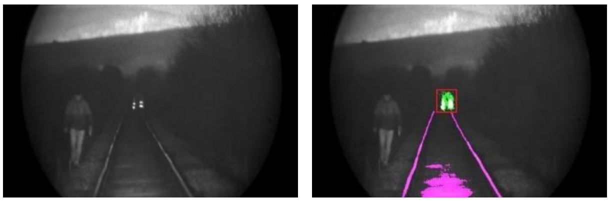

Figure 12. One object out of ROI, another in ROI (left), Only object in ROI marked as obstacle (right) [7]

Experiments and results showed that IR camera and Night vision system coupled with intelligent image processing algorithm can be used for obstacle detection on railway infrastructure at night conditions. Quality of captured images has significant effect on obstacle detection process. On the other side, that quality is strongly dependent on amount of light in environment.

A safe stop requires not only detecting an obstacle but also determining the distance from the locomotive to the detected obstacle. However, there are two types of methods used for measuring and estimating the distance between two objects - active and passive [13]. Active methods are based on the use of sensors (ultrasonic, radar, laser, etc.) that send different types of signals to the object to measure the distance. Passive methods use cameras to receive information from the surrounding environment about the position of the object and thus evaluate the distance from the object to the camera [14].

Homography, also called projectivity, is defined as *invertible mapping h from* P^2 *to itself such that three points* x_1, x_2, *and* x_3 *lie on the same line if and only if* $h(x_1)$, $h(x_2)$, *and* $h(x_3)$ *do* [11]. This definition is given in terms of geometry. An equivalent algebraic definition of projectivity is that *a mapping* $h: P^2 \rightarrow P^2$ *is a projectivity if and only if there exists a non-singular 3×3 matrix H such that for any point in* P^2 *represented by a vector x it is true that* $h(x) = Hx$ [15]. Matrix $\boldsymbol{H}$ is so-called a homogeneous matrix.

For distance estimation it is necessary to calculate homography matrix $\boldsymbol{H}$ and map pixels from one to another image. Calculation of matrix $\boldsymbol{H}$ needs four points, for which coordinates in real world and in image is known. In railway application, points that are intersection of the detected objects and the detected rail tracks were considered as image pixels corresponding to real world coordinates. Mapping of pixels is based on process where a point $\boldsymbol{x}$ from the rail tracks plane is mapped to a point in the image $\boldsymbol{x'}$ according to [7]:

$$\boldsymbol{x'}=\boldsymbol{Hx} \tag{1}$$

where $\boldsymbol{x}$ is the homogeneous vector of the point from the real-world plane, $\boldsymbol{x'}$ is the homogeneous vector of the corresponding point in the image plane and $\boldsymbol{H}$ is 3x3 homography matrix.

The estimation of the distance d_h between the camera and any real-world point from the rail tracks plane can be calculated using of inverse of homography matrix $\boldsymbol{H}$ as [7]:

$$\boldsymbol{x} = \begin{bmatrix} \boldsymbol{x} \\ \boldsymbol{y = d_h} \\ \boldsymbol{1} \end{bmatrix} = \boldsymbol{H^{-1}x'}, \tag{2}$$

By analyzing the presented results in [8, 16, 17], the homography shows a slight increase in error with increasing distance. This indicates the fact that this method does not show good results when the homography matrix is calculated using the coordinates of points that are at great distances from each other. In addition, the main disadvantage of homography is that in the case of a change in level e.g., due to a change in the elevation angle of the camera or a change in the slope of the terrain, it is necessary to recalculate the homography matrix. On the other side, homography method is very sensitive on input image quality, that is dependent on light and weather conditions. Integrating homography method with artificial intelligence may compensate for the shortcomings that have been noticed during use of homography method.

IV. AI Powered Image Fusion

Taking into account all advantages and disadvantages of system with IR camera, Night vision system and homogrpahy method for distance estimation, as well as named experiments and results of obstacle detection on railway infrastructure, it can be noticed that those two systems cannot be used in all conditions – night, low-light and weather. However, as it is not possible to influence illumination and weather conditions, and changes of the hardware - IR camera and night vision system, can be long and expensive, optimization of obstacle detection system can be performed by fusing images from those systems [18]. The main goal of image fusion is to use data from both captured images i.e., object that is not visible on IR image may be visible on image from night vision system. Image fusion can be done in several levels of image processing. At first, images can be fused after capturing in order to obtain as much data as possible. However, at this level, there is possibility of data overlapping that can lead to significant decreasing of image quality. That can cause low quality image at input of image processing algorithm, or even unusable image, thus error in obstacle detection can be much greater than one without fusion. Image fusion can be done after rail track detection in order to more accurate determination of ROI, and those increasing of obstacle detection accuracy. Also, image fusion can be performed after obstacle detection phase, where results from individual detection should be fused. In this new approach, system may be powered by artificial intelligence (AI) tools, and structure may be organized at three levels Fig 13.

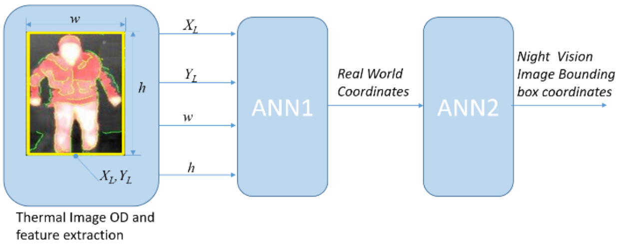

Figure 13. Image fusion system powered by AI

The first level may include: image processing and obstacle detection in IR image. Outputs from this level - X_L and Y_L coordinates in pixels of the centre of bounding box of detected obstacle in the rail track plane and bounding box width w and height h in pixels may be used at next level as inputs in artificial neural network (ANN1). The output from this level may be determined real world coordinates of detected obstacle. Then, next level may include one more artificial neural network (ANN2) where input may be output from previous level – ANN1. Finally, output from ANN2 may be coordinates of bounding box on image from Night vision system. Then, image processing algorithm may be applied on particular part of image.

V. Conclustion

In order to be able to offer customers an economical, flexible and attractive service, the railway must follow the automation trend. Different levels of autonomy are already present in other modes of transport - autonomous road vehicles, autopilots in air and water transport, but also Automated Guided Vehicles (AGV) in warehouses, distribution centers and ports. The constant striving for the improvement of railway traffic through increasing the efficiency, capacity and quality of services requires the use of autonomous train operation (ATO). One of the very important parts of such systems is the Obstacle Detection System. This system must operate in different light conditions because, visibility has great role in accurate and timely detection of obstacles on the rail track and/or in its vicinity.

In this paper, the new approach of image fusion for obstacle detection optimization, is presented. The main idea is to fuse images from IR camera and Night vision system in order to improve accuracy and reliability of obstacle detection at rail tracks and close vicinity. Images are captured by Obstacle Detection System developed in framework of HORIZON 2020 S2R-OC-IP5-01-2015 project "SMart Automation of Railway Transport - SMART". However, there are few limitations: sensors have hardware limitations due to different light and environmental conditions, image processing algorithm for obstacle detection is based on region-based segmentation and dependent on quality of input images, and homography method for estimation of distance from sensors to detected obstacle give variable results. Presented approach includes use of artificial neural networks in combination with homography method for increasing of distance estimation accuracy. Also, image fusion is powered by two artificial neural networks in order to do feature and data extraction from IR image and get coordinates of bounding box on image from Night vision system.

Artificial intelligence has a great potential for image fusion. Also, it is applicable for distorted images and in in low-light scenarios and difficult weather conditions. In addition, systems powered by artificial intelligence can significantly improve image processing speed by mapping bounding box from one type of image to another. This enables faster processing of all images due creating bounding boxes only on, for example IR image, while on image from Night vision system bounding box will be mapped based on results from IR image and without image processing, and vice versa. It can help in preparation of big CNN training database for night/thermal image understanding, feature extracting and optimizing obstacle detection process through increasing accuracy and quality of, and thus to improve safety and reliability of the SMART Obstacle Detection System.

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