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Wireless Protection of Vulnerable Road Users

Seminar Thesis in Computer Science Master's

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Wireless Protection of Vulnerable Road Users

Seminar Thesis in Computer Science Master's

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(Philip Frerk)
Paderborn, January 30, 2018

Abstract

Protecting Vulnerable Road Users (VRUs) is a very important task as in roughly 50 % of all traffic accidents VRUs are involved. VRUs are pedestrians or drivers of two-wheeled vehicles. A technology is needed that warns both the VRU and the car driver if an accident between them is likely to happen so that they can react accordingly. This is a challenging task, because the warnings have to be sent in time and also it has to ensured that no people are warned who are not really affected by the approaching car. To achieve that goal, Wireless Networking, GPS and Sensor Perception will be used. Results show that the number of accidents with VRUs involved can be reduced dramatically. As the initial results are promising, research in this area is being expanded, especially as there are many further challenges, for example situations with many VRUs and many cars in dense cities.

Kurzfassung

Der Schutz von gefährdeten Verkehrsteilnehmern ist eine sehr wichtige Aufgabe, da an rund der Hälfte aller Verkehrsunfälle solche Verkehrsteilnehmer beteiligt sind. Gefährdete Verkehrsteilnehmer sind definiert als Fußgänger oder Fahrer von zweirädigen Fahrzeugen. Es wird eine Technologie benötigt, welche sowohl den gefährdeten Verkehrsteilnehmer als auch den Fahrer eines Autos warnt, wenn es wahrscheinlich ist, dass ein Unfall zwischen ihnen passiert. Das ist eine schwierige Herausforderung, da die Nachrichten schnell genug ausgetauscht werden müssen und auch dafür gesorgt werden muss, dass keine Fußgänger gewarnt werden, die eigentlich nicht in den Unfall verwickelt werden können. Um dies zu ermöglichen, werden Drahtlos-Netzwerke, GPS-Technologie und Computer Vision eingesetzt. Die Ergebnisse zeigen, dass dadurch die Anzahl der Verkehrsunfälle deutlich gesenkt werden kann. Wegen dieser vielversprechenden Resultate wird zukünftig noch mehr Forschungsarbeit in dieses Thema gesteckt werden. Dies ist auch nötig, da die Systeme noch nicht fähig sind, in Situationen mit sehr vielen Fußgängern (bzw. gefährdeten Verkehrsteilnehmern) umzugehen, was aber in dicht besiedelten Städten oft der Fall ist.

Contents

Chapter 1

Introduction

The thesis starts by giving a short motivation for the topic, and then providing an overview about how the work is structured.

1.1 Motivation

Within the last century the usage of motorized vehicles has grown rapidly. While this fact brings the great benefit of full mobility, it does not come without its downsides. One of them is the high number of traffic accidents. According to [1] in roughly half of all traffic accidents, Vulnerable Road Users (VRUs) are involved. Hence, there is huge potential to prevent injuries or even deaths of many people. This thesis will give you an overview of the current state of research in this area. While there are many approaches beyond the discipline of Wireless Networking (e.g. Computer Vision for pedestrian recognition), this thesis will focus mainly on how to prevent traffic accidents by using Wireless Networking Technology. However, the other areas will also be explained briefly since they often work hand in hand with Wireless Networking.

1.2 Structure of the Thesis

The thesis is structured as follows. Chapter 2 is the main part of the thesis and will show the different ways for protection of VRUs by using Wireless Networking. In chapters 2.1, 2.2, 2.3, we will look at different solutions which rely solely on Wireless Networking. We will then see why such systems are often not satisfying, and in chapter 2.4 we will take a look at an approach which combines Wireless Networking and Sensor Perception in order to improve the performance and precision. In chapter 2.5, motorbikes will be discussed as a different class of VRUs.

Finally, in chapter 3 all the approaches will be summarized and also we will see what future tasks are still left in this area to make it usable in the real world.

Chapter 2

Protecting Vulnerable Road Users

The basic idea behind Vehicle to Pedestrian Communication Systems (V2PCSs) is that a driving vehicle (most often a car) and a VRU (most often a pedestrian) exchange messages over a wireless network in order tell each other their positions. By doing that, accidents between them can be prevented because both the car driver and the pedestrian can react to the received messages.

There are several approaches to implement such a system and they will be discovered in this chapter.

2.1 Special Device as Warning Unit

First, we will look at such communication systems which use a special device for the VRU in order to send his messages. In [2] and [3] such systems have been proposed. As [3] is more about the details of the deployed devices (e.g. energy consumption, price, complexity), we will focus on [2] since it is more related to Wireless Networking.

The device for the pedestrian from [2] can be seen in the bottom of figure 2.1. In the top of figure 2.1 you can see the warning unit that will be installed in the car.

The task of the device for the pedestrian is to periodically send "Hello"-Messages including the pedestrian's position so that the warning unit in the car can receive those messages and detect a probably dangerous situation. Then the warning unit for the car sets itself into a warning status (like in the top of figure 2.1 with the blinking LEDs).

It is very important that the car driver does not get too many warning messages because otherwise he would loose sensibility for the warnings. Therefore, a key issue is to ensure that only warning are created if the distance between car and pedestrian decreases gradually.

Figure 2.1 – The Warning Unit for Cars and the Warning Device for Pedestrians from [2]

Figure 2.2 shows the alerting probability on the vertical axis and the distance between the person and the car on the horizontal axis. The alerting probability decreases as the distance increases, as expected. The red parts of the bars represent the amount of meaningful warnings, which are roughly half of all warnings. By meaningful warnings we mean warnings that are only delivered to participants (pedestrians or cars) which could be really be involved in an accident. The low ratio of meaningful warnings is due to the fact that in this test scenario only one pedestrian is present.

In figure 2.3 you see the same statistics, but for a scenario with 10 pedestrians. Here the ratio is almost 100%, due to the higher number of pedestrians which makes it way more likely that a warning is meaningful, and such a scenario will be more likely in real world conditions, for example in cities.

2.2 Smart Phones as Warning Devices

In [1], another approach has been developed which is based on the same idea as [2], but it is more detailed. Moreover, it has the great benefit that no additional device for the VRU is needed because in this system a smart phone or tablet will be used as the warning device for the pedestrians.

The approach is more detailed, because it formulates precise requirements that an implementation of a V2PCS should have in order to be able to work in reality. The requirements basically boil down to the following: One has to calculate the distance between the car and the pedestrian at which the warning messages are to be delivered. In section 2.1 we have already seen that this distance should not be too big, because otherwise too many meaningless warnings would be received. But

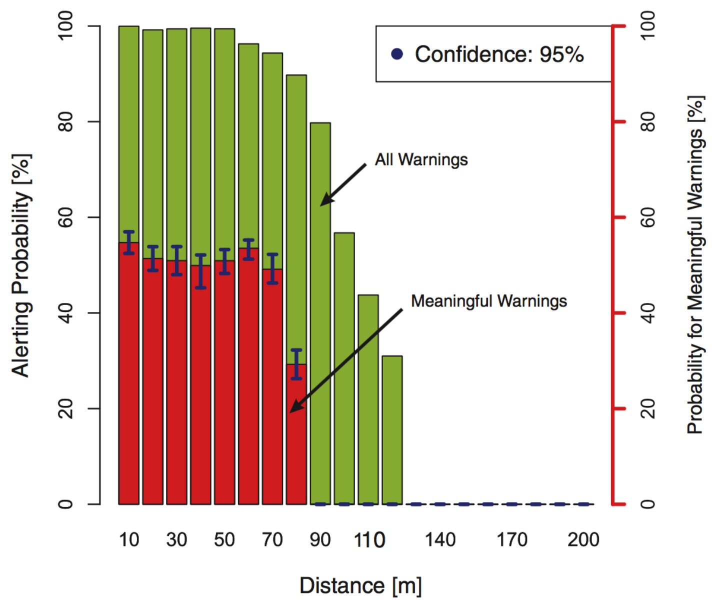


Figure 2.2 – Warning statistics in a test scenario with one pedestrian from [2]

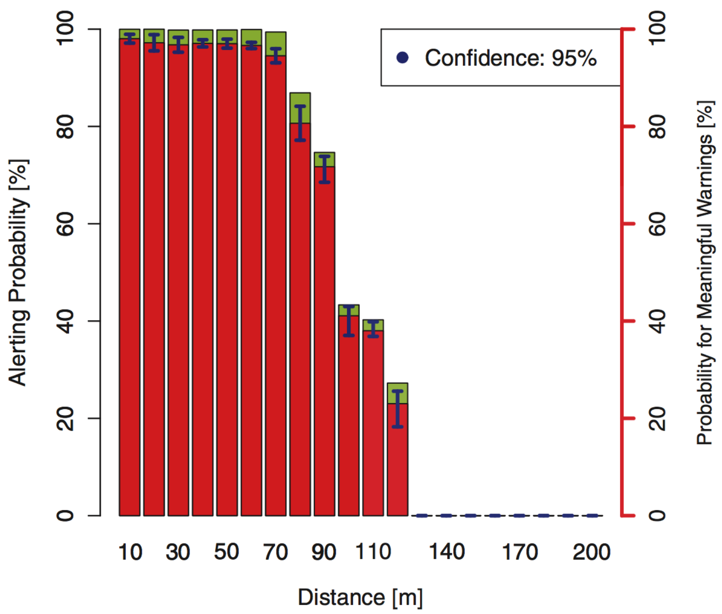


Figure 2.3 – Warning statistics in a test scenario with 10 pedestrians from [2]

accordingly, the distance must not be too small, because the pedestrian and the car driver must have enough time to react to the messages.

To calculate this distance, the authors of [1] have taken into consideration many parameters, e.g. the velocity of the car, the expected reaction time of the pedestrian, the expected positioning error of GPS (which is approximately 10m), the expected packet transmission time of Wi-Fi and so on. As an example, we take a look at equation 2.1 where the lower bound d_{min} of the distance is written down.

$$d_{min} = v \times (t_p + t_r + t_{tx}) + gnss_{err_{car}} + gnss_{err_{ped}} \tag{2.1}$$

Here v is the car's velocity. Moreover, t_p is the time for perception of the pedestrian, t_r is the reaction time of the pedestrian, and t_{tx} is the packet transmission delay. $gnss_{err_{car}}$ and $gnss_{err_{ped}}$ are the positioning errors of the car and the pedestrian, respectively. Of course, when v increases, d_{min} has to increase as well, therefore v is multiplied by the sum of t_p, t_r and t_{tx}.

For simplification, we will not look in every detail of this calculation as it is elaborate. But in principle it is crucial to compute a lower and upper bound for the distance at which the warning messages should be sent. Because you can then check whether your system always fulfills these bounds which the system from [1] does.

Finally, the distance calculated is 39.5, 52.3, and 72.0 m, when the velocity of the car is 30, 50, 80 km/h, respectively (for typical values of the other parameters). [1]

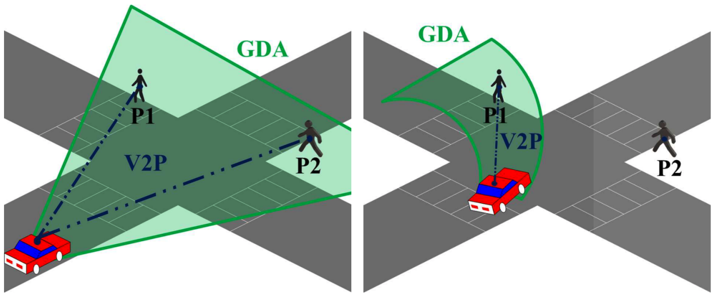
Another important concept in this context of when to send warning messages is the so called Geographical Destination Area (GDA). You can understand the concept by considering figure 2.4. In (a) a car is approaching two pedestrians, P1 and P2. As the car is yet far away from P1 and P2 it is possible that both P1 and P2 could be involved in an accident with the car, therefore both of them are in the GDA (green area).

In (b) the car has already come nearer to P1 and P2 and is currently turning left. Due to that fact, it is no longer possible for the car to approach the position of P2. So, P2 is no longer in the GDA of the car and P2 will not receive a warning message, only P2 will get one.

The GDA of a car will be computed periodically and this makes sure that even less meaningless warning messages will be sent. The GDA can be computed by taking several parameters of the car (e.g. the yaw rate, speed, etc.) into account.

2.3 Faster WiFi Message Exchange by using Beacon Stuffing

The principle from chapter 2.2 has one disadvantage that has not yet been emphasized. Typically, when two devices want to communicate with each other over WiFi, they have to establish a WiFi connection first. This process usually takes a



(a) Vehicle is moving straight. (b) Vehicle is turning.

Figure 2.4 – The Geographical Destination Area of a moving car at two different points in time, from [1]

few milliseconds which can be crucial in such a dynamic situation. But there is an approach from the authors of [4] to avoid that connection establishing phase by using WiFi Beacon Stuffing. Beacons are usually used in order to propagate the existence of a WiFi network. They are broadcasted periodically by the WiFi access point and contain information about the network (e.g. the SSID).

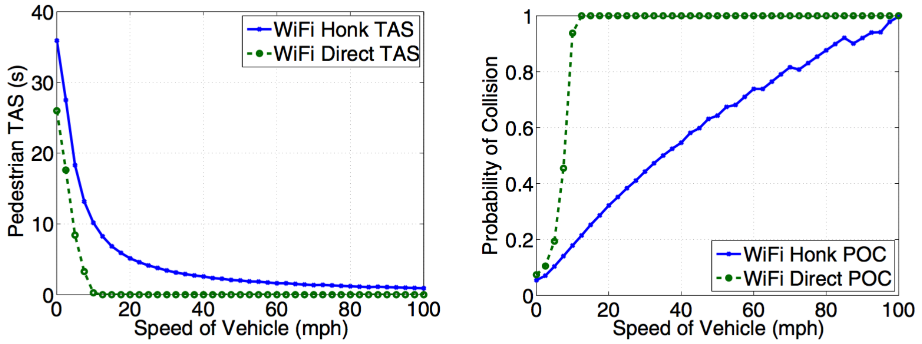
In [4] the SSID field is replaced by a so called WiFi Honk Information Packet, which includes information about the moving car, namely the latitude, longitude, speed, and direction. VRUs or other cars then receive this information and compute the likelihood of an accident.

Figure 2.5 shows the results of [4] compared to WiFi without Beacon Stuffing. Sub figure (a) shows that pedestrians have a little more time to react, but obviously if the velocity of the car comes close to 100 mph there is almost no time to react. This fact cannot be changed by Beacon Stuffing. Sub figure (b) shows the Probability of Collision (POC) after receiving an alert, depending on the car's speed, on which Beacon Stuffing has a decisive impact. POC is defined by equation 2.2.

$$\text{POC} = \frac{\text{Required Time To Stop}}{\text{Time to Recognize Alert} + \text{Time Available to Stop}} \tag{2.2}$$

POC is much smaller when using Beacon Stuffing, because "Time to Recognize Alert" and "Time Available to Stop" become greater.

The Beacon Stuffing approach is a useful technique which can be added to V2PCSSs to enhance the packet transmission time.



(a) VRU time available to stop (b) Probability of collision

Figure 2.5 – Evaluation of Beacon Stuffing, from [4].

2.4 Fusion of Perception and V2P Communication

Apart from the discipline of Wireless Networking there is another approach for detecting VRUs. Nowadays, cars are equipped with sensors which are supposed to detect objects in the environment. In [5] the different types of sensors are presented. First, cameras are used as sensors, when pictures are taken, the interesting information has to extracted from the picture. In [6], the authors explain how the extraction works. In the first step, the so called noise has to be removed from the picture, in particular the background. In the second step, the different objects in the picture have to be classified, e.g. a tree is not as important as a pedestrian. This process is done by Machine Learning Algorithms and it is difficult due to the fact that humans look quite differently, as they can have different heights, can carry around other objects, or ride on bicycles etc.

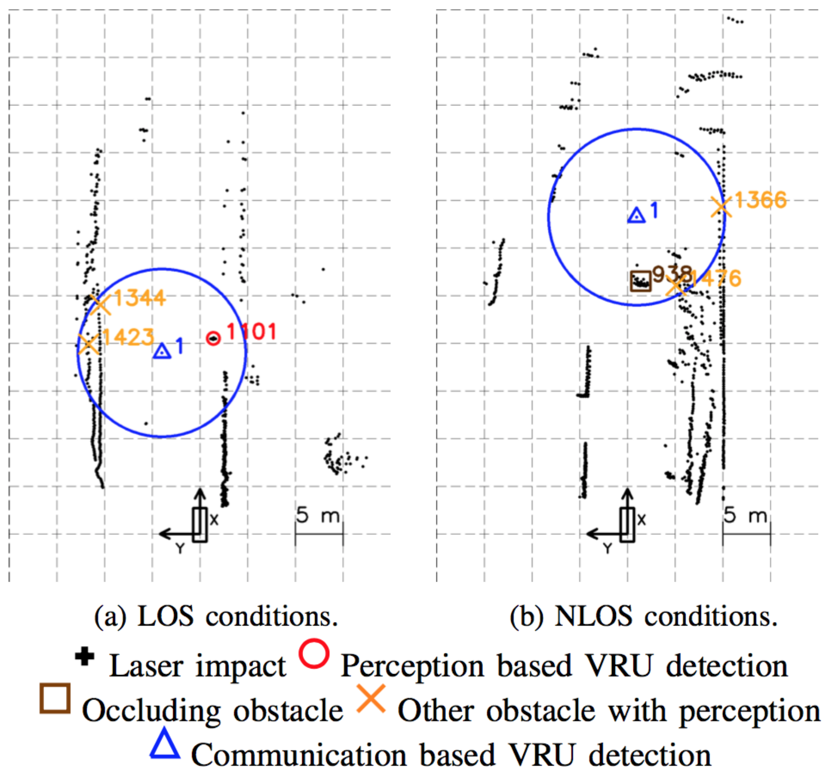
Because of the complexity of the classification step, other types of sensors are presented in [5]. Thermal sensors can be used which detect humans by their body heat. Therefore, they can locate humans very precisely and a classification step is not necessary. But in hot day conditions, they are not reliable, because the heat difference becomes smaller.

Nowadays, lasers are used most often as they are very precise and work in all weather conditions. Some years ago lasers were very expensive, but after the development in the last years they have become affordable.

The biggest disadvantage of using sensors for pedestrian detection is that they are not able to work when the pedestrian is occluded by an obstacle. So, it is not satisfying to only use Sensor Perception for protecting VRUs. But Sensor Perception has also some advantages in comparison to V2PCSs.

That is demonstrated by figure 2.6 where in sub figure 2.6 (a) the Perception System determines the position of the pedestrian more precisely. The blue triangle is the position transmitted by WiFi Communication (by using GPS), and the red circle is the position calculated by the Perception System. The Perception System works better here, because this is a Line-of-sight (LOS) situation which means that the pedestrian is not occluded by any obstacle. The Perception System is capable of determining positions very precisely whereas GPS can always have a small positioning error, as mentioned earlier.

In sub figure 2.6 (b) the condition is different, there we are confronted with a Non-line-of-sight (NLOS) situation. So, the pedestrian is not detected by the Perception System, because lasers or cameras obviously cannot look through obstacles. But the V2PCS still detects the pedestrian (blue triangle).



(a) LOS conditions. (b) NLOS conditions.

Figure 2.6 – Two different scenarios for VRU detection, from [7]
In (a) Perception works better (due to LOS conditions) and in (b) WiFi communication works better (due to NLOS conditions).

After seeing the advantages and disadvantages of both Perception Systems and V2PCSs the big task is now the fusion of data generated by the two systems. Since this process is quite complicated only the core idea will be explained here.

The objective of the fusion is to determine whether a communicating VRU is visible or hidden by some obstacle. In order to understand that, we take a look at sub figure 2.6 (a) again. The big blue cycle represents the area in which the pedestrian can be located, considering the GPS positioning error from the transmitted position of the pedestrian via the V2PCS. In (a) the pedestrian is visible, so the system could associate him with some of the objects in the blue area. But obviously, it should associate him with the correct object (the pedestrian himself). This can be done by receiving many tracks of the V2PCS, which will all be a little different due to the GPS positioning error. By looking at the set of those different locations, you can see that they will settle around a particular object detected by the Perception System and so the combined system can select the correct object and take the location computed by the Perception System as it is more precise.

In contrast, in sub figure 2.6 (b) the pedestrian is not visible. So, the Perception System will only detect other objects in the blue area. Again, by looking at the several tracks from the V2PCS, you realize that they will not settle around any of the objects detected by the Perception System. Therefore, you can conclude that the Perception System has not detected the pedestrian and rely solely on the data of the V2PCS (GPS position).

The results from [7] show that the combined system benefits from the advantages from both the V2PCS and the Perception System. In LOS conditions, the system can locate the pedestrian more precisely because of the very precise data from the Perception System. As the distance between the car and the pedestrian increases, the Perception becomes useless, and only the data from the V2PCS can be used. The same holds for NLOS conditions. Moreover, the combined system has yet not been tested for situations with many communicating cars and pedestrians which will strain the system more. Nevertheless, the fusion approach is a very useful and promising technique for VRU protection.

2.5 Wireless Protection of Motorbikes

We will now look into a different topic, which is protecting drivers of motorbikes by using Wireless Networking. Yet we have focused mainly on pedestrians as VRUs, but motorbike drivers are VRUs as well, and due to the high popularity of motorbikes this area is also very important. The protection of motorbikes is more related to Car-To-Car-Communication than it is to protection of pedestrians, and is therefore treated as a different topic in this thesis.

There are already approaches for so called Intelligent Transportation Systems (ITSs), for example in [8]. There, Wireless Sensor Networks are used in order to exchange information between cars. Those systems are also designed to enhance efficiency on the road, but of course also in order to provide more safety. Therefore, the cars will exchange messages including the typical parameters like speed, direction etc.

But those ITSs typically do not focus particularly on motorbikes, as the requirements for motorbikes are partly different to the ones for cars. In [9] such an integration of motorbikes into existing ITSs has been proposed.

One of the special requirements for motorbikes is that the communication system has to consume less energy than in cars. Therefore, the hardware from [9] is battery-powered. Also the human interface on a motorbike cannot be as rich as in car. Therefore, LEDs and a buzzer can be used.

The system works as follows. It receives the several messages from other vehicles including information like speed, direction etc. It then maintains a database of vehicles nearby and computes which other cars can possibly be involved in an accidents with the own motorbike by taking into account the own speed, direction etc. (analogously to a V2PCS as we have seen before). If it detects a dangerous situation the driver will be warned by the blinking LEDs and the buzzer.

Of course, the systems also broadcasts its data to other vehicles over WiFi in order to inform them.

Apart from that, the system is also capable of running in cars, and in that case informs the driver about other cars and also about nearby motorbikes because the own car is considered a potential threat for those other motorbikes. In contrast, when running in a motorbike, the system focuses on warning the bike driver about nearby cars as they are a bigger threat for the motorbike driver.

A future task will be to make the system runnable in 4G networks as well in order to improve the performance.

Chapter 3

Conclusion

This thesis gave an overview of the current state of research in the area of protecting VRUs by mainly using Wireless Networking. That topic is of high interest because many accidents happen between vehicles and VRUs, so a large number of accidents could be prevented.

This protection basically works by exchanging messages between VRUs and cars over a wireless channel and then calculating the likeliness of an accident between the two. We have also seen that a V2PCS as stand alone are not sufficient, mostly due to the imprecision of GPS. Therefore, Sensor Perception will be used in addition, as those sensors are generally more precise than GPS. The fusion of those two types of VRU-detection can then benefit from the advantages of both WiFi and Perception, whereby the disadvantages (imprecision of GPS and low range of Perception) can be eliminated.

Apart from that, we have also considered motorbikes as another class of VRUs. The main goal is to integrate motorbikes in ITS-systems that are already under development, but mostly for cars. This is challenging because of the special requirements that motorbikes will yield (e.g. less energy consumption, more compact human interface etc.).

In general, you can state that there are two different approaches for future research, either focusing on the fusion of V2P Communication and Perception, or concentrating on a technology more precise than GPS and then only using V2P Communication. Those technologies are currently under development, like the one in [10], where GPS is extended and the accuracy is improved by up to 48%.

The future work will show which way will lead to better results.

List of Abbreviations

GDA	Geographical Destination Area
ITS	Intelligent Transportation System
LOS	Line-of-sight
NLOS	Non-line-of-sight
POC	Probability of Collision
V2PCS	Vehicle to Pedestrian Communication System
VRU	Vulnerable Road User

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