TRACKSS Approach to Improving Road Safety through Sensors Collaboration on Vehicle and in Infrastructure

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Abstract—**There are various technologies that can be used to improve road safety, but they tend to be self-contained and do not interact much with other technologies. This might provide sufficient service as such, but we believe better systems can be developed if we allow these technologies to collaborate and share information with each other. This paper outlines the work we have carried out within the EU-funded TRACKSS project in order to allow two sensing technologies (near-infrared camera and smart dust) to work together, especially in developing more robust V2Vand I2V safety applications.**

Keywords-road safety; collaborative sensors; V2V; I2V; wireless communication

I. Introduction

The emergence of new technologies affects many aspects of our lives. This also covers areas such as transportation, where these technologies can be applied in improving road safety [1][2]. In particular, various I2V applications – such as road sign detection and recognition systems (e.g., [3][4]) – have been developed, but they tend to rely on one sensing technology alone and they are often based on passive instead of active detection.

Even though stand-alone-technology approach might provide adequate solution, we believe there is room for improvement. In most cases, it is possible to make several of these technologies to work together by sharing information or providing a service that can improve the performance of the others. This allows us to overcome the limitations of a particular technology, and in the end, it enables better and more robust systems to be developed and deployed, both on vehicle and in infrastructure.

In this paper, we discuss our experience in working with various technologies that are relevant for transport applications. In particular, we focus on the approach taken in the TRACKSS project [5], highlighting the collaboration between two sensing technologies as an example. This collaboration is illustrated through a case study that shows how V2V and I2V applications can enhance road safety by assisting drivers in identifying objects or hazard on the road.

This work is supported by EU-funded, Framework 6 TRACKSS project (http://www.trackss.net)

II. TRACKSS Approach

TRACKSS project [5] aims to develop new systems for cooperative sensing and predicting flows, infrastructure and environmental conditions surrounding traffic, with a view to improving road transport safety and efficiency. To achieve this, the project has carried out research in advanced communication concepts, and open interoperable and scalable system architectures that allow easy upgrading and integration of various sensing technologies. These serve as a platform for the construction of intelligent cooperative systems supporting a range of functions in the areas of road and vehicle safety, as well as in traffic management and control.

Among the sensing technologies used in TRACKSS are the near-infrared optical identification sensor from LIVIC and the Zigbee smart dust devices (motes) from Newcastle University. These seemingly unrelated sensors actually work well together and complement each other in their functionalities.

A. Optical Identification Sensor

LIVIC has developed an optical identification sensor that can detect, identify, and localize objects (vehicles or roadside objects) in the road scene. Coupled with a radio-communication system, the sensor is able to determine which object is the source of a given message. This technology has been patented in 2007 [6].

Figure 1. The emitter part of the optical identification sensor

This sensor is composed of two parts: an *emitter* part and a *receiver* part. The emitter is a near-infrared led-based lamp (see Fig. 1) that actively sends an identifier (a number coded by an embedded controller using a defined frame protocol). The signal is time-coded (instead of space-coded), which enables important ranges and robustness enhancement to be implemented, as compared to traditional spatial-pattern-based identification systems.

Figure 2. The receiver part of the optical identification sensor

The receiver part is a high frame-rate, low-resolution CCD camera (Fig. 2), along with a decoding algorithm. The algorithm extracts the emitter spot in the image captured by the camera, tracking it in successive images, and decoding the resulting succession of bits (1=”spot on”, 0=”spot off”) with regard to the frame protocol. The (X,Y,Z) position of the identified and tracked emitter is estimated from the (x,y) position on the image, knowing the pitch angle of the receiver-equipped vehicle, and the height of the emitter relative to the road surface. Indeed, Z (depth, or distance) is correlated to the height in the image, with a given pitch angle, and a static road-emitter vertical distance. The algorithm is described in detail in [7].

The efficiency of the sensor is due to the very low spatial and camera-resolution constraints, and the tracking algorithm which rejects most of the false alarms caused by other near-infrared emitters such as solar reflections, sky portions, vehicle- or traffic-lights.

Camera capabilities and experimental tests led us to choose a Pulnix greyscale 200 images/second CCD camera. With a resolution of 320x120, and a corresponding maximum frame-rate of 514 images/second, we are able to run the decoding algorithm in real-time, allowing a 210Hz emitter frequency. This configuration gives the following performances: 400m identification range in the best case (grey weather or at night), 110m identification range in the worst case (very sunny weather), 100ms identification time (time between the first appearance of an emitter in the camera view and the delivery of its identification number, with the tracking being performed at the speed of the emitter, i.e. 210Hz). Actually, the range is mainly determined by the power of the emitter, which could easily be adapted according to the light conditions: strong light → difficult conditions → increased emitting power.

B. Smart Dust Motes

Smart dust (also commonly known as mote) is a micro-electro-mechanical device equipped with a processor, memory and a radio chip that allows it to communicate wirelessly with other smart dust devices within range.

The smart dust concept has been around for some time, but they were originally intended for static (in term of movement) applications. Only recently has smart dust been considered for transport applications, which involve motes installed both on vehicle and in infrastructure. This poses some challenges, in particular, regarding the wireless communication with fast-moving motes ported on vehicles. Smart dust’s main benefits – its characteristics of being highly portable and highly customizable – allow us to rapidly deploy it in almost any situation, and to develop specific applications suitable to our need. It is also perceived that smart dust has the potential to become the low-cost, ubiquitous sensor of the future, once its size has shrunk substantially to merit its name.

There is a selection of smart dust devices available on the market. We use off-the-shelf MICA family motes from Crossbow Technologies [8] – in particular, the MPR2400 MICAz motes that are equipped with a Zigbee [9] radio chip. This radio chip enables a MICAz mote to communicate wirelessly with other MICAz motes or other Zigbee-ready devices within range (approximately 70 meters). The main components of MICAz mote are shown in Fig. 3.

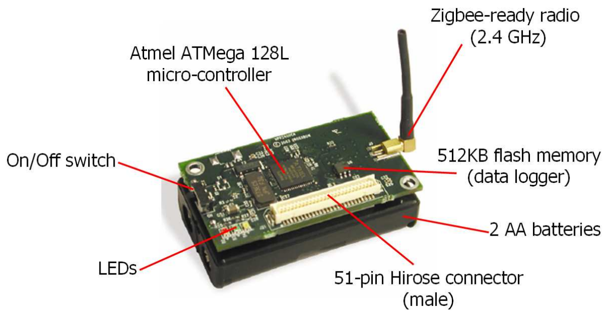

Figure 3. MPR2400 MICAz mote

These motes are programmable, and they can also be augmented with additional sensors (such as those for detecting light, temperature and acceleration), hence enhancing their features and making their application areas virtually limitless.

Newcastle University has carried out research in transport-related applications of smart dust for over three years, through projects such as ASTRA [10], ASK-IT [11], EMMA [12] and TRACKSS [5]. The results gathered so far have been very positive, indicating that smart dust has a great potential for deployment in transport domain [13][14].

In TRACKSS project, several smart dust-based applications have been identified. These include:

- *Road sign detection*. In this I2V application, each road sign is equipped with a smart dust mote broadcasting the identity of the sign. A vehicle equipped with a smart dust (see Fig. 4) will be able to receive this information when in range, and this information can be displayed on a visual display unit (such as a laptop or a PDA) to alert the driver.

Figure 4. Smart dust-equipped vehicle

- *Vehicle detection and counting*. This V2I application allows smart dust receiver on the side of the road to monitor smart dust-equipped vehicles (which broadcasts the identity of the vehicle) passing that particular section of the road. This application can be extended to include vehicle identification and classification.

C. How the two technologies complement each other

Every technology has its limitations, and this also applies to the two technologies described above. For example, the near-infrared identification sensor has a very good range, as well as localization features, but it relies on visual detection. This makes it susceptible to errors due to certain objects blocking the view, or in inclement weather conditions. On the other hand, the smart dust devices cannot easily determine the location of a target object (since this device relies on detection through radio signal, which does not readily carry information regarding the direction and location of the detected object), but the radio signal is free from visual impairment.

By combining the positive characteristics of these two technologies – augmented by the support from the TRACKSS framework (outlined below) – we have developed several applications that are more robust and reliable. These applications will be discussed in Section III.

D. TRACKSS Support

One of the major results of the TRACKSS project is the framework that provides support allowing communication between various sensors to be implemented readily and in a straightforward manner. This framework was designed to enable collaborations among infrastructure sensors, vehicle sensors, as well as vehicle and infrastructure sensors. Multiple scenarios have been designed, describing how the various sensors might collaborate through infrastructure, vehicle and mixed applications. We will focus on vehicle applications in this paper.

There are two important concepts defined and implemented in TRACKSS:

1) Knowledge Sharing Model (KSM)

The KSM serves as the core of the framework, defining the XML format of the data to be exchanged among sensors, and providing a common API for communication. Data are classified into several pre-defined types of knowledge, and they are passed around using "publish and subscribe" mechanism supported by the KSM. The KSM platform is implemented through two executables: *ServerSAM* (which acts as the coordinating server, through which all communication is processed) and *TrackssRouter* (which handles the communication related to each sensor).

2) Knowledge Sharing Sensor (KSS)

In TRACKSS, each sensor is turned into a KSS by integrating the common communication protocols into its corresponding software. Each KSS can publish and/or subscribe to certain types of knowledge; the communication details are handled automatically by the KSM platform.

Fig. 5 presents the simplified version of the communication mechanism between two KSSs in TRACKSS. More details on TRACKSS KSM and KSS can be found in [15].

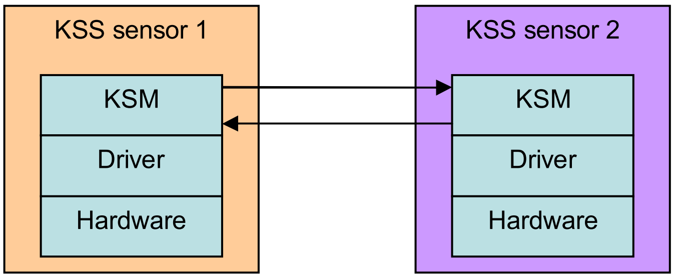

Figure 5. TRACKSS KSM and its support for KSS

Using the support provided by the KSM and its executable platform, the collaboration between the optical identification sensor and the smart dust motes has been fulfilled through the implementation of the corresponding KSSs for these two sensors. This is discussed in the next section.

III. CASE STUDY

There are many transport applications that can benefit from the collaboration of the two sensing technologies mentioned in this paper. We have developed a case study to illustrate how the collaboration can be implemented, and how much benefit they can bring to road safety and efficiency.

A. Description of the case study

Imagine the following two scenarios:

- Peter was driving his TRACKSS-equipped car on the road. He had been driving behind this Mercedes for the last ten minutes. He was quite tired, and began to lose focus on the road. Suddenly, he was alerted by an emergency warning and by an automatic braking. What happened? He did not notice that the Mercedes in front had performed a sudden braking action as its driver tried to avoid hitting a child crossing the road. The Mercedes broadcast a message just as the brake was applied to warn the vehicles around. Peter's car, thanks to the TRACKSS system on board, interpreted the message using the optical identification sensor and the embedded smart dust device. The system decided that the message was relevant because the source of the message was localized to be in Peter's driving lane, then it warned Peter of the danger. Finally, the car trigged an emergency brake, since Peter did not react immediately.

- Simon was driving on a road that he is not familiar with. He was looking for an address with some help from a GPS device. While looking on his GPS device, he did not notice the stop sign 25 meters ahead. Fortunately, his TRACKSS equipped car detected and identified the stop sign using the optical identification and the smart dust sensors. The car then performed an automatic brake to avoid any accident.

These two examples highlight the importance of integrating appropriate technologies to road infrastructure, as well as to vehicle. These technologies can then form the base for driver assistance systems which, among others, can be used for improving road safety.

B. *Implemented system*

The case study has been implemented using the optical identification sensor and the smart dust motes through two applications below:

- *Localized V2V communication (emergency braking application)*. The emitter part of the optical identification sensor attached at the rear or a vehicle allows this vehicle to be detected, identified and tracked by a following-vehicle. This, combined with the radio communication system provided by the smart dust devices, allows messages to be passed between vehicles, and for the following-vehicle (equipped with the optical identification sensor receiver) to localize the source of the inter-vehicles messages in order to determine whether the messages are relevant. Fig. 6 shows the screen capture of the emergency braking application, which has been implemented and tested, and was presented in September 2007 to an audience at the PIARC World Congress in Paris, France [16]. These images are still-captures of the video obtained from the optical identification sensor camera, where the image on the left shows the identification and tracking of the vehicle in front, while the image on the right shows the situation when this vehicle suddenly applies the brake.

Figure 6. Emergency braking application screen capture

- *Localized I2V communication (road sign recognition application)*. By attaching the optical recognition sensor emitter and the smart dust transmitter to a road sign, suitably equipped vehicles can detect, identify and localize the road sign ahead with sufficient time and even in poor visibility. This application has also been fully implemented and tested, and Fig. 7 shows the screen capture of this application. The image on the left shows the capture of the application window on the vehicle, and the image on the right is a still-capture of the video tracking the identified road sign.

Figure 7. Road sign recognition application screen capture

We have also implemented several other applications, including a cooperative traffic light application (where the smart dust is used to broadcast the current color and the time remaining of this color, while the optical identification sensor is used to localize the source).

C. *Results*

We have obtained encouraging results from running and testing these applications, especially in overcoming the limitations of the stand alone sensors, which might lead to a number of false detections. In the case of optical identification sensor, false detection could occur due to difficult weather conditions, where in very sunny conditions, some reflections on the road might be erroneously identified as a certain object. In the case of the smart dust sensor, false detection could occur when the vehicle travelling in the opposite direction might also pick up the signal (since the detection relies on radio signal, which does not carry the information regarding the detection direction). The collaboration between the two sensors eliminates these false detections, hence increasing the reliability and the confidence on the information coming from the combined system.

We have also gathered data regarding the detection range of the combined system. In general, the optical identification sensor has a greater range than the smart dust sensor. In our tests, we placed the smart dust transmitter 30m ahead of the optical identification emitter, in order to allow both sensors to agree on the detection with sufficient time. The speed of the vehicle also affects the range of identification, where at higher speed, the range is somewhat reduced, but nonetheless, there is still enough time for accurate detection. Fig. 8 shows the detection range when the vehicle is travelling at 50 km/h, whereas Fig. 9 shows the detection range at 130 km/h. In these diagrams, the y-axis relates to the identification number of the road signs – in this case: 7 (representing a danger sign), 9 (representing an end of 50 km/h speed limit) and 20 (representing a traffic light). These road signs are placed in successions at a test-track facility provided by LCPC, and the x-axis represents the distance covered by the test-vehicle on the test-track. The rectangles represent the start and the end of detection for each road sign, as detected by the optical identification sensor, the smart dust sensor, and the combined system (this is the one considered as the actual "detection range").

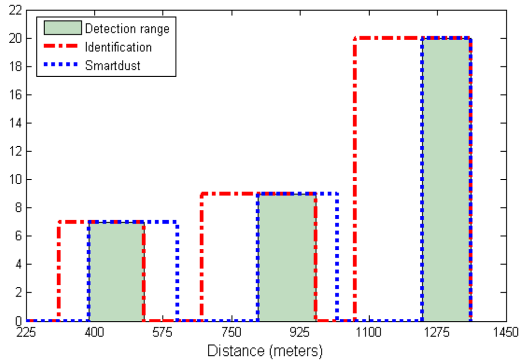

Figure 8. Combined detection range at the speed of 50 km/h

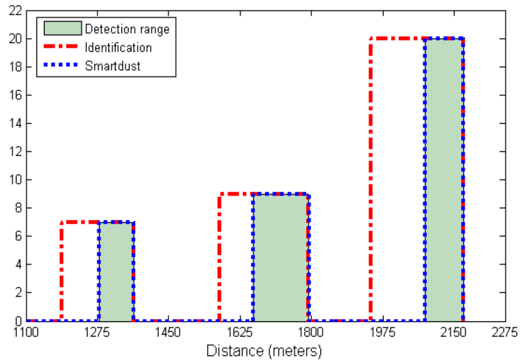

Figure 9. Combined detection range at the speed of 130 km/h

From these detection range data, we can also derive information about the "distance-to-be-covered and available-time before passing the road sign". As can be seen in the diagrams above, this value is very much affected by the speed of the vehicle. Table I shows the values for each identified road sign at two different speeds.

TABLE I. DISTANCE AND TIME RANGE OF ROAD SIGN DETECTION

Speed (km/h)	Road sign ID	Distance (m)	Time range (s)
50	7	141.7	10.2
50	9	133.3	9.6
50	20	125.0	9.0
130	7	89.5	2.4
130	9	135.2	3.7
130	20	95.5	2.6

These values compare favorably to the standard driver's reaction time of 1 second. Even at 130 km/h, we have at least 2.4 second anticipation time before the road sign.

IV. Conclusion

We have demonstrated how two different sensing technologies can work together in order to provide a more robust and reliable road safety applications. A lot of support for implementing this collaboration comes from the TRACKSS framework of Knowledge Sharing Model and the concepts of Knowledge Sharing Sensors.

These applications have been fully implemented and tested, and based on the positive and encouraging results obtained from running them, we envisage such collaboration to have beneficial impact towards improving road safety and efficiency. Several other applications – including V2I applications – are currently being investigated.

Acknowledgment

We would like to thank Jean-Marie Chevreau and Antoine Fusée from LIVIC for their precious technical help in setting up the applications. We also thank Alan Tully and Phil Blythe from Newcastle University for their input towards this paper.

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