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DEVELOPMENT OF A COOPERATIVE ESAFETY-SYSTEM USING COMMUNICATION AND LOCALIZATION

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Abstract: *The core concept of the project, presented in this paper, is to enable the future availability of a modular cooperative system that will bring together sensor and communication technologies permitting to all road users (vehicles, motorcycles, bicycles, pedestrians) to take an active part in the reduction of the number of accidents that involve vulnerable road users. For this, legacy detection technologies, such as infrared or radar are enhanced by a RF-based communication. This paper shows the results of a system development in hardware and software.*

Keywords: *Cooperative System, Localization, Ranging, RF, Time of Flight, eSafety*

1. INTRODUCTION

Road accidents in the twenty-seven European countries involving vulnerable road users are still an unacceptable number. Various projects are carried out for research and development aimed at the design and development of a system for the prevention of accidents that involve vulnerable road users in urban and extra-urban areas [1]. In legacy systems, optical or other measurement principles were used (infrared, radar, image processing). The results may be largely improved through the use of cooperative systems, being networked together. This is already the idea behind car-2-car-communication [2]. However, this idea may be extended to vulnerable road user (VRU), e.g. pedestrians, bicyclists, power two wheelers [3]. Apart from an increased quality of information and a remarkably reduced amount of false alerts, a good number of additional user scenarios can be covered.

2. USE CASES AND PREVIOUS WORK

The communication between vehicles (vehicle2vehicle or V2V), and between vehicles and infrastructure (vehicle2infrastructure or V2I) is already quite well established (e.g. within [2]). Until now, much less attention is paid to the integration of so called vulnerable road users (VRU), whose relative number of blessed persons is growing due to the successful efforts for in-car safety.

Current approaches include:

- radar detection, which a strong incline to metallic objects, instead of human beings.
- optical recognition is increasingly used [5] with the help of optical or infrared cameras. Previous EC projects in this field were PROTECTOR and SAVE-U [6]. However, those optical recognition technologies are not mature for pedestrian protection [12], yet.
- RF-based communication between vehicles and pedestrians is limited to the exchange of positioning data, e.g. [7] or higher-level management data [8].
- positioning data may be derived from self-positioning, i.e. from satellite-based systems, i.e. GPS- or Galileo. However, the accuracy from civil systems for intra-urban scenarios is still very limited [9].

Yet, most cooperative systems include only different sensor systems, such as [10]. There is only one attempt known to the authors, which fuses communication and localization [11]. Fortunately, this project has close links to our WATCH-OVER project [3], which adds a communication flow between the vehicle and the VRU to the localization. Currently, pure sensor-based systems do not reliably cover urban scenarios. As an effect, the following (selected) use cases are targeted, which cannot be covered with legacy technologies and which provides a statistically important amount of blessed VRU [4].

- VRU crossing the road from the right to the left (or from the left to the right) (cf. fig. 1)

- VRU crossing the road from the right to the left (or from the left to the right) occluded from parked or stopped cars or other obstacles (cf. fig. 2).
- Vehicle turning left at an intersection, VRU crossing the road from the right to the left (or from the left to the right).
- Vehicle turning right at an intersection, VRU crossing the road from the right to the left (or from the left to the right).
- Vehicle on a crossroad, VRU crossing the road from the right (or from the left).

A complete of use cases can be depicted at [4].

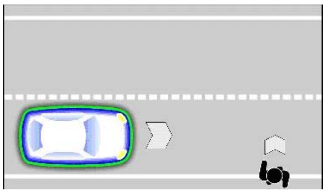

Fig. 1. – Selected scenarios with a high estimated occurrence and a consequent high relevance for road safety [4]: Pedestrian (or cyclist) crossing the road from the right to the left.

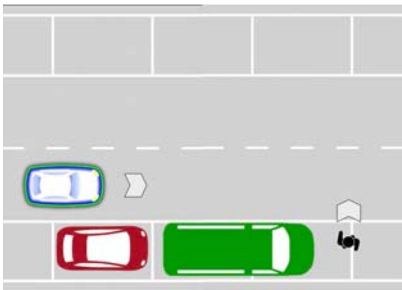

Fig. 2. – Selected scenarios with a high estimated occurrence and a consequent high relevance for road safety [4]: Pedestrian (or cyclist) crossing the road from the right to the left (or from the left to the right) occluded from parked or stopped cars or other obstacles.

3. SYSTEM DESIGN

The developed system is composed from different parts, which cooperate at the identification of vulnerable road users that are in front or surrounding a vehicle moving in the complexity of an urban scenario (cf. Fig. 3).

While the vehicle proceeds, the vision sensor focuses on the frontal part of the car and recognizes objects and their motion; the communication module gathers the responding signals in the area covered from the antenna and calculates their relative position; the on-board computer collects the different input and output with a certain frequency a data fusion result which time by time evaluates the risk level for possible colliding trajectories. In case the risk level passes a certain threshold there will be both an alert to the driver and a message sent to the VRU module.

The vision sensor module is able to collect information about the presence of VRU within the opening angle and the range of the camera, while the communication module, depending on the architectural design, has the possibility to cover a circular area surrounding the vehicle within the range of the communication mean. The region covered from both sensors can give contemporary input to the on-board unit, possibly augmenting the precision of the elaboration.

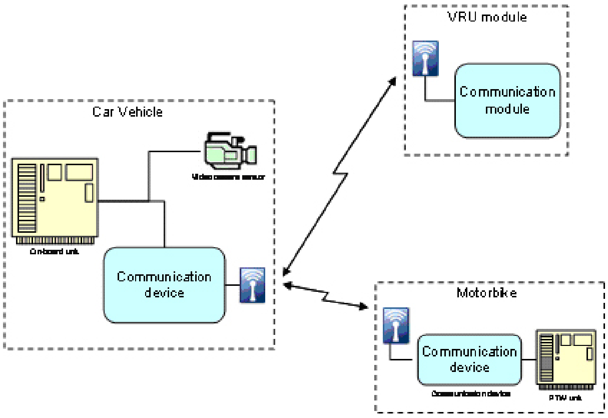

Fig. 3. – Reference architecture and components selection.

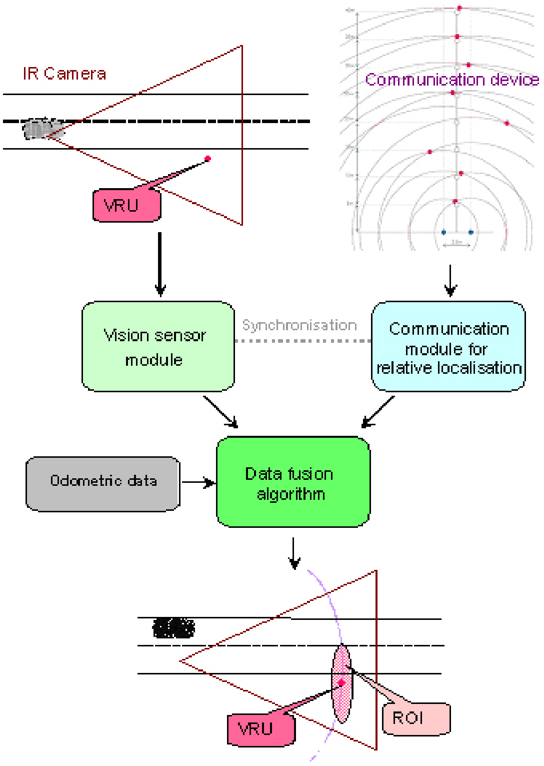

Fig. 4. – Data Fusion for VRU Detection.

The contribution of communication device leads to the definition of a region of interest (ROI) in the camera image determined by localisation based algorithms (see Fig. 4). The ROI covers a limited area of the camera picture, which contains interesting objects, e. g. VRUs. This reduced region enables a substantially faster and more reliable detection of VRUs and hence a more trustworthy recognition of dangerous situations. Finally, the distance information between the vehicle and the VRU generally delivers more confidence in estimation of the actual traffic scenario and allows a relatively precise calculation of the time to a possible collision to generate a warning signal.

Because of fundamental physical conditions a relatively good distance accuracy and resolution of about 1 m is expected, which is in contrast to only poor angle estimation. Therefore, we anticipate that a sufficiently exact angle estimation is not possible for the definition of an angle limited ROI. In this case the use of the relatively exact distance estimation determines at least the dimension of the bounding box in the IR image according to the VRU pattern. This delivers an additional benefit in image processing.

4. COMMUNICATION SYSTEM

Short-range wireless networks (SRWN) are an important platform for an increasing number of applications. Apart from the pure communication benefit and other added values, e.g. ease-of-installation, support of mobility, high level of redundancy and reliability, wireless networks can bring in an important additional feature: localization.

Mainly, three different measurement principles are used today for RTLS: angle-of-arrival (AOA), received-signal strength (RSS), and propagation-time based systems that can further be divided into three different subclasses: time-of-arrival (TOA), roundtrip-time-of-flight (RTOF) and time-difference-of-arrival (TDOA) [13]. An overview of the principles is shown in Figure 5.

The technology scouting and various real-life tests within a technology scouting phase showed that time-of-flight-based technologies promise the best trade-off between accuracy, cost, and today’s availability.

In addition, the technology scouting also resulted in the insight that for the given period of time, only one single-chip transceiver is available, which combines TOF-based ranging and communication: the nanoLOC [14] ASIC from [15].

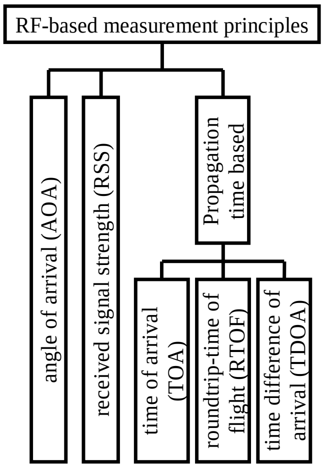

Fig. 5. – Measurement Principles for Localization Techniques [13].

5. SYSTEM DEVELOPMENT

Whereas the first measurements were still done with discrete hardware prototypes (DHP), the latter were already based on monolithically integrated ASIC.

The following preconditions are met for all measurements:

- The measurements are done in the 2.4 GHz-band with a raw bandwidth of 80 MHz and an effective bandwidth of 64 MHz.
- All measurements are performed with 24 up- and 24 down-chirps per measurement point, respectively. The control and the summing up of these values are performed in hardware.
- Consequently, each measurement consumes approximately 2 ms.

In the meantime, a number of platforms are already at the market to use the ASIC. However, they are limited to bulky evaluation boards and dedicated and early version firmware, mostly available as library only.

This situation finally led to the decision to start an own system development for hardware and firmware.

The special challenges for the hardware development were the following:

- minimum size of PCB to enable a pocketable device,
- high output efficiency at low power consumption to make good use of battery energy,
- large bandwidth of the transceiver (80 MHz).

The result of the design is shown in Figure 6. It includes an MSP430 low-power microcontroller, a NA5TR1 single chip transceivers, and the corresponding RF-circuitry. The PCB is equipped with a chip antenna, which can be extended to an external dipole antenna. A serial interface PCB can piggy-backed to the base PCB.

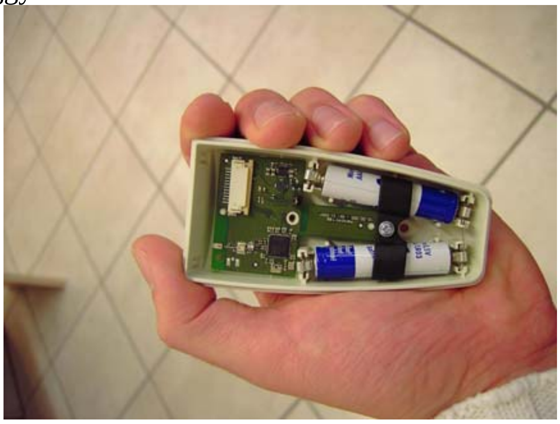

Fig. 6. – nanoLOC application board using the NA5TR1 single chip transceivers developed within the project.

The firmware and the drivers are completely redesigned in order to achieve high stability, small footprint and, above all, good scalability. This is extremely important for the network administration, as all devices should work on the same shared channel, which is not centrally administered, but operated under a distributed coordination function (DCF). The DCF approach may leave room for collisions and thus may lead to inefficient usage of the channel.

The system is accessible via RS232-serial link with a command set, described in the system specification [16].

At the time of writing, the system is in the last days of completion, so next step will be measurement sessions. They will be reported later. The measurements shown in this paper are still made with evaluation boards and prototype software. They were already presented at [17].

6. MEASUREMENT RESULTS

6.1. FREE FIELD SCENARIOS

The first measurements were taken in a free field scenario, which is depicted in Fig. 7.

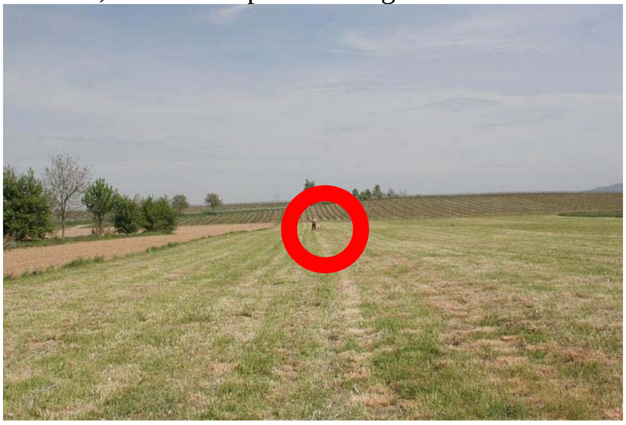

Fig. 7. – General conditions of free-field environment.

Fig. 8 and 9 show the results of the measurements. The maximum distance, which could be achieved repeatedly with an output power of 0 dBm, was 120 m.

The absolute error is constantly below 2.5 m. It is practically independent from the measured distance, which can be explained with the measurement principle of time of flight, where absolute timing errors occur with no dependency from the absolute time difference. Thus, the relative error practically monotonously decreases with increasing distance and is well below 1 % in the given range.

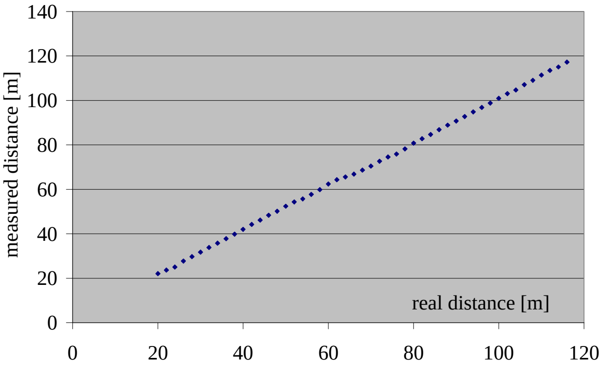

Fig: 8. – Measured distances in free field scenario.

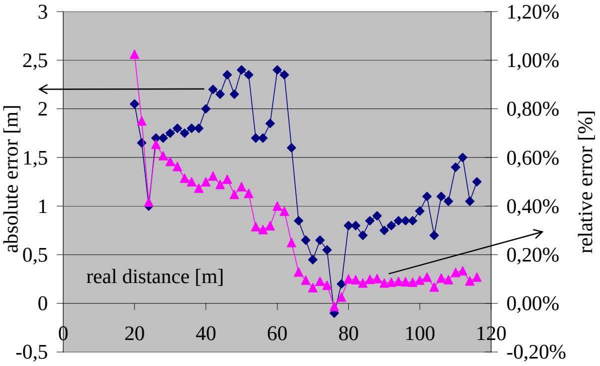

Fig: 9. – Measured distances in free field scenario.

6.2. URBAN SCENARIO

These measurements were performed in real-life environment. The results discussed below were taken in a residential area with a queue of parking cars. One station was placed on a rig, whereas the other station was put into a car, with its antenna mounted on the car's roof at a height of approx. 2 m. Fig. 10 gives an impression of the setting.

Fig. 11 and 12 show the values directly measured from the transceiver for the two edge values 10 m and 60 m. The maximum absolute error of the median value in the case of 10 m is around 0.8 m, which corresponds to around 8%, in the case of 60 m around 0.42 m, corresponding to around 0.7 %.

6.3. INFLUENCE OF OBSTACLES

Further tests with obstacles showed

- good stability also in the presence of metal objects, causing reflections and thus multipath propagation.
- only minor measurement errors. Practically, the measured distances increased with the envelope of the objects. The measurements remained stable, as long as the first indirect wave comes with the largest amplitude. This was the case in all measured outdoor use-cases, including the scenario shown in Fig. 2.

Fig. 10. – General conditions of urban environment.

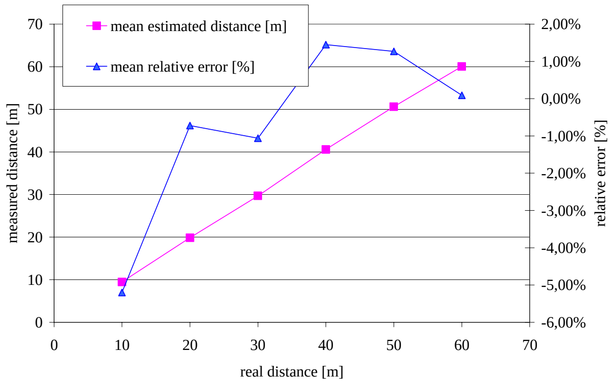

Fig. 11. – Mean estimated distances and relative error for static measurements without obstacles in urban environment.

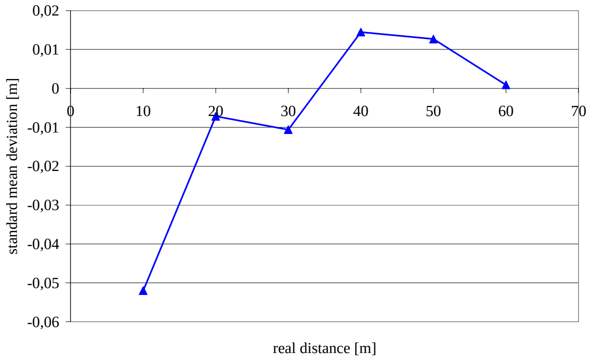

Fig. 12. – Standard mean deviation for static measurements without obstacles in urban environment.

7. FILTER DESIGN

For further processing, raw data must be filtered to suppress noise. Two methods are investigated here: simple averaging and Kalman filtering.

The dimension of the Kalman filter is ‘1’ for the static case depicted in Fig. 13.

It must be at least ‘3’ for the dynamic accelerated movement, shown as an example in Fig. 14. There, it can be seen that even temporary interruption of the connection can be handled by the filter without resetting.

8. CONCLUSION

The measurement results confirm previous experiments using DHP. The results are promising in terms of absolute errors and stability. Current activities include the integration of self-localization into the RF data flow and sensor fusion with video systems.

Furthermore, the establishment of temporary networks of multiple VRUs and cars will be implemented to find out the bandwidth limits of this approach.

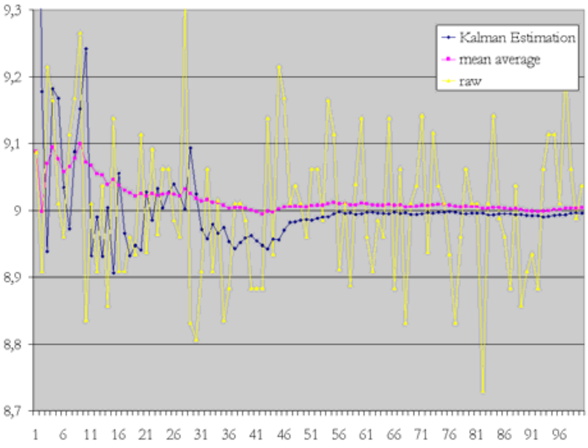

Fig. 13. – Filtering of 100 raw measurements at a real distance of 9 m.

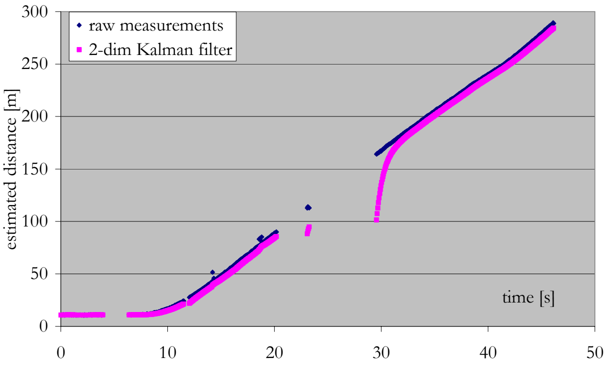

Fig. 14. – Filtering of dynamic measurement.

6. ACKNOWLEDGMENT

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In 2002, he founded the Steinbeis-Transfer Centre for Embedded Design and Networking, which is active as a R&D center, offering training, consulting, project and product implementations, as well as standard communication protocol suites, including the generic and extremely flexible emBetter TCP/IP-protocol stack. The center's major activities are in the field of wireless and wired connectivity of embedded systems. Scientific research and development projects are processed in his Steinbeis

Research Institute for Wireless Communication, where algorithms and protocols for energy-aware and -autonomous ad-hoc wireless networks are developed, simulated and implemented.

Dr. Sikora is author, co-author, editor and co-editor of several textbooks and numerous papers in the field of embedded design and wireless and wired networking.