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SMART concept of an integrated multi-sensory on-board system for obstacle recognition

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Abstract

In this paper, a conceptual solution and preliminary results regarding the integrated multi-sensory on-board obstacle detection (OD) system are presented. The presented system is under development within the project "SMART-SMart Automation of Rail Transport", which is funded under the H2020-Shift2Rail-RIA funding scheme. The proposed SMART conceptual solution will provide prototype hardware and software algorithms for OD. The system will combine different vision technologies: thermal camera, night vision sensor (camera augmented with image intensifier), multi stereo-vision system and laser scanner in order to create a sensor fusion system for mid (up to 200 m) and long range (up to 1000 m) obstacle detection, which is independent of light and weather conditions. The overall requirements for the integrated multi-sensory object recognition system are described, and preliminary results of processing of individual sensor data are given.

Keywords: Automation of railway cargo haul; Autonomous obstacle detection.

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1. Introduction

The project "SMART-SMart Automation of Rail Transport" is funded by the Shift2Rail Joint Undertaking under the European Union's Horizon 2020 research and innovation programme (http://www.smartrail-automation-project.net). The main goal of this project is to increase the effectiveness and capacity of rail freight through the contribution to automation of railway cargo haul at European railways by developing of:

- a prototype of an autonomous obstacle detection system, and
- a real-time marshalling yard management system.

In this paper, the focus is on a conceptual solution and preliminary results regarding the integrated multi-sensory on-board obstacle detection (OD) system.

According to the Shift2Rail Multi-Annual Action Plan-MAAP, Shift2Rail (2015), one key challenge, which has so far hindered automation of rail freight systems, is the lack of a safe and reliable on-board obstacle detection system for freight trains within existing infrastructure. Project SMART will contribute to tackling this challenge, and so contribute to the long-term vision for an autonomous rail freight system, by the development, implementation and evaluation of a prototype integrated on-board multi-sensor system for reliable detection of potential obstacles on rail tracks. The obstacle detection solution resulting from these activities should be ready for later integration into the automated freight train described in the MAAP, Shift2Rail (2015). As such, the SMART project is one of the Shift2Rail Innovation Programme 5 (IP5) projects and it will directly contribute to the expected impact set out in the Shift2Rail work program under the topic S2R-OC-IP5-01-2015 – "Freight Automation on lines and in yards", to introduce the automation of rail freight operations.

The presented solution for autonomous obstacle-detection on rail tracks ahead of a train, which incorporates multiple sensors, is not a new solution. Different combination of sensors, such as stereo vision, mono cameras, radar and laser, were already used in related work, e. g. Weichselbaum et al. (2013). However, the combinations of sensors used to date achieved relatively short range obstacle detection, that is, up to 100 m. Also, these combinations were mostly used for day vision. Noticeable little work has been published on night vision for obstacle detection, e. g. in Forth et al. (2015) a night-vision device including a thermal camera was presented. The SMART project will advance state-of-the-art by developing a prototype OD system which will integrate a night vision sensor (a camera augmented with image intensifier) with a thermal camera, multi stereo-vision system and a laser scanner. The SMART OD system will therefore be a novel fully integrated multi-sensor on-board system for mid (up to 200 m) and long range (up to 1000 m) obstacle detection, which can operate in day and night conditions as well as in poor visibility conditions.

The SMART project is a collaborative project employing distributed development, so different sensor modules are being developed by different geographically distributed partners. This paper reflects the status of the OD system's development during the first project year. This paper presents preliminary results achieved in experiments conducted with individual sensors, stereo vision, a laser scanner and a thermal camera, on different test sites. At the time of performing the presented experiments, a night vision sensor for inclusion in the OD system was still under development and so was not available for use in the presented experiments. However, the preliminary results on reconstructions of objects on the rail tracks achieved with the available individual sensors illustrate some open problems and suggest directions for further development of the fully integrated on-board multi-sensory system.

2. SMART obstacle detection system

The SMART solution for autonomous obstacle detection (OD) will provide prototype hardware and software algorithms for OD. As illustrated in Fig. 1, the system will combine different vision technologies: thermal camera, night vision sensor (camera augmented with image intensifier), multi stereo-vision system (cameras C1, C2 and C3) and laser scanner in order to create a sensor fusion system for mid (up to 200 m) and long range (up to 1000 m) obstacle detection, which is independent of light and weather conditions.

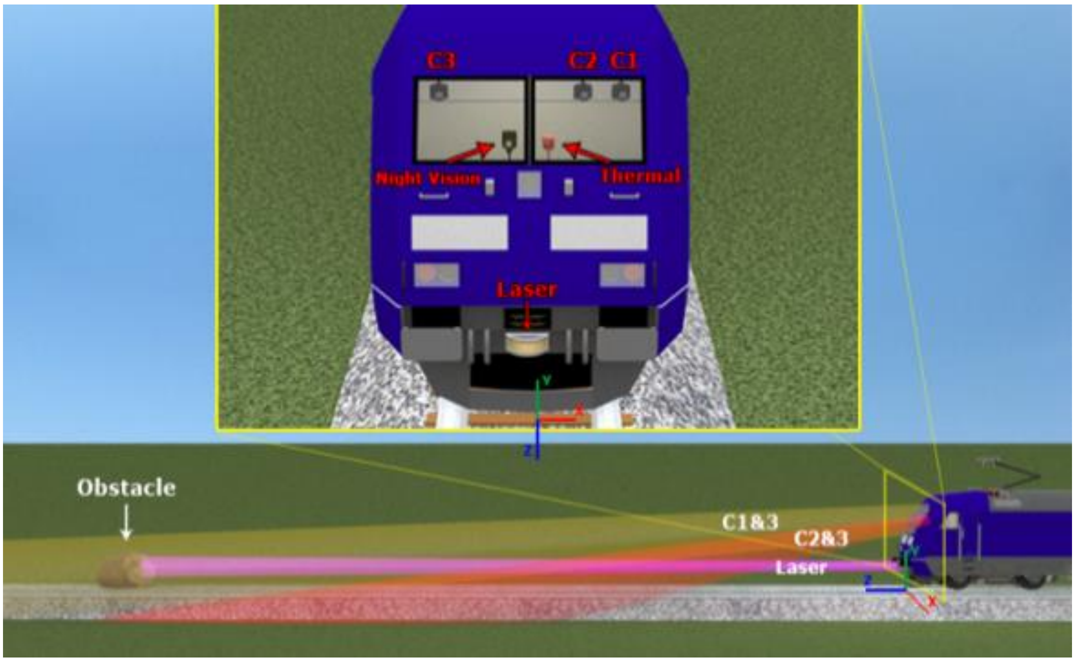


Fig. 1 Concept of the SMART multi-sensor OD system (top) Front view of the sensors mounted on a locomotive and the attached world coordinate system as needed for sensors calibration; (bottom) Side view of the range sensors and an obstacle detection scene

The main idea behind the multi-sensory system is to fuse the sensor data as sensors individually are not yet powerful enough to deal with complex obstacle detection tasks in all the SMART defined application scenarios, which include day and night operation and operation in poor visibility condition. Because of this, the development of an adequate data fusion system, which effectively combines data streams from multiple sensors, is required. The layout of the architecture of the integrated SMART obstacle detection system is shown in Fig. 2.

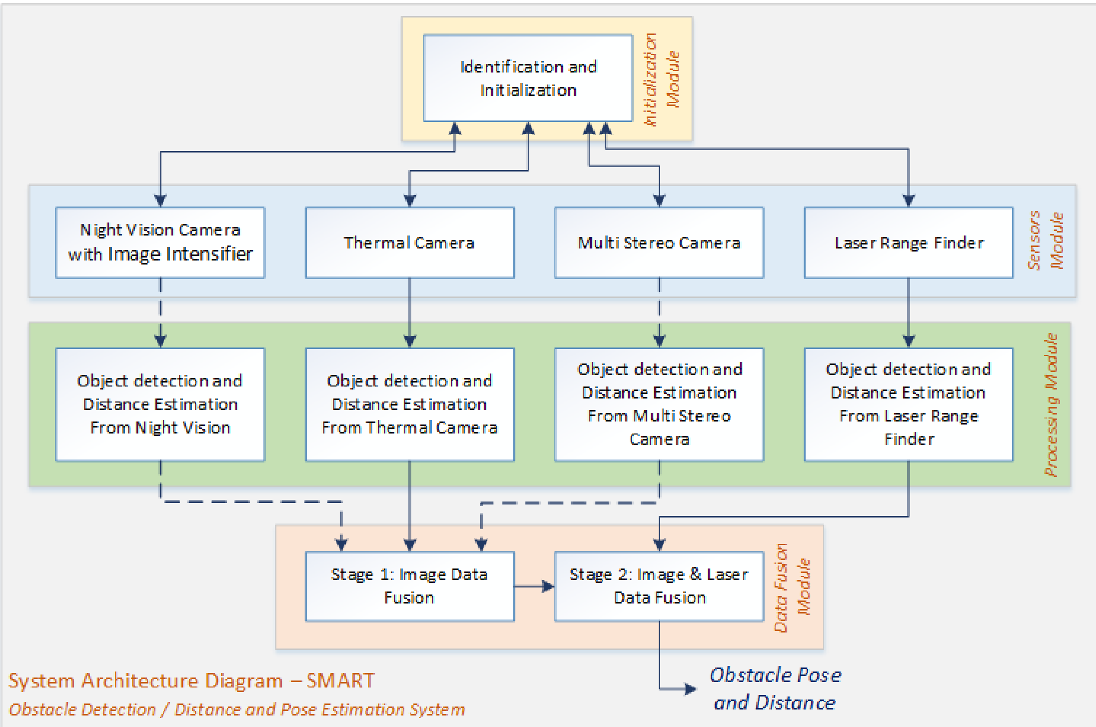


Fig. 2 Layout of the architecture of the SMART integrated multi-sensory system

The data fusion approach will be designed based on sensor data availability. Namely, independently of the illumination condition, sensor data from the thermal camera and laser scanner will be always available (solid line in Fig. 2). In contrast to that, the stereo camera system fails to generate data under poor illumination conditions, and the night vision camera can not operate during the day (denoted with dashed lines in Fig. 2). In order to perform sensor fusion, a calibration procedure will be performed with respect to an appropriately defined world coordinate system, such as the one illustrated in Fig. 1. The calibration procedure will result in sensors' calibration matrices, which will be used for data fusion. After obtaining fused data, based on the individual advantages of each sensor, the resulting data stream will be used for detection of obstacles on the rail tracks and for calculation of the distances from the locomotive to detected obstacles.

3. Evaluation of the SMART obstacle detection system

During the project lifetime, the SMART integrated OD system will be tested in several evaluation scenarios. One of the scenarios will be realised on the testing track of the Department for Rail Vehicles and Transport Systems (IFS) of RWTH Aachen, one of the SMART partners. There will be also several possibilities to evaluate the developed OD prototype on Serbian railways network using the vehicle, the electric locomotive ŽS series 444, owned by "Serbia Cargo" (http://srbcargo.rs). The assuring of permissions for all the evaluation tests will be responsibility of the University of Niš, one of the SMART partners.

The SMART project is a collaborative project employing distributed development, so different sensor modules are being developed by different geographically distributed partners. In next sessions, preliminary results achieved with individual sensors on different test sites are given. In the first evaluation scenario, multi-stereo cameras and a laser sensor module, developed by the SMART partner Institute of Automation (IAT) at University of Bremen, were used. In the second evaluation scenario, one of two sensor modules to be developed by Serbian SMART partners, HARDER digital SOVA and University of Niš, thermal camera module, was used.

3.1. Evaluation scenario 1 – Preliminary results

For the evaluation of the SMART OD system on the testing track of the Department for Rail Vehicles and Transport Systems (IFS) of RWTH Aachen, the IFS Research Vehicle (former CargoMover AGV) (Fig. 3(a)) will be used.

a b

Fig. 3 (a) IFS Research Vehicle used in SMART evaluation scenario; (b) Sensors mounted on the front rail of the IFS Research Vehicle for the purpose of preliminary tests

This evaluation scenario will be used in the SMART framework for: specification of the evaluation methodology, metrics and procedures; initial evaluation of developed technologies during the development stage; and technical validation of the OD prototype for distances up to 200 m.

In this paper, the results of preliminary tests performed with the multi-stereo vision system and laser scanner are presented. The sensors, three mono cameras (C1, C2 and C3) and a laser scanner, were mounted on the front rail of the IFS Research Vehicle as shown in Fig. 3(b).

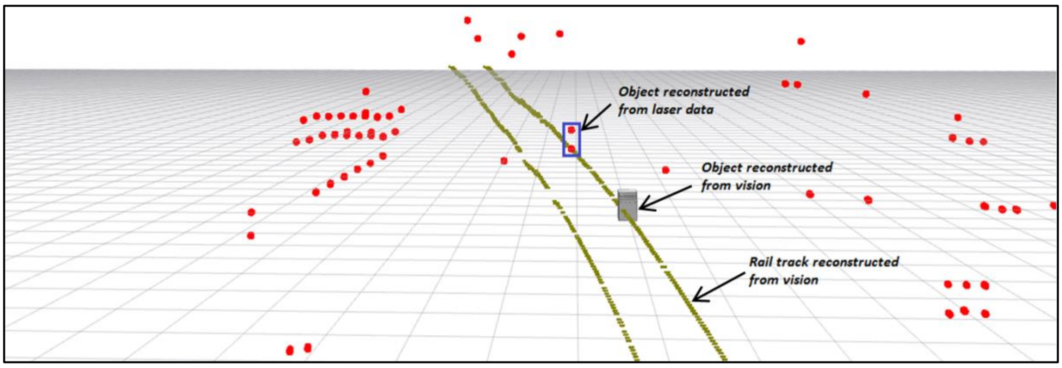
In order to meet the main requirement to develop a sensory system for reliable mid (up to 200 m) and long range (up to 1000 m) obstacle detection ahead of the locomotive, a multi-baseline camera system has been developed. Three mono cameras (C1, C2 and C3 in Fig. 3(b)) form two pairs of stereo cameras, C1 and C2 with shorter baseline and C1 and C3 with longer baseline. The preliminary tests presented in this paper concern initial determination of appropriate lengths of baselines to be used in the final system prototype. The preliminary results of stereo-vision based 3D reconstruction were obtained in experiments where the shorter baseline was 0.4 m and the longer baseline was 1.05 m. As shown in Fig. 3(b), a laser scanner was placed between cameras C2 and C3. The laser range finder was placed at the same elevation as the cameras to allow one of the requirements of the final prototype to be fulfilled, namely that all sensors should be located in a housing that could be easily mounted and demounted from the test locomotive (test-vehicle). This requirement influences the field of view of the laser scanner (LD_MRS_3D_LiDAR). In order to fuse data from all the sensors used in the presented preliminary experiments, at first the monocular and stereo calibration of the cameras was done using the "chessboard" pattern, as is usual in the stereo-vision community Hartley et al. (2000), as shown in the photo in Fig. 4(a). The performed calibration assumes also the rectifying and undistorting of images, which results in the images as cameras would be fully parallel. The calibration of the laser sensor with respect to the left camera (C1) was done using the known geometry of the sensor configuration, i.e. known distance between the laser and the left camera, as it was considered that the world coordinate system was aligned with the coordinate system of this camera. The rectified image of the left camera (C1) is given in Fig. 4(b). As can be seen, the scene in front of the sensors to be reconstructed was the scene of the rail tracks with an object (a suitcase) placed onto the rail track to imitate a possible obstacle in front of the test vehicle. The test vehicle was static when the sensor data was recorded.

The starting point of development of the stereo-vision based obstacle detection system was previous work by the SMART partner IAT on autonomous obstacle detection for a driver assistance system in the car industry Leu et al. (2012). After detecting the rail track and object in 2D stereo images of the C1 and C2 camera by applying some of established segmentation methods of 2D image processing, so-called 2D to 3D mapping was done. This mapping is based on the knowledge of the corresponding points detected in stereo images, of the baseline and of the focal length of stereo cameras. Starting from that knowledge, the 2D to 3D mapping was performed as in Leu et al. (2012) and Petrović et al. (2013). The result of the performed 2D to 3D mapping were the offline calculated 3D coordinates of the points of detected rail tracks as well as of the object placed onto the rail track with respect to the coordinate system of the left stereo camera (C1). The calculated 3D points were plotted together with the 3D points extracted from the laser scanner data, as shown in Fig. 4(c). Fig. 4(c) was obtained using the Rviz ROS Visualization. The object and the rail tracks reconstructed using vision sensors are shown in gray and brown colour respectively, and the laser data points are shown in red colour. After merging the 3D points reconstructed by both type of sensors, vision and laser, the laser data points which were close to or between the rail tracks were considered as points belonging to significant object as represents with the blue box in Fig. 4(c).

The distance of the object measured by the laser scanner with respect to world coordinate system (left camera) was 54.947 m which is, as expected, comparable with the measured real distance of the object of 55 m. The distance of the object with respect to the left camera as reconstructed from vision data was 51.278 m. The error in vision-based distance calculation is a consequence of uncertainty in 2D images processing of rectified images, and in particular of uncertainty in finding the stereo corresponding points. However, in spite of this error, the presented preliminary results illustrated the necessity of merging the data of different sensor technologies. Namely, although laser scanners have the advantage of direct and accurate measuring of distances to obstacles, vision gives more detailed information about the surrounding environment. In the given configuration of sensors, the laser scanner possesses limitation due to narrow vertical field of view and sparse point cloud due to low resolution, which makes it difficult to detect the rail tracks from laser scanner data. Because of this, the so-called region of interest (ROI) defined by vision-based scene reconstruction fused with the laser data points enabled finding of the important laser data points.

a

b



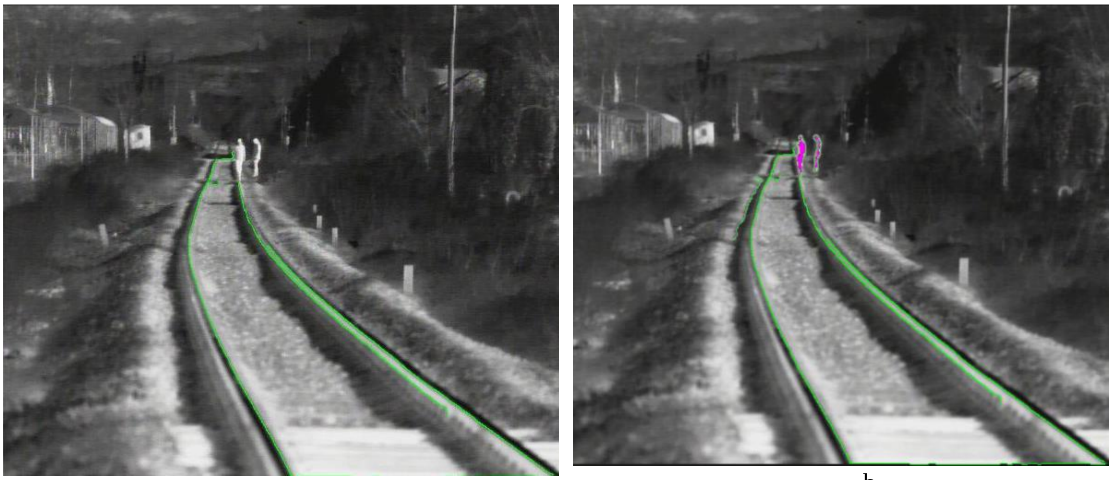
c

Fig. 4 (a) Calibration of the multi-sensory system mounted on the front rail of the IFS Research Vehicle; (b) Image of the left camera of the scene in front of the IFS Research Vehicle; (c) Visualisation of 3D scene points as detected by laser scanner and 3D scene points as reconstructed from vision data

3.2. Evaluation scenario 2 – Preliminary results

The first experiments with thermal camera were performed on the closed rail track section at dusk; that is, under poor light conditions. The used FLIR F series thermal camera (FLIR Tau 2 thermal imaging cameras) was mounted on a static stand, viewing the scene of rail tracks involving the unmarked and unilluminated crossing 75 m away from the camera stand. Two SMART team members imitated two pedestrians crossing the rail tracks on that crossing. A thermal image of the scene is given in Fig. 5(a). As can be seen, this image is overlaid with the detected rail tracks, as depicted with green lines.

The starting point of development of the thermal image processing module was previous work by the SMART partner University of Niš on thermal image-based human detection and tracking Ćirić et al. (2016). After detection of the rail tracks using an established edge segmentation method based on pixel values discontinuity, the significant break in the detected rail tracks was detected. This break was considered as an object on the rail track, a potential obstacle. In the performed experiments the detected object was the pedestrian crossing the rail tracks at 75 m distance from the camera stand, as illustrated in Fig. 5(b) with pink colour.



a b

Fig. 5 (a) Thermal image of unilluminated rail crossing during night with rail tracks detected; (b) Detected object on the rail track

In order to estimate the distance between the camera and the detected potential obstacle, a homography based method was performed as in Hartley et al. (2000). A homography matrix H was calculated which defined mapping between two planes, camera image plane and rail tracks plane. Using the calculated homography matrix H, the distance between the camera stand and the point on the rail tracks belonging to detected object (beginning of the significant break in the rail track) was estimated as being 68,42 m.

The error in thermal camera-based distance estimation is a consequence of uncertainty in homography matrix H calculation as well as object detection (detection of exact point on the rail track where the object was). In future SMART development, the estimation method will be improved using more advanced processing methods. However, in spite of the error in thermal-image based distance estimation, the presented preliminary results illustrated the necessity of merging the data of different sensor technologies. Namely, using the redundancy of the final multi-sensor integrated system, the rail tracks and objects detection in thermal images will be merged with rail tracks and objects detection in stereo camera images to increase the object detection accuracy and so to increase the accuracy of definition of region of interest (ROI) to support segmentation of laser data point cloud. On the other hand, improved segmentation of laser data point cloud will lead to accurate calculation of distances between the vehicle and the significant objects.

4. Conclusion

In this paper, a concept solution of a multi-sensory on-board system for reliable detection of obstacles on the rail tracks ahead of the locomotive, to be developed within H2020 Shift2Rail SMART project, is presented. Preliminary results of the experiments performed with some of the individual sensors that will finally be integrated into SMART prototype, stereo vision, a laser scanner and a thermal camera, are given. These results indicate necessity of using different, suitably chosen sensors so to utilise the specific advantages of each particular sensor

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