A Physical Analysis of an Accident Scenario between Cars and Pedestrians

Alexander Flach and Klaus David

Chair for Communication Technology (ComTec), University of Kassel
Kassel, Germany

david@uni-kassel.de

***Abstract*—Every year still thousands of people are injured or killed in accidents with cars, trucks and busses. Many of these people are pedestrians or cyclists. Several research groups work on solutions to avoid accidents between cars and pedestrians with the help of different technologies.**
In this paper we present an innovative approach for a collision avoidance system which should be able to tackle these accidents. To understand the potential of this approach, we will present a physical analysis of the system time available between detection, warning and reaction. We also discuss different architectures of our approach utilizing ad-hoc and/or cellular technologies. Additionally, we present experimental results of connection establishment and ping response times of these wireless technologies.

I. Introduction

The official figures given by [1] show that 16700 pedestrians were killed in accidents with cars in 2006 in the 29 countries listed. Inattention either by the car driver or by the pedestrian is one reason for dangerous situations and collisions between cars and pedestrians. As most accidents between cars and pedestrians occur in urban areas we will consider the following typical accident scenario as a representative accident scenario, see Fig.1: A car drives down the street from left to right at 50km/h. A pedestrian is setting out to cross the street passing through the gap between parked cars. He is not visible to the car driver because of the parked cars. The pedestrian does not pay attention to the traffic and steps on to the street. As soon as the pedestrian steps on to the street the pedestrian becomes visible to the car driver. At this point it may already be too late to react and an accident may happen.

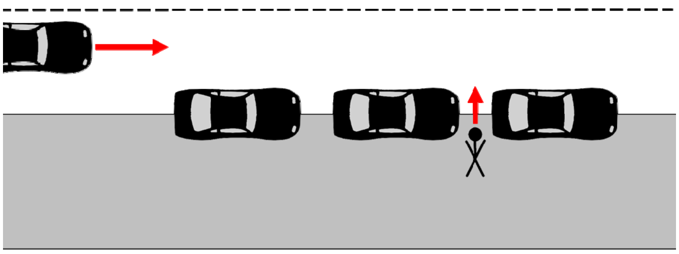

Fig. 1: TYPICAL ACCIDENT SCENARIO

This accident scenario, as well as other typical accident scenarios, contains different challenges to be solved to make the driver aware of the pedestrian and/ or make the pedestrian aware of the approaching car.

These challenges include: to get the positions of pedestrian and car, to conclude whether an accident might happen or not i.e. to be able to filter between unimportant and important pedestrians/ cars, to be able to communicate all necessary information, like positions, warnings etc. Finally appropriate action must be taken, like warnings.

In this paper we address two issues: Presenting our idea of the architecture of a collision avoidance system and giving both an analytical as well as a measurement based analysis of the timing, one prerequisite to facilitate such a collision avoidance system.

The document is organised as follows: Section II gives an overview of the literature of the different approaches of pedestrian detection and collision avoidance as well as a short description of our idea of the architecture of a collision avoidance system.

In Section III, a physical analysis of the accident scenario above, describing the dependencies of different parameters influencing the system time available for a collision avoidance system is given. Section IV presents the results of our experimental measurements of connection establishment times and ping response times within ad-hoc and cellular networks to investigate if these radio communication technologies are candidates for implementing a collision avoidance system. In Section V the conclusions are given.

II. Different approaches of pedestrian detection and collision avoidance

Several research groups are working on different approaches to find a solution to the challenge of pedestrian detection to avoid collisions between cars and pedestrians. The approaches can be categorized as:

- video based approaches based on visible light,
- video based approaches based on infrared light,
- laser distance measurement approaches and
- radar based approaches.
- Tag based approaches

In [2] an overview of the different approaches is given. The sensors used in these approaches are either mounted on a car or on road side infrastructure. The approaches have in common that they need line of sight to the pedestrian to work

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properly. The system may not work properly or fail altogether if there is insufficient contrast between the pedestrian and the surroundings, if the pedestrian is partially obstructed by an object or if there is no line of sight at all see Fig. 2.

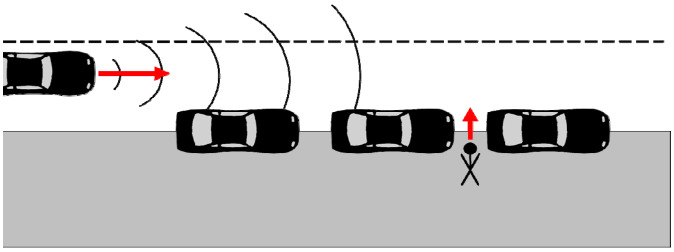


Fig. 2:TYPICAL ACCIDENT SCENARIO WITH RADAR AS PEDESTRIAN DETECTION

Research is also done on tag based approaches as described in [3] and [4]. In this approach an RFID tag, attached to the pedestrian is used by a transmitter and receiver device mounted on a car to detect the position of the pedestrian, track the movements and calculate predictions of the next movements of the pedestrian. The system described in [3] and [4] works for detecting pedestrians up to a distance of 60m. This promising approach needs no line of sight but has a limited maximum communication radius, and offers little information about the pedestrian and therefore advanced filtering might be difficult.

An approach presented in [5] uses GPS based location and radio communication between a mobile phone of a pedestrian, a navigation system of a car and a central server for pedestrian detection and collision avoidance. The central server estimates the risk of a collision with the help of location data and additional information, which is not specified in detail. The result is sent to the mobile phone and the navigation system. In case of high collision risk a direct communication based on WLAN is established. We have a very similar vision as the approach presented in [5] but with slightly different architectures and a more detailed view on filtering. We do consider a solution for collision avoidance based on cellular networks and/ or ad-hoc networks as well as using three different ways of exchanging profile and position data: ad-hoc network based as shown in Fig. 3, cellular network based which is shown in Fig. 4 and a hybrid communication combining the use of cellular networks and ad-hoc networks.

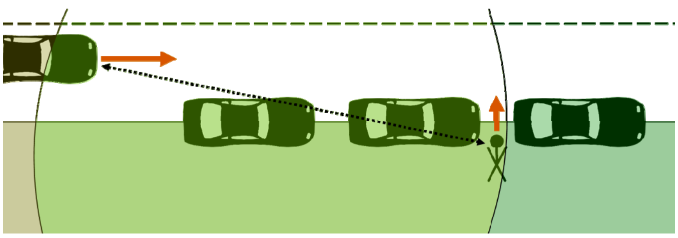


Fig. 3: COLLISION AVOIDANCE SYSTEM BASED ON AD-HOC NETWORKS

The different communication technologies also enable different architectures for placing processing units and load balancing. If ad-hoc networks are used the calculations have to be done by either the car and/ or the mobile phone of the pedestrian. When cellular networks are used it is also possible to use a central server for calculations and just send the results to the car and pedestrian. As the server is dedicated for collision avoidance the load of the processing unit of the car and/ or the mobile phone of the pedestrian is reduced. We assume that the location information of the pedestrian as well

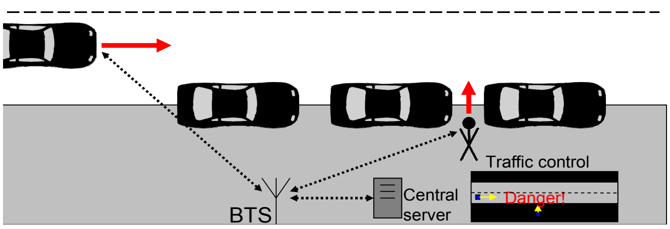


Fig. 4: COLLISION AVOIDANCE SYSTEM BASED ON CELLULAR NETWORKS

as of the car is given with sufficient precision like 10cm either by e.g. GPS or Galileo or another positioning approach.

This location information will be available to the collision avoidance system which runs depending on the architecture on a mobile phone of a pedestrian, in a car-system and/ or on a central server. Furthermore context information and an extended information set, i.e. the pedestrian's personal profile, can be available for use by the collision avoidance system for an intelligent filter. The personal profile can contain information about the pedestrian like age, agility and acceleration, maximum speed, personal calendar, etc. as well as a movement history, the current speed and direction. When a car enters a certain distance to the pedestrian, the personal profile can be exchanged with the help of radio communication technologies. The exchanged as well as context information is used by the filter mechanism to make calculations about the risk of a collision. If the risk of a collision is estimated as high, a warning is sent to the car driver and/ or the pedestrian. Further details of this approach will be presented in a future paper.

All collision avoidance approaches discussed above, independent of the different approaches, are faced with the following constraint. They all have to do their operations of detection, calculation, estimation and warning in the very short time available. A comprehensive analysis of the timing will be presented below.

III. PHYSICAL ANALYSIS OF AN ACCIDENT SCENARIO

In this section we will present a physical analysis of the different time intervals that occur in an accident scenario as shown in Fig. 5. The time available for detection of a car/

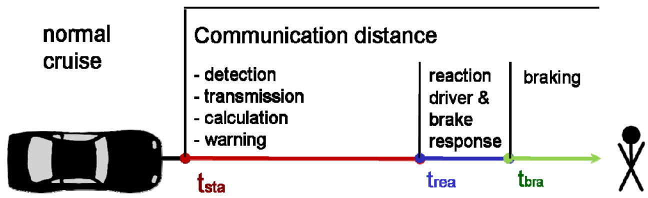


Fig. 5: OVERVIEW OF TIME INTERVALS IN THE SCENARIO

pedestrian, transmission of data, calculations and warning to make the driver/ pedestrian aware of dangerous situations to avoid a collision, i.e. the system time available t_{sta}, is determined by the speed of the car v_{car}, the deceleration a_{car} of the car and the communication radius s_{com} see (1). Without much loss of generality, the speed of the pedestrian is assumed to be zero here.

$$t_{sta} = \frac{(s_{com} - (\frac{v^2_{car}}{2 * a_{car}}))}{v_{car}} - t_{rea} \quad (1)$$

- s_{com}: the communication radius which also can be named detection distance is the distance up to which a mobile phone of a pedestrian and a communication device of a car are able to communicate with each other. If cellular networks are used for communication the communication radius is then virtual. This still makes sense to have a first spatial filtering for detecting only pedestrians which are close and might cause a collision. This spatial filtering, automatically neglects pedestrians which are out of range and therefore not "able" to be involved in collisions and reduces the complexity of the further filtering.
- a_{car}: the deceleration of the car is calculated by $a_{car} = v_{car}{}^2/2s$, with *s* being the braking distance from the initial speed to 0 happening in the braking time t_{bra}.
- t_{rea}: this value consists of two parts. The first part is the driver's reaction time which is the time between the occurrence of an event and the driver's reaction. The second part is the time taken up the brakes' response to the driver's action. The studies in [7] and [8] analyse this topic by means of experimental measurements and give an average reaction time of a driver with 0.63s. The average response time of the brakes is given with 0.2 seconds. These two values added together result in 0.83 seconds on average between the occurance of an event and the start of the car's braking process. This average value is used in our analysis throughout this paper.

If the system time available t_{sta}, the time for reaction of driver and brakes t_{rea}, and the time for braking t_{bra} are added together the result is the total time t_{tot} which is the time available in the communication radius s_{com}.

A. Dependency between a_{car} and t_{sta}

With the help of improved brakes collisions can be avoided and the system time available for a collision avoidance system is increased. In Fig. 6 the system time available $t_{systime\_av}$ as a function of a_{car} is shown for different combinations of communication radii s_{com} and v_{car}. a_{car} is chosen between 8m/s² and 11m/s² because these are typical values for deceleration. Average modern cars achieve a deceleration of 10.4m/s² which can be calculated with the help of the braking distances given by [6]. The v_{car} for moving vehicles is chosen between 50km/h and 70km/h. These are "typical" speeds in urban areas considered. s_{com} of 50m and 100m are chosen to show how t_{sta} differs when the communication radius is doubled. t_{sta} shows a linear dependency on a_{car}. The chosen change in a_{car} just produces changes in the range of 0.2 - 0.4 seconds but this minimal time difference, however, is nonetheless important because sometimes these 0.2 - 0.4 seconds can decide if an accident happens or not.

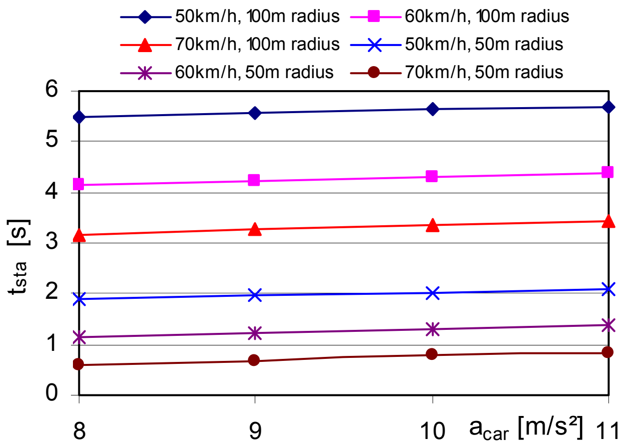


FIG. 6: T_{STA} AS A FUNCTION OF A_{CAR}, SHOWN WITH DIFFERENT V_{CAR} AND S_{COM}

B. Dependency between s_{com} and t_{sta}

To show the dependencies between s_{com} and t_{sta} calculations for s_{com} between 50m and 125m, a_{car} = 10.4m/s² and v_{car} = 50km/h are done. The increase of t_{sta} that can be achieved by increasing the radius of s_{com} is also linearly dependent. This linear dependency can be seen in Fig. 7. The linear dependency is a result of the constant v_{car} with which the car covers distances larger than the braking distance, in our case here 9.725m.

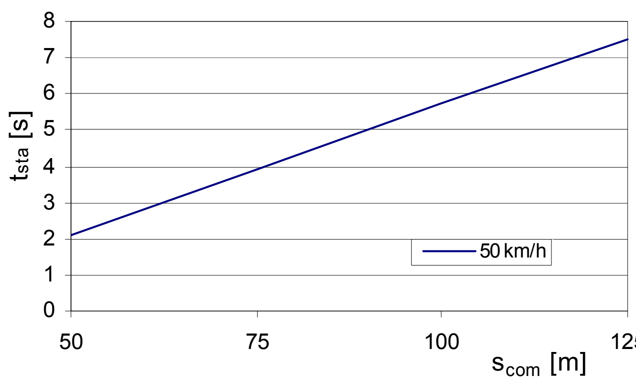


Fig. 7: T_{STA} AS A FUNCTION OF S_{COM}

C. Dependency between v_{car} and t_{sta}

The last parameter influencing t_{sta} is v_{car}. The increase of v_{car} causes a quadratic increase of the braking distance and decreases the time needed to cover a distance. The result of increasing v_{car} is presented in Fig. 8 as well as the information up to which speed a collision avoidance system may work for a certain distance if the information about time needed for transmission and calculations is a known value. The chosen a_{car} in this diagram is 10.4m/s² and s_{com} is 50m. The figure shows the decrease of t_{sta} for increased speeds being the result of two influencing components being the decreased time to cover a certain distance and the increase of the braking distance.

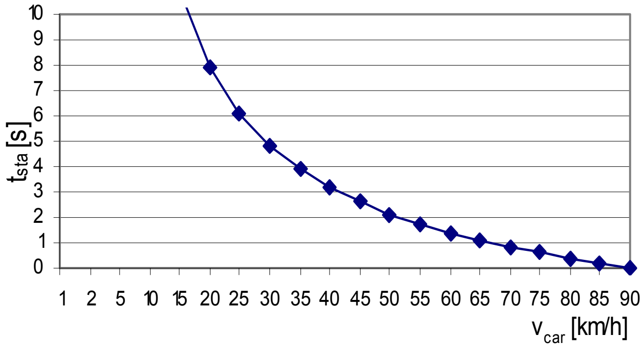


FIG. 8: T_{STA} AS A FUNCTION OF V_{CAR}

For the chosen a_{car} braking distances are 9,725m for 50km/h and 37,5m for 100km/h. So the available system time decreases in the presented example from about 6.1 seconds at 25km/h to about 2.1 seconds at 50km/h and to about 0.8 seconds at 70km/h. At a speed of about 90km/h there is no more time available for a collision avoidance system, for the chosen scenario parameters.

As an overall conclusion of the section the system time available for a collision avoidance system using the scenario we described in the beginning, i.e.: v_{car} = 50km/h, s_{com} = 50m, a_{car} = 10,4m/s² and t_{rea} = 0.83s is given by t_{sta} = 2.1s and t_{sta} = 5.6s if s_{com} is extended to 100m. As we will also show with practical measurements in the next section we strongly believe that the system time available of about 2 seconds gives sufficient time for the realisation of functioning, real systems. In addition, it is worth mentioning that with 2 seconds the time available is larger than with the radar, video and laser based approaches discussed in the introduction.

IV. TIME DELAY MEASUREMENT RESULTS FOR RADIO COMMUNICATION TECHNOLOGIES

To relate our physical analysis given above with real wireless systems we present in this section measurement data. For a future collision avoidance system potentially new wireless system standards such as IEEE 802.11p might be the best choice. Nevertheless, to obtain a first evaluation regarding the feasibility of such a collision avoidance system, we present measurement data of currently available systems. I.e. we use currently available products, specifically IEEE 802.11b, GPRS, EDGE, UMTS, HSDPA, HSUPA. The latter two are optimized for lower latencies whereas all other standards are not optimized for this requirement. It can be expected that future standards such as IEEE 802.11p or LTE will be even better concerning low latencies.

D. Ad-hoc architecture measurements represented by WLAN

For the measurements we have used the following devices:

- PDA: HP iPAQ H4150
- Smartphone: Qtek 8310, N95
- Typical laptops: Toshiba M200, Siemens Lifebook C1320

The PDA and smart phone are representatives for mobile devices of pedestrians. We made measurements with all combinations of devices connected to laptops for communication radii up to 60m.

First we consider the time needed to establish a connection in ad-hoc networks because a connection has to be established between the communication devices first before data can be exchanged. The time between one communication device entering the communication radius of another device and a connection being established we refer to as connection establishment time.

Our measurement results, see Fig. 9, show that there is quite a variation for different devices of the connection establishment time. For some it is less than 1s and for others plus/ minus 4 seconds. The variation due to distances is negligible.

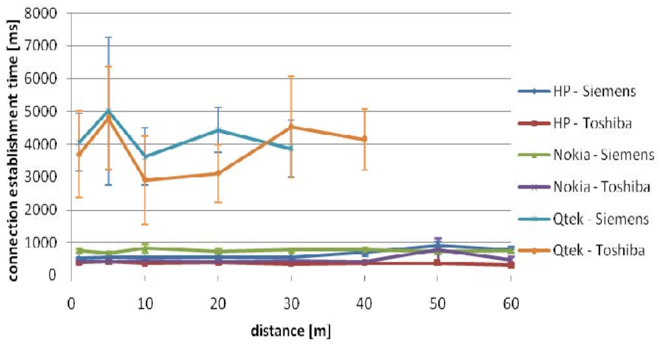


Fig. 9: CONNECTION ESTABLISHMENT TIME AD-HOC NETWORKS.

Second, we consider the time needed to exchange data between the communication devices. To get an estimation about time needed for data exchange we have sent ping packets giving the minimum roundtrip time of data exchange. The measured ping response times for communication radii up to 60m are shown in Fig. 10.

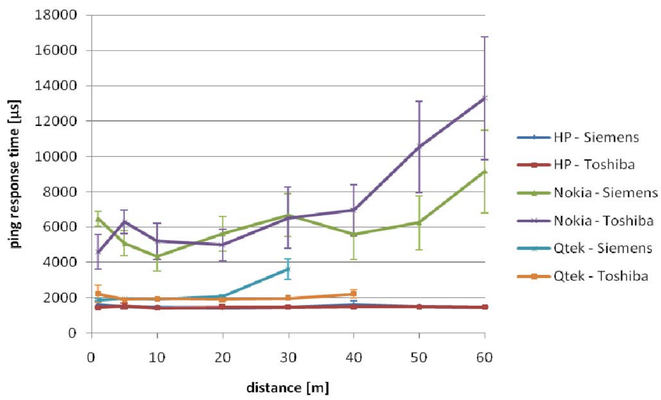


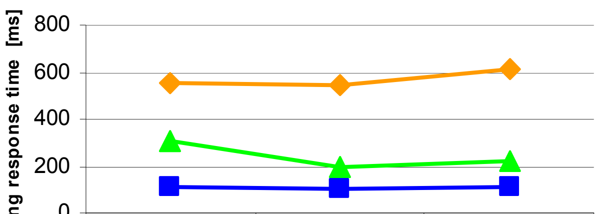
Fig.10: PING RESPONSE TIMES WLAN, DIFFERENT DISTANCES, DIFFERENT COMBINATIONS OF COMMUNICATION DEVICES

For the length of the ping packet we chose 50 Bytes to represent some information of the personal profile. Again there are variations between different devices. Nevertheless, even for the worst result of 16ms, putting this into respect with the overall system time available of 2 seconds, from which we have to subtract one second of connection establishment time, leaves us the possibility to have more than 60 ping responses within the time constraints.

B. *Cellular architecture measurements of current systems*

For cellular networks we can assume zero connection establishment time. This is due to the fact, that the use of cellular networks allows for the assumption that both the pedestrian and the car have established a cellular connection well before a distance of 100m.

For our tests we used a HP Pavilion ze2000 laptop and Novatel Wireless Merlin U530 GPRS/ UMTS PCMCIA card for GPRS und UMTS measurements and a Huawei E870 PCMCIA card for HSDPA/ HSUPA measurements. We made ping response time measurement tests to different servers to eliminate the influence of a server being overloaded or having other problems with connectivity. The ping response times for cellular networks are shown in Fig. 11.



	www.google.de	www.t-online.de	141.51.12.84
GPRS	554	543	614
UMTS	304	198	224
HSDPA	107	101	108

Fig. 11: PING RESPONSE TIME FOR CELLULAR NETWORKS.

As can be seen GPRS has a maximum ping response time of about 600ms, UMTS shows ping response times within a range of about 200ms – 300ms, whereas HSDPA with HSUPA as the latest cellular network has a delay of about 100ms.

The ping time as such are one order of magnitude larger than for WLAN. Nevertheless the overall time balance for HSDPA for example, will still allow for about 20 pings for the time constraints of 2 seconds, because here the connection establishment time is 0.

With the help of the physical analysis and the practical measurements we did, we have shown that our approach of a radio communication based collision avoidance system between cars and pedestrians presented here is feasible based on the chosen scenario parameters. The measurements we did with current smartphones, a PDA and laptops equipped with the current radio communication technologies instead of using laptops with car roof antennas as presented in [9] to show that these available and already used devices are adequate to be used for information exchange in our approach of a collision avoidance system. The remaining time for collision avoidance may even be increased by expanding the communication radius if cellular networks are used or by optimized radio communication technologies available in the future.

V. Conclusion

In this paper we have presented the different issues related to collision avoidance between cars and pedestrians being pedestrian detection, filtering, prediction calculation, communication, and warning. We have proposed an innovative approach for a collision avoidance system, being based on ad-hoc or cellular networks for the communication and on filtering which can be supported by personal profiles and context awareness.

One important prerequisite for any working collision avoidance system is to stay within the timing constraints. A comprehensive analysis, considering the important parameters: communication radius, deceleration and speed of the car, respectively, has been presented in this paper. For a car driving with 50km/h, a deceleration of 10.4m/s², a reaction time of 0.83s, and a communication radius of 50m the system time available is 2.1s (for 100m it is 5.6s).

As has been confirmed by measurements, 2s would be sufficient for a non latency optimized ad-hoc system using IEEE 802.11b, to include the connection establishment time (about 1s and still being able to have several 10^{th} of profile exchanges (each one lasting about 2ms)). Also confirmed by measurements, e.g. HSDPA/ HSUPA with a roundtrip time of about 100ms would allow for several loops of profile exchange.

So the investigation presented here has shown that the timing constraints are tight but we are convinced that it should be possible to handle them. For a further evaluation of our innovative approach further investigations, especially of the filter and its timing demands and of the influence of position inaccuracy are required.

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