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Data Analysis of the APROSYS Side Pre-Crash Sensing System

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Abstract— **The EU funded Integrated Project APROSYS aims to increase the safety of road users. Among others, Subproject 6 (SP6) "Intelligent Safety Systems" develops, realises and verifies novel side pre-crash systems.**

Previously we presented an application analysis, the resulting system definition and the selection of sensors of a suitable side sensing system. The sensing system is based on a stereo video rig and a short-range radar subsystem.

Now, a prototype system has been built up and first data were taken. These were analysed, a data fusion module was implemented and the data analysis algorithms were optimised with respect to the specific requirements of the side pre-crash application.

I. Introduction

WHILE front and side crashes occur with comparable frequency, the risk of an injury from a side crash is much higher. This is due to the close distance between an occupant and an incoming object. For the same reason, existing in-crash sensing technology does not allow for timely deployment of collision mitigation measures.

In the Subproject 6 (SP6) "Intelligent Safety Systems" of the European Integrated Project APROSYS (**A**dvanced **PRO**tection **SYS**tems, see [1]), a technology showcase will be realised showing the potential of a combination of advanced technologies in an integrated side crash protection system. This system will consist of a sensing system and an actuator system. The actuator system applies shape memory alloys to realise a reversible and adaptive actuator which is also faster than electromagnetic devices.

This paper's focus is on the sensing system which was designed on the basis of commercially available components that will only be adapted to the specific needs of the application. The sensing system consists of

- a radar network subsystem consisting of two radar sensors,
- a visible light stereo camera subsystem and
- a fusion module.

The derivation of the system definition from accident analyses has been described previously [2]. The setup of the sensing system including the communication architecture of the sensing subsystems is described in Section II. The output data of the subsystems and the concept how to associate video and radar data is described in Section III. The data of a real world scenario is analysed in detail in Section IV. Section V summarises and gives an outlook to the work ahead.

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II. The Sensing System

The side sensing system of APROSYS SP6 has to determine correctly the distance and relative speed of potential bullet objects. To allow for an adaptive actuator operation, additional information about size and shape has to be provided. All this information has to be available for objects in a distance range of up to 20 m and an azimuth range of 80° under all weather and illumination conditions.

Special attention must also be paid to correct and fast detection. Tracking of objects must be performed down to extremely low distances of some 10 cm.

To cope with the requirements of precise distance and range measurement, and to comply with the all-weather operation requirement, we selected a radar sensor network for side sensing. In order to provide reliable object shape information, we added a video system to the radar sensors. The combined sensor system has thus good resolution in range (due to the radar sensors) as well as in azimuth and elevation (due to the video sensors).

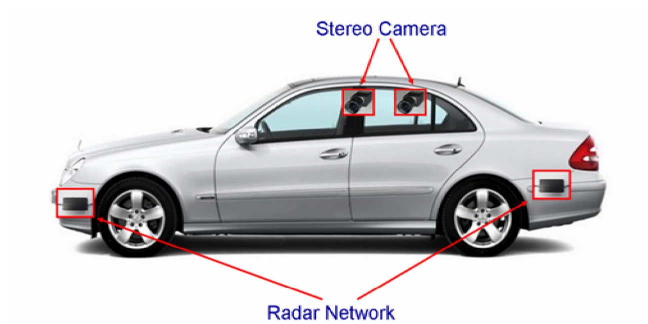

Fig. 1. The sensing system was integrated into a test vehicle looking to the left side. It consists of two radar sensors integrated under the front and the rear bumper and a stereo rig in the rear window.

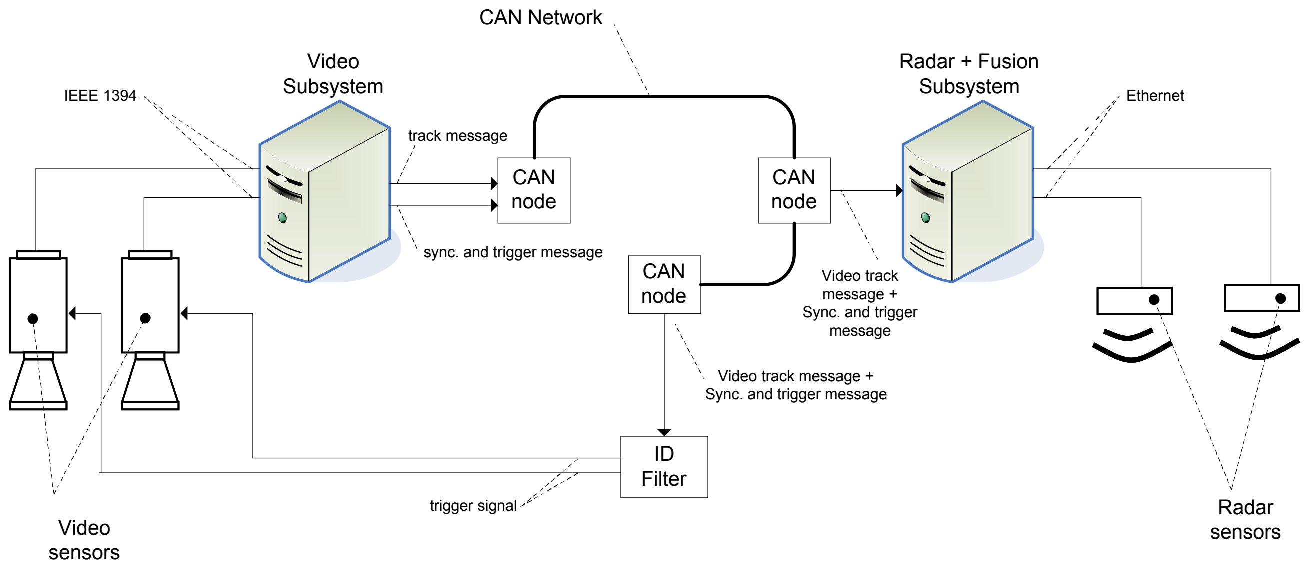

Fig. 2. The communication system used for exchange of data. One PC processes Video data, another one processes radar data and performs the data fusion. The video cameras are triggered by CAN messages, which are also received by the fusion subsystem. This way, the fusion system can relate the video

A. Radar Subsystem

The radar subsystem will be based on a commercially available Short Range Radar. It combines an FMCW radar principle with a phase comparison monopulse principle. Thus it allows for simultaneous measurement of range, radial velocity and azimuth.

For flexibility, the radar processing is performed on a PC. The individual measurements are tracked by an extended Kalman filter [3] taking into account the non-linear transformation functions from a Cartesian state space into its measurement space.

B. Video Subsystem

The Video Subsystem is based on a stereo algorithm which builds sparse disparity maps. It is supported by an optical flow based point tracking. Resulting point clouds in 3D space are clustered together to object hypotheses, which are then classified and tracked. Tracking is performed using an extended Kalman filter.

C. Communication System

The fusion module is integrated into the radar processing PC as shown in Fig. 2. The communication between the video and fusion subsystems is performed via CAN bus. CAN messages are used to transmit video object hypotheses to the fusion system. An object hypothesis contains an object number, a classification (e.g. truck, car, motorcycle), position, dimension, orientation and velocity.
The video PC generates synchronisation messages that contain the system time of the video PC. This message is received by both the fusion system and a dedicated hardware referred to as “ID Filter” in Fig. 2. The ID Filter makes sure that the image acquisition by the video cameras is performed synchronously, and by the time the synchronization message is transferred over the CAN bus. The synchronization message is also received by the fusion system and at that time given a precisely known time on the fusion system, in the following called "fusion time". As the radar sensors are triggered on the same PC, the fusion time of a radar measurement is also known. Hence, the systems can run independently from each other and an asynchronous fusion can be performed.

III. The Fusion Module

The task to combine radar and video data can be subdivided into two aspects. Firstly, radar- and video-tracked objects have to be associated to each other in order to enhance precision and reliability of the individual tracks. Secondly, the corresponding fused objects have to be classified.

A. Data Association and Tracking

The data from radar and video subsystem are “pre-tracked”, i.e. object hypotheses have been formulated and are tracked within each subsystem.

The objects reported by the video system (cars, motorcycles etc.) can be modelled in the simplest approach as cuboids. Their projection to the x-y-plane, which is the most important for a later risk assessment, is shown in Fig. 3. The error due to usual cars not having rectangular shape is expected to be small, but has to be studied and quantified.

The video system reports the position of the center of gravity of the potential bullet object, as well as its width, length and height. Also the orientation phi with respect to the x-axis is measured. From this information, the position of the closest edge of the object can be computed. This way, the cuboid is defined unambiguously. The radar system, however, reports mainly information about radar reflection points of the scene objects.

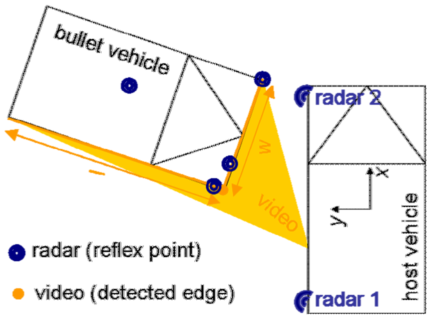

Fig. 3. Schematic view of an impacting object and its parameters measured by the radar and the video system. The radar sensors measure radar reflection points, while the stereo video system reports a cuboid with a certain width w, length l, position and orientation.

The task of the fusion module is to associate these different types of information.

In general, several radar reflection points will be at fixed positions on the bullet vehicle, although mostly only for short periods of time. This holds true in particular with large trucks or vans (LTVs). These can be associated to the video reported cuboid by their x- and y- positions. As the radar reflection points are fixed on the bullet vehicle, they can be used to enhance the velocity estimation of the object. However, radar reflection points at higher distances than the closest edge usually tend to appear and disappear intermittently. Also, the possibility of sliding and jumping radar reflection points has to be studied.

There is a high probability that there will be a radar reflection point near to the closest edge of the bullet vehicle. Since the closest edge is available from the video subsystem, the range precision of the camera can be substantially enhanced. An impact position and time relevant for the detection of a side impact can be determined based on this edge only.

Thus, radar and video objects can be associated using their positions. If a radar reflex point is inside the cuboid reported by the video system, it is associated. Here, the measurement accuracies have to be taken into account. This way, it is possible in particular to have more than one radar reflex point per video object.

Using these concepts the combined tracking can be more stable than the individual tracks e.g. when a radar track is present all the time and a video track can only be associated from time to time or vice versa.

IV. Data Analysis of a Specific Scenario

The complete sensing system was put into operation and calibration datasets were taken for spatial and temporal alignment of the two sensor systems.

Several real-world scenarios were taken in order to characterise the performance of the sensing system. One of these will be detailed in the following.

The host vehicle carrying the sensing system on the left side stood waiting at a junction with traffic ongoing from left to right as depicted in Fig. 4.

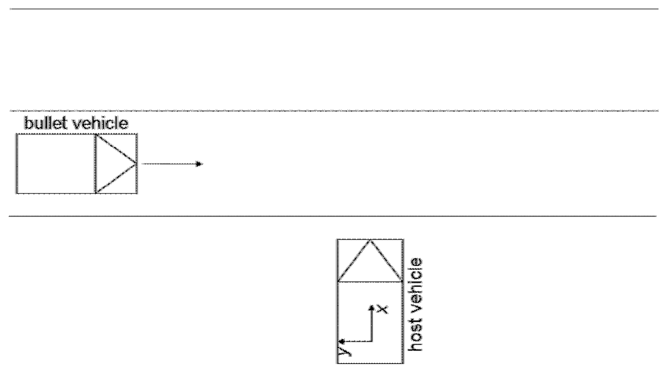

Fig. 4. Typical traffic scenario, when the side impact protection system has to show high performance: the host vehicle carrying the sensing system waits at a junction in order to give way to traffic passing from left to right.

Fig. 5 shows an image of this scene taken the left camera of the stereo rig. The blue points indicate stereo correspondences and cover a passenger car, the potential bullet vehicle in this scenario.

Fig. 5. Image of the left camera of the stereo rig taken at fusion time 480.026 s. The blue points indicate pixels, for which correspondences in the right image were found and hence 3D-information is available.

The fusion application displays the sensor data from both sensing systems in a bird's eye view (Fig. 6). As the video system is slower, i.e. it has a longer cycle time, the velocity reported by the video subsystem is used to extrapolate the video objects to the time, when the last radar measurement was taken. The video object is measured with the correct position and velocity, while its orientation and size are slightly wrong. Nevertheless, the radar reflection points are inside the video object and can thus be associated.

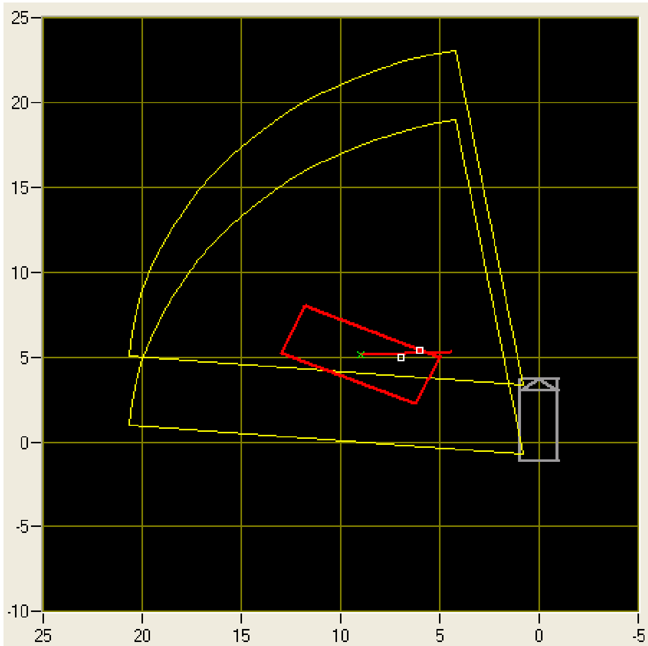

Fig. 6. Bird's eye view of the scene as reported by the sensing systems at fusion time 480.520. The coordinate system has its origin in the centre of the rear axis of the host car, which is indicated. The fields of view of the two radar sensors are indicated as segments. The red rectangle is the video object hypothesis with a line from its centre indicating the velocity by pointing at where the centre is expected to be after one second. The white points are radar reflections.

In Fig. 7, the measured x and y positions of video and radar are plotted versus the fusion time. While the video object and the radar reflection points stay at the same x, y decreases as the passenger car approaches. Because the bullet vehicle misses the host car, this goes on until the bullet vehicle leaves the field of view of the sensing system The sensing systems report measurements which agree within their standard deviations, no significant disagreements are visible. Especially in the velocity plots, the converging errors of the radar reflections are visible. There are three radar reflections, which have to be tracked, while the video 3D points are clustered to one object during the observation time. The velocity estimate v_y for the object derived by the video subsystem appears to be slightly biased. For both sensing systems it is a challenging task to cope with large azimuthal velocities. The velocity $v_y = -10$ m/s in this case is in the beginning mainly radial and becomes more and more azimuthal. Both systems have been adapted to reliably track objects with such movements.

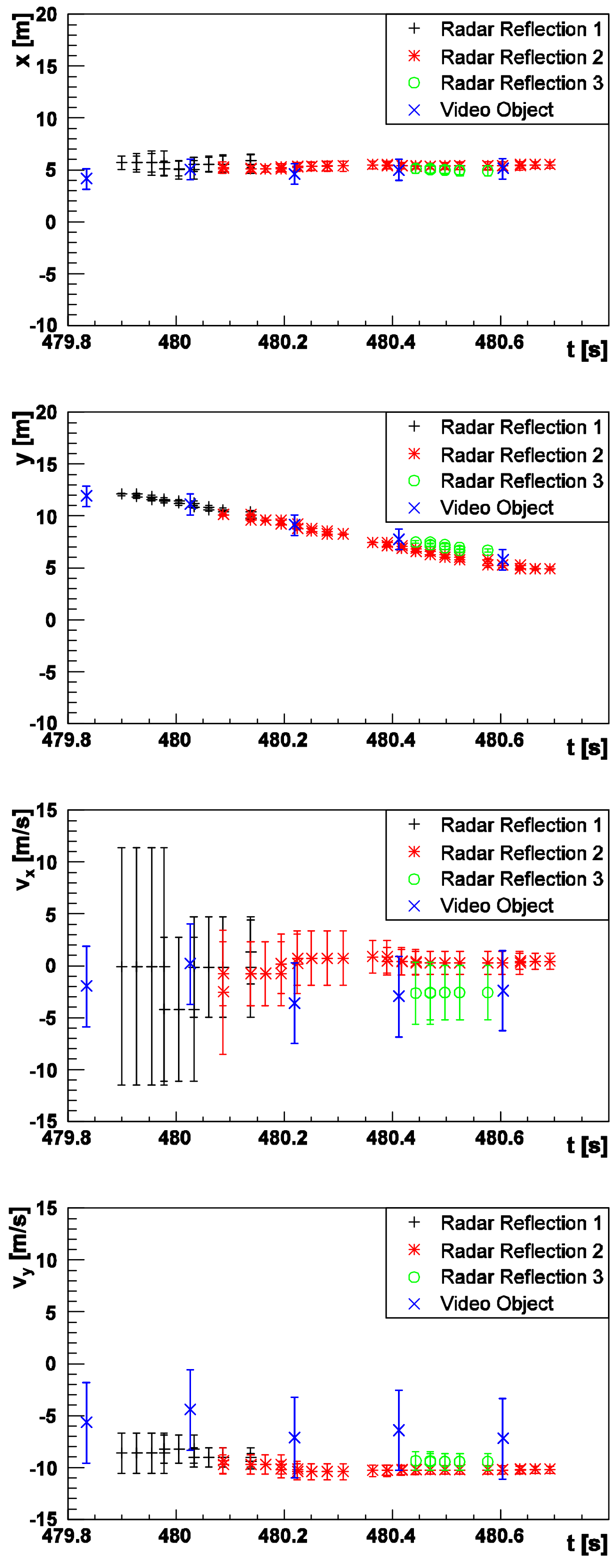

Fig. 7. Measured x and y positions of video and radar system versus fusion time and the corresponding velocities. The error bars indicate standard deviation errors obtained from the tracking algorithms. The two radar sensors run simultaneously. Thus sometimes, there are two updates of a radar reflection at the same time.

V. Summary and OUTLOOK

After deriving the system concept from accident analysis, the sensing system of the integrated APROSYS SP6 side impact protection system was built up, calibrated and first real-world data were taken. The sensing system consists of a video and a radar subsystem, which are fused in order to benefit from their complementary advantages.

Both systems can reliably track possibly impacting objects. The fusion module relates the measurements of both systems in time and space in real-time. It is thus able to provide high quality data to a decision module with the high update rates required for a pre-crash system. The video system will still be optimised to realise higher update rates.

At a later stage, the decision module decides on an imminent collision and eventually triggers actuators adaptively, depending on e.g. speed and impact point of the impacting object.

In the final phase of the project an extensive test suite will be performed. It has already started with a sensor system test in a crash facility [4]. It will proceed with defined scenarios with critical objects in a steering robot laboratory and a false alarm analysis in real traffic [5]. Then, statistical measures are obtained, characterising the decision quality in terms of impact detection efficiency and false alarm rate.

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