Reliable Obstacle Detection for Smart Automation of Rail Transport

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Summary

This paper presents the obstacle detection scheme being developed within the project “SMART-SMart Automation of Rail Transport”, which is funded by the Shift2Rail Joint Undertaking under the European Union’s Horizon 2020 research and innovation programme. The conceptual solution and preliminary results regarding the integrated multi-sensory on-board obstacle detection system are presented.

Keywords: Automation of railway cargo haul; Autonomous obstacle detection

1 Introduction

The main goal of the project “SMART-SMart Automation of Rail Transport” is to increase the effectiveness and capacity of rail freight through the contribution to automation of railway cargo haul at European railways. According to the Shift2Rail Multi-Annual Action Plan-MAAP [1] 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.
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 Figure 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.

*Figure 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 Figure 2.
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 Figure 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 Figure 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 Figure 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. For the evaluation of the SMART OD system, the IFS Research Vehicle (former CargoMover AGV) (Figure 3) will be used.

![Figure 3: IFS Research Vehicle used in SMART evaluation scenario](image)

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 Figure 4. The used sensors are SMART sensor modules, developed by the SMART partner Institute of Automation (IAT) at University of Bremen, which will be integrated into the final prototype. The SMART project is a collaborative project employing distributed development, so different sensor modules are being developed by different geographically distributed partners. At the moment of performing the presented experiments, the night vision and thermal vision sensors were still under development by two Serbian SMART partners, HARDER digital SOVA and Faculty of Mechanical Engineering of University of Niš, and so were not available for use in the presented experiments. However, the preliminary results of the fusion of available sensors
illustrated some open problems and suggested directions for further development of the fully integrated on-board multi-sensory system.

Figure 4: Sensors mounted on the front rail of the IFS Research Vehicle for the purpose of preliminary tests

3.1 Preliminary results

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 Figure 4) 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 Figure 4, a laser scanner [5] 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 [5]. 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 [6], as shown in the photo in Figure 5(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 Figure 5(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 [2]. 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 [2] and [3]. 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 Figure 5(c). Figure 5(c) was obtained using the Rviz (ROS Visualization) [4]. 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 Figure 5(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.

4 Concluding part

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 sensor modules that will finally be integrated into SMART prototype 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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Figure 5: Calibration of the multi-sensory system mounted on the front rail of the IFS Research Vehicle (a). Image of the left camera of the scene in front of the IFS Research Vehicle (b). Visualisation of 3D scene points as detected by laser scanner and 3D scene points as reconstructed from vision data (c).
Literature


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