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COOPERATIVE ROAD SIGN AND TRAFFIC LIGHT USING NEAR INFRARED IDENTIFICATION AND ZIGBEE SMARTDUST TECHNOLOGIES

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Abstract. Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I as well as I2V) applications are developing very fast. They rely on telecommunication and localization technologies to detect, identify and geo-localize the sources of information (such as vehicles, roadside objects, or pedestrians). This paper presents an original approach on how two different technologies (a near infrared identification sensor and a Zigbee smartdust sensor) can work together in order to create an improved system. After an introduction of these two sensors, two concrete applications will be presented: a road sign detection application and a cooperative traffic light application. These applications show how the coupling of the two sensors enables robust detection and how they complement each other to add dynamic information to road-side objects.

Keywords: sensor fusion, near infrared, smartdust, cooperative system, road sign detection, intelligent traffic light

INTRODUCTION

Advances in technology affect many aspects of our live, including the way we travel and the transportation systems in general. More and more vehicles are equipped with state of the art equipments and sensors, and the road infrastructure is becoming smarter and provides additional supports to the road users. First and foremost, these advances should be utilized to improve road safety, for example, by reducing the number of accidents and minimizing those that involve fatality or horrific injuries. On top of that, road travel experience can be made more enjoyable thanks to intelligent transportation systems that reduce the effort required by the drivers and the time saved through more efficient systems.

It is not possible to achieve all these by relying solely on one sensor technology. Multiple sensors need to be deployed in order to build a complete system where one sensor's capabilities can complement others'. This is the approach we took in our work. Starting with two individual sensors – a near infrared remote identification sensor and a Zigbee smartdust communication device – each with its own features and limitations, we investigated how the two can complement each other. For example, the near infrared identification sensor has a very good range and localization features, but it relies on visual detection. This makes it prone to errors when objects may obstruct the view, or in inclement weather conditions. On the other hand, the Zigbee smartdust sensor cannot easily determine the location of a target (since it relies on radio signal, which does not carry information on the detection direction), but the radio signal is free from visual impairment. By combining the positive characteristics of these

two sensors, we have developed a new system that provides a more robust detection and identification of objects on the road.

In this paper, we demonstrate the benefits of this collaboration through two applications:

- A road sign detection application
  This application enables road signs on the side of the road to be detected, identified and localized accurately in advance. As a result, drivers will become aware of the road conditions with sufficient time to react, hence improving the road safety.
- A cooperative traffic light application
  By knowing how much time is left for a particular colour of the traffic light, drivers can plan when to change the movement of the vehicle (for example, whether they should be preparing to move again after a stop), hence they can save time.

There are many other applications that can be constructed using this collaboration, but for now, we will focus on the two above. But before we get into details with these two applications, we will introduce each individual sensor and discuss their capabilities.

OPTICAL IDENTIFICATION SENSOR

General Overview of the Sensor

The Optical Identification Sensor was developed at LIVIC. Its purpose is to detect, identify objects (vehicles or roadside objects) and localize them in the road scene. Coupled with a radio-communication system, the sensor enables us to determine which object is the source of a given message. It has been patented in 2007 (2).

Some systems use vision-based pattern (including license plate) recognition and they need high resolution cameras and have low ranges. Other systems use infrared light for classification purposes (4), or infrared beacons with a dedicated radio signalling protocol for synchronization (5). Our sensor has a much higher range, and only needs a low-resolution camera and a simple infrared beacon.

The sensor is composed of two parts, an Emitter part and a Receiver part. The Emitter is the active part. It is a near-infrared led-based lamp (see Figure 1), which, thanks to an embedded controller, codes an identifier (a number) using a defined frame protocol. The signal is thus time-coded (blinking light) and not space-coded. This enables important ranges and robustness enhancements, compared to traditional spatial-pattern-based identification systems.



Figure 1: The emitter part of the optical identification sensor

This Emitter continuously emits a cycling frame, containing a start sequence (4 bits), the usable code (identification number), a zero and a parity bit. Figure 2 shows the Emitter's frame protocol.

Previous frame	Start code	Id code	'0'	Parity bit	Next frame

Figure 2: Emitter frame protocol

The Receiver is a high framerate, low-resolution CCD camera, equipped with an IR-bandpass filter, plus a decoding algorithm. The full description of the algorithm can be found in (3), here we will give a brief explanation about the decoding process.

A low-level algorithm processes the input image to extract the spots corresponding to the emitters. Most of the false detections (which can be caused by other infrared sources such as the sky or vegetation) are eliminated by shape analysis. The order of operations is:

1. IR-filtered image is acquired. Emitters appear like bright round spots
2. Image is converted to strict black and white using a threshold, so that only the brightest pixels are kept (IR sources)
3. Regions are made more consistent, less fragmented, using morphological dilatation
4. White pixels are clustered: each connected region is a labelled cluster
5. Regions are accepted or rejected depending on their size and roundness. Large regions, corresponding to the sky, and regions which do not look like a spot, for example pieces of vegetation, are rejected.

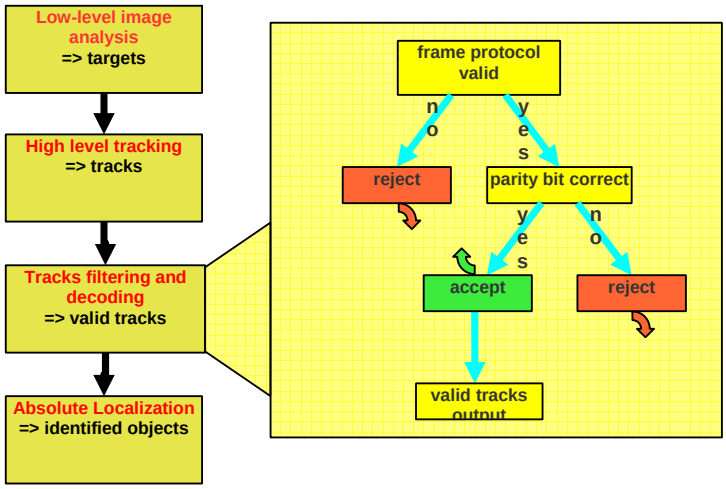


Figure 3: Optical Identification decoding algorithm

Then, a high-level algorithm (Figure 3) tracks the detected spots over time (in successive images) to follow their movement and analyze their logical state (0=un-lit, 1=lit). The tracking algorithm uses a simple neighbourhood prediction technique. The resulting bit stream, for each tracked spot, is continuously analyzed. If it conforms to the frame protocol, it is accepted as a valid Emitter signal and the decoded identification number is output.

Finally, the (X,Y,Z) position of the identified and tracked Emitter is estimated from the (x,y) position in 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. This estimation procedure is detailed in (3).

Sensor Capabilities

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. The sensor can be tuned using 3 parameters:

- Receiver camera resolution: this parameter has influence on the accuracy of Z estimation. The smaller the vertical resolution, the lower the accuracy.
- Receiver camera framerate: the higher this parameter, the higher the Emitter frequency
- Emitter frequency: the higher this parameter, the lower false detections (because the Emitter signal evolves faster than environmental near-infrared signal like solar reflections or blinking turn lights). The quicker the identification time, and the higher the tracking efficiency

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 framerate of 514 images/second, we were 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.

Figure 4 shows the detection ranges of three roadside objects. The vertical axis represents the identification numbers of the objects (which are 9, 7, and 20 in this case). The horizontal axis represents the distance covered by the vehicle, where the elevated lines signify the detection of a particular roadside object. The vehicle was travelling at 50km/h in good weather conditions. The detection in the middle (for roadside object with identification number of 7) has more than 350m detection range.

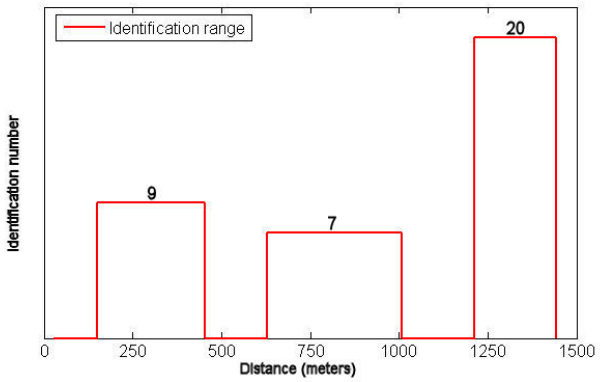


Figure 4: Optical Identification Sensor detection range

These results, even in the worst-case scenario, are good enough to enable an efficient detection and identification of objects by the Receiver travelling at the speed of up to 130km/h. This enables applications like localized vehicle-to-vehicle (V2V) communication, road sign recognition, as well as long-range cooperative vehicle detection and tracking to be developed.

The sensor however has a low, but not null, false-detection rate when used in bad conditions (very sunny weather), because of the high number of near infrared sources, especially direct sunlight through vegetation. This scenario generates hundreds of little blinking spots of infrared light, that most of the time are eliminated by the high-level tracking algorithm, but in rare cases can generate a false detection, lasting a couple of milliseconds. Of course, a top-level filtering (on the minimum duration of a tracked detection) can eliminate this threat, but this introduces some latency, wasting a couple of meters in the detection range, or fractions of a second in the case of an appearing object.

Concerning the accuracy of localization of identified objects, the lateral positioning on the road has a precision of one meter at 40 meters distance. This is enough to determine on which driving-lane the object is, with a good detection range. The longitudinal positioning (distance) is less accurate, but this is not so important in our case. This distance measurement can be enhanced by increasing the vertical resolution of the camera, which we do not want to do, since we aim to use a low-resolution, low-cpu consumption Receiver. The details are presented in (3).

With these capabilities, the following applications were successfully developed:

- Localized vehicle-vehicle communication
  Attached at the rear of vehicles, the Emitter lets these vehicles to be detected, identified and tracked by a Receiver-equipped vehicle. So, coupled with a radio-communication system (WiFi for example), it becomes possible for the Receiver-equipped vehicle to localize on the road the sources of inter-vehicle messages. In a hazard-warning application, this enables filtering of messages with regard to whether their source is a vehicle in the same lane as the Receiver vehicle or not. For example, a vehicle detecting a dangerous curve (by ESP activation) can broadcast this information through WiFi, and the following vehicle, getting this message and knowing – thanks to our sensor – that the message comes from the followed vehicle, takes this information into account. The same goes for an emergency braking warning application (see Figure 5). These applications have been implemented, tested and presented in September 2007 to an audience of people from the PIARC world congress in Paris, France (8).



Figure 5: Emergency braking application screen capture

- Road sign recognition
  Attaching the Emitter to a road sign enables an approaching vehicle to detect and identify, i.e. to recognize the road sign, within the sensor range. The Emitter codes an identification frame characterizing the type of road sign. Additional information can be added to the

Emitter, like advised speed for a dangerous curve road sign for example. During the time that the road sign is being detected, it is also localized, and a symbolic representation of it can be projected inside the filmed scene. Two example graphical displays can be seen on Figure 6. The left one shows a symbolic representation of the road sign and the right one shows an "augmented reality" view, where the road sign is drawn at its real position on the image. One can easily understand the benefit of this application for night-time driver assistance. This application was implemented, tested and also presented at the PIARC demonstration.



Figure 6: Graphical display for road sign recognition

- As our identification sensor is able to detect vehicles up to more than 300m, it can be used for long range cooperative obstacle detection. Indeed, the detected Emitters can provide seeds on a high resolution image where heavy computational image processing algorithms, such as stereovision can then extract regions of interest to focus their calculations on. This allows stereovision-applications to work with high resolution images in real-time, thus dramatically increase their range.

ZIGBEE SMARTDUST SENSOR

General Overview of the Sensor

Smartdust (or mote) is a micro-electro-mechanical device, typically composed of a processing unit, some memory, and a radio chip, which allows it to communicate wirelessly with other smartdust devices within range. Depending on the radio chip, the wireless communication operates in frequency bands around the 800-900MHz, 2.45GHz or 5.8-5.9GHz using communication protocols such as IEEE 802.15.4 (Zigbee) (13). This wireless capability makes it possible for smartdust devices to form a Mobile Ad-hoc NETwork (MANET) – a collection of mobile computing devices which cooperate to form a dynamic network without using fixed infrastructure.

These devices 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.

Smartdust's main benefits are its characteristics of being highly portable and highly customisable. These allow us to rapidly deploy them in almost any situation, and to develop

specific applications suitable to our need. It is also perceived that smartdust has the potential to become the low-cost, ubiquitous sensor of the future.

Sensor Capabilities

We use off-the-shelf smartdust devices from Crossbow Technologies called MPR2400 MICAz motes (7). These motes are equipped with a Zigbee (13) radio chip, which enables them to communicate with other MICAz motes or other Zigbee-ready devices within range (approximately 70 meters). Figure 7 shows MPR2400 MICAz mote and its size comparisons.

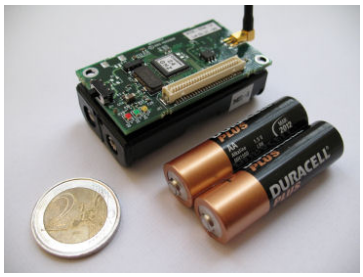


Figure 7: MPR2400 MICAz mote

This mote can be programmed using a language called nesC on the TinyOS platform (9) and it can be plugged-in to a programming board using the 51-pin Hirose connector. In turn, the programming board is connectable to a laptop or a PC using either serial (RS-232), USB or Ethernet cables. Through this programming board, new software can be uploaded onto the mote. This board can also serve as a "base station", acting as a gateway between the mote(s) and the application running on the laptop (see Figure 8).

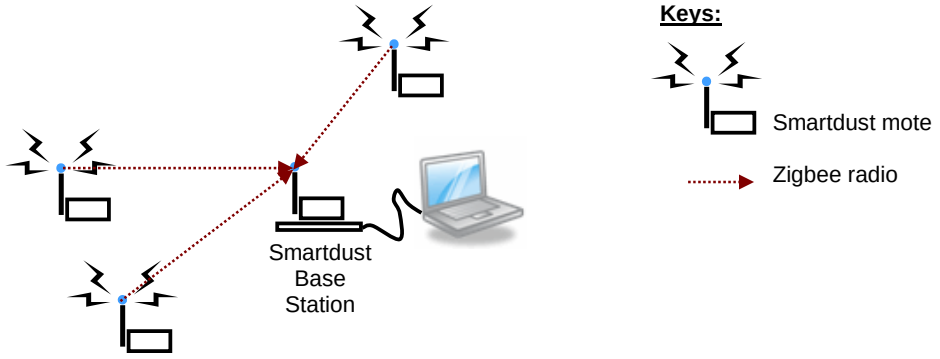


Figure 8: Interaction with smartdust motes around the base station

By writing suitable software, we can interact wirelessly with these motes through the laptop. This opens up a host of applications for smartdust, for example:

- Road sign recognition
  We place several motes on the infrastructure (on the side of the road). Each mote is programmed to broadcast a unique identity, representing a particular traffic sign. Each mote is then placed next to the actual traffic sign. We equip a car with a laptop and a smartdust base station, and when the car approaches the traffic sign, the base station will pick up the identity of the smartdust on the side of the road. This is then processed by the application on the laptop and an appropriate warning can be displayed (Figure 9). This application will be discussed further in the next section.

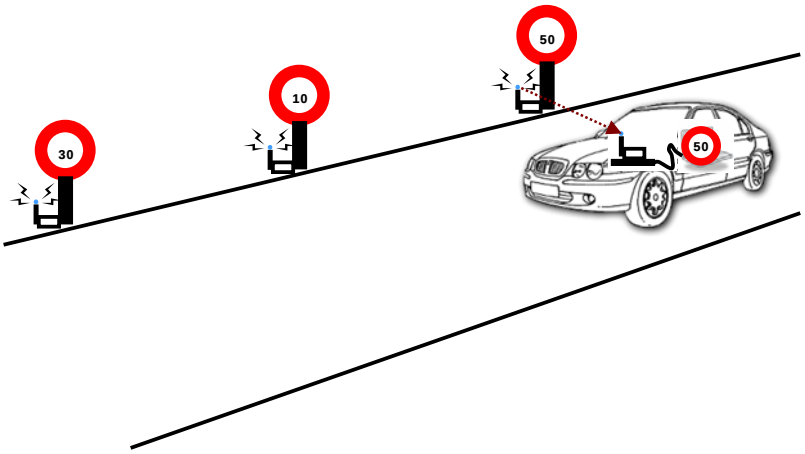


Figure 9: Road sign recognition application using smartdust

- Vehicle detection and counting
  Each vehicle is equipped with a smartdust broadcasting a unique identity. We put the smartdust base station on the side of the road (as a monitoring station). When these vehicles pass the monitoring station, they will be detected and counted. Since the information broadcast by the smartdust motes can be customised according to our need, this application can be extended by augmenting the broadcast data with – among others – the vehicle classification and its registration number.

We had carried out tests investigating the feasibility of using smartdust in V2I and I2V applications. There was initially some concern about the suitability of Zigbee radio for applications involving vehicles moving at high speed (for example, due to the Doppler Effect), but we have demonstrated that this is not really the case (6). From our tests, we also worked out that the communication range of smartdust (between a moving vehicle and a stationary object on the side of the road, or vice versa) is approximately 50 meters. We envisage that there should be no problem in deploying smartdust in V2V applications.

One of the beneficial features of smartdust is that it does not need visual contact in order to communicate with other smartdust devices around. This means smartdust does not suffer from visual-related impairments (such as obstructive objects, shading, or inclement weather conditions) which could affect a lot of camera-based sensors used in transport domain. On the down side, the detection range of smartdust is rather limited. Although this does not cause much problem in static settings (we can just add extra smartdust devices if we want to cover a greater range or distance, hence creating several hop points or even a MANET), it might pose some restrictions on its applicability in transport scenarios.

This is one of the areas that the TRACKSS project (11) aims to answer: how diverse sensors and technologies can collaborate together in order to obtain better measures. A sensor's weak point can be overcome by making that sensor collaborate with another sensor that can address the problem. At the same time, the first sensor might have features that can complement the second sensor.

APPLICATIONS

For the demonstration, we equip a car with an optical identification receiver (camera), a smartdust mote (sitting on its base station), and a computer connected to these sensors, on

which the applications controlling these sensors are running. We also place infrared emitters and smartdust motes on the side of the road; they act as the broadcaster of signal for representing the road signs and the traffic light. Figure 10 provides a diagrammatical representation of this set-up.

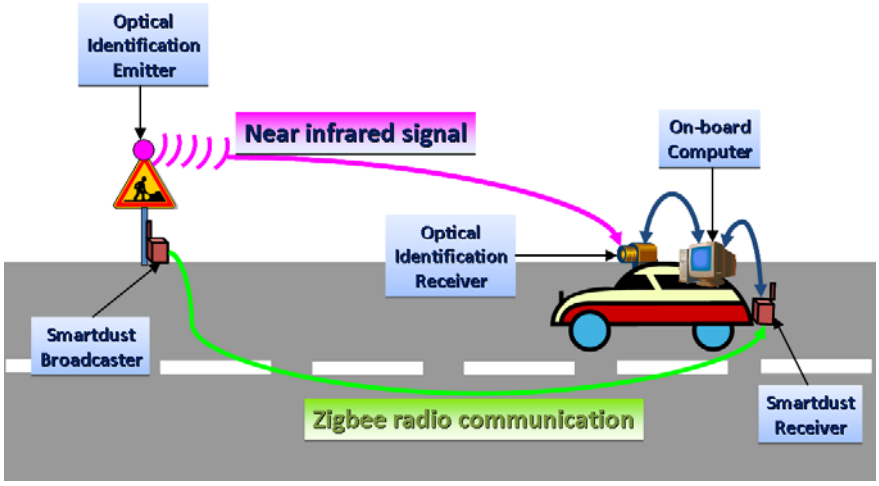


Figure 10: The set-up of the equipments used in our applications

On the on-board computer, both sensors communicate using a unified library developed within the TRACKSS project: the KSM, which stands for *Knowledge Sharing Model*. This KSM is a middleware that encapsulates a common communication protocol of all the sensors used in the TRACKSS project, turning these sensors into *Knowledge Sharing Sensors* (KSS). A KSS uses this standard communication API (Application Programming Interface) as a means for sharing information with other KSSs as depicted in Figure 11. The purpose of the TRACKSS project is to make sensors collaborate using this generic middleware. Further details on the TRACKSS KSM can be found in (1).

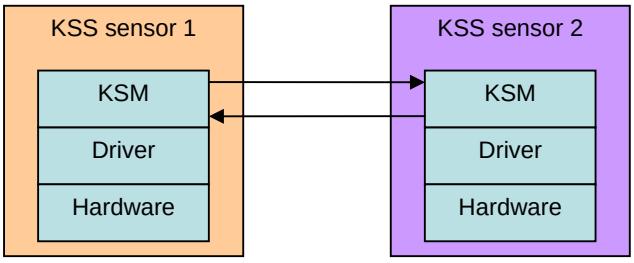


Figure 11: The KSM communication layer

Application to Cooperative Road Sign Detection

We combine the long detection-range capabilities of the near infrared camera with the visual-independence feature of the smartdust in order to develop a more robust system for road signs detection.

In most cases, the near infrared camera picks up the signal from the infrared emitter prior to the smartdust base station picking the signal from the smartdust mote on the side of the road. In these cases, the latter provides a confirmation of the detected road sign to the former, hence increasing the confidence of the result.

In other cases (for example, around the bend or if there is some visual impairment), the smartdust picks up the road sign signal before the camera. The system will then warn the driver that a road sign is detected nearby, but we do not have 100% certainty until this is confirmed by the camera.

Application to Cooperative Traffic Light

In this application, we program the smartdust mote to mimic the behaviour of a traffic light, including the time delays for each traffic light colour. This mote then continuously broadcasts a signal representing the current colour displayed by the traffic light, as well as the time left for that colour. The near infrared camera is used to pre-warn the driver regarding the presence of the traffic light ahead (since it has a longer detection range than the smartdust), and to initialise the traffic light display application on the car. Once the smartdust signal is picked up by the smartdust base station on the car, the application will show the current traffic light colour and its remaining time. The frequency of the smartdust broadcast is every 100ms, enabling the application to show the time left for the current colour in the nearest (rounded down) second.

This application has major advantages in terms of reduction of latency time when vehicles are starting on green light. When all vehicles have the information in advance when the light gets green, all the drivers can prepare for start, and save a couple of seconds per vehicle.

On the image below (Figure 12), you can see an example graphical user interface that we propose. The time before colour change is shown on the top left of the drawn traffic lights. Two kinds of interfaces are proposed: a symbolic one (on the left) showing only the traffic light with the time left, or an “augmented reality” version, with the traffic light drawn on overlay of the road scene. This latter version can be adapted to a head-up display device.



Figure 12: Graphical display for cooperative traffic light

A similar system had been developed by Toyota (10) using different technology.

Experimental Results

The first major experimental result of these applications is given by the fusion of identification information from two different sensors with different technologies. When the fusion strategy is a confirmation of one sensor by the other, then the limitations of each sensor can be compensated.

The aforementioned false detections that can occur in difficult weather conditions with the optical identification sensor are totally eliminated because they are not confirmed by a smartdust signal. So, there is no need for a high-level filtering as explained above, which means we save detection- and reaction-time. On the other hand, where the smartdust sensor can not provide the precise relative position of a road sign, the optical identification sensor gives sufficient accurate positioning to be able to decide if the road sign is on the driving lane or another lane.

Concerning the detection range, with our confirmation strategy (where the target must be within range to be simultaneously detected by both sensors), the final range is highly influenced by the range of the smartdust sensor. This is because the optical identification sensor has a much higher range than the smartdust sensor. But our application does not need a range over hundreds of meters. It needs to be able to detect a road sign sufficiently early to warn the driver or start an action, at any speed up to 130km/h. The range of smartdust is sufficient. Anyhow, the range of smartdust sensor can be easily increased by chaining multiple smartdust sensors in an ad-hoc network ahead of the road sign. The maximum range of the optical identification sensor can then be covered.

The graphs below show the ranges of the optical identification sensor, the smartdust sensor, and the coupled sensors at different speeds. When placed next to the optical identification sensor, the smartdust continues the detection even after the road sign has been passed (whereas the optical identification sensor ceases the detection after the road sign has been passed). This is due to the fact that the smartdust sensor relies on a radio signal, which is not directional but is based on the radius of the signal. This shows the benefits of the optical identification sensor which provides the information that the road sign detected by the smartdust is not relevant anymore since after it has been passed. On Figure 13, we placed the smartdust 30m ahead of the actual road sign (with the identification emitter still placed next to the actual road sign), so that the total range of smartdust is included in the range of the identification sensor. The figure on the left shows the measurements at the speed of 50km/h, whereas the figure on the right at the speed of 130km/h.

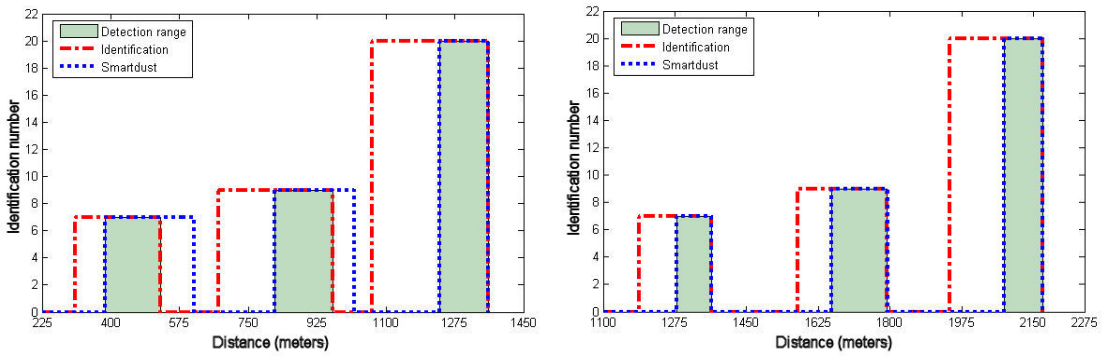


Figure 13: Application detection range

The smartdust range on the left figure is not included within the optical identification range, but is in the right figure. This is due to smartdust range limitation when driving at high speed. So we calibrated the optimized position for the smartdust sensor based on the range at 130km/h. You can also notice that the optical identification range is not as large as the one presented above. This is due to the different weather conditions. Nevertheless, we reach more than 200m range here.

CONCLUSION

This paper highlights the benefits of fusing information from two different sensors – optical identification sensor and smartdust sensor – in order to create a more robust and improved system. We have demonstrated the feasibility of this collaboration through two applications, namely the cooperative road sign detection and the cooperative traffic light application.

Ideas of enhancements include a range extension for smartdust by using two or more motes chained in a multi-hops network, to reach the range of optical identification. More complex applications can be imagined, for example, adding extra information to a road sign – such as extra details for a dangerous curve road sign – or even an enforcement of the advised speed limit.

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