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MSc THESIS

WATCH-OVER; A cooperative approach on vulnerable road user protection

Daan Mastenbroek

CE-MS-2009-23

Abstract

Every year many vulnerable road users get injured or die in accidents with vehicles that could have been prevented if the vehicle driver and the vulnerable road user were aware of the dangerous situation that was ahead. Besides non-technical aids like road safety education and wearing lights for more visibility, there are numerous road safety projects. Manufacturers and governments aim at the reduction of traffic accidents. Road safety is a major concern of the European Union and therefore they have started amongst others the *vehicle-to-vulnerable road user cooperative communication and sensing technologies to improve transport safety* [Watch-Over] and *cooperative vehicle-infrastructure systems* [CVIS] projects. These projects should come up with innovative ideas to reduce the number of accidents and casualties.

The innovative concept of Watch-Over is a system based on the cooperation between the vulnerable road users and vehicle drivers. By means of a wearable device for the vulnerable road user and an onboard unit for the vehicle.

This thesis work contributes to this project by improving the wearable device capabilities, by increasing the working range and by adding functionality. It also contributes to the CVIS project by the integration of this cooperative approach in the their open service environment, which enables a wider use of this concept.

Working Tomorrow / Business Competence Intelligent Transport Systems

Faculty of Electrical Engineering, Mathematics and Computer Science

WATCH-OVER; A cooperative approach on vulnerable road user protection
protecting the vulnerable road user

THESIS

submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE

in

COMPUTER ENGINEERING

by

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I dedicate this document to my girlfriend and my family,
for their love and support.

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Daan Mastenbroek
Delft, The Netherlands
August 23, 2009

1 Introduction

This MSc project aims at creating a hardware implementation of a wearable device and at integrating it into a cooperative open service environment. The wearable device is designed for vulnerable road users and will cooperate with in-vehicle safety systems. This system is developed for increasing the chance of detection of vulnerable road users by vehicle drivers and thus reducing the number of causalities. This project was carried out at the Working Tomorrow program of Logica.

1.1 Logica

This Masters thesis is written during an internship at Logica Netherlands. Logica is a leading IT and business services company, employing 40,000 people across 36 countries. It provides business consulting, systems integration, and IT and business process outsourcing services. Logica works closely with its customers to release their potential - enabling change that increases their efficiency, accelerates growth and manages risk. It applies its deep industry knowledge, technical excellence and global delivery expertise to help its customers build leadership positions in several markets including telecommunication, financial services, energy and utilities, industry, distribution and transport and the public sector [26].
The project is placed inside the Working Tomorrow [WT] [27] program of Logica. As depicted in Figure 1.1, the WT program is a product of cooperation between all divisions. Within this program, students can review new technological developments on feasibility and possibilities for their graduation project or thesis. Prototypes and demonstrators are developed by the students to present the new insights gained and showing how new technology can be applied in real-world applications. Along these lines, the students get a possibility to carry out innovative projects in a commercial surrounding and Logica gets to emphasize its innovative character.
Before its latest reorganisation Logica consisted of several divisions, which are showed in the middle layer in Figure 1.1. In each division several Business Units are distinguished. The research this Master's thesis reports on, is placed in the public sector division in the Business Unit (BU) Business Competence (PSBC) and will be employed in the competence group Intelligent Transport Systems (ITS).

The following subsections describes the two European projects within which this thesis project was done. The Watch-Over project and the CVIS project.

1.1.1 Watch-Over

The Vehicle-to-Vulnerable roAd user cooperaTive communication and sensing teCHnologies to imprOVE transpoRt safety [WATCH-OVER] project is an European project

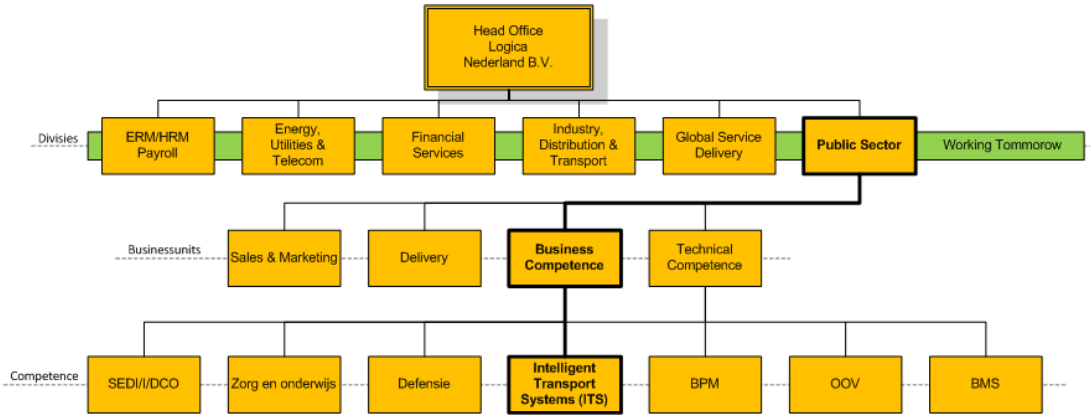


Figure 1.1: Organization structure of Logica Netherlands [26]

within the objective 'eSafety Cooperative Systems for Road Transport'. The goal is the design and development of a cooperative system for the prevention of accidents involving vulnerable road users in urban and extra-urban areas [15, 32]. This is in line with the ambitious goal of the European Union to reduce road fatalities by 50% [10]. The innovative concept is represented by an on-board platform and a vulnerable road user module, the system is based on short range communication. This system can be used in cooperation with other in-vehicle safety systems like autonomous sensor systems based on radar or infrared.

1.1.2 CVIS

Cooperative Vehicle-Infrastructure Systems [CVIS] [19] is a major new European research and development project aiming to design, develop and test the technologies needed to allow cars to communicate with each other and with the nearby roadside infrastructure. Within CVIS, an open service architecture framework [FOAM] [25] is defined and validated for cooperative system applications. This FOAM environment is build on the OSGi [22] Service Platform Knopflerfish Pro [16]. Knopflerfish Pro is an open source implementation of OSGi and is maintained by Makewave. It is used as execution environment for both in-vehicle and for the road-side equipment. Makewave Ubicore is used as the CVIS deployment and provisioning system, enabling life-cycle management of CVIS applications in vehicles and road-side equipment. Applications can reuse developed common core components within the open architecture.

1.2 Context and motivation

The huge number of road accidents that involve vulnerable road users like pedestrians, cyclists and motorcyclists is of concern of the European Union government. The European Commission plans to marshal efforts around the target of halving the number of road deaths over that period [10]. There are several initiatives started by the European

Union to explore and test possible solutions to reduce the number of road accidents. WATCH-OVER is one of them, with as target reducing the number of road accidents involving vulnerable road users.
Two of the several objectives of the CVIS project are to improve traffic safety for all road users and better and more efficient response to hazards. Both of these objectives correspond with our goal to reduce the number of road accidents involving vulnerable road users.
Logica is a leading provider of mobility telematics services and solutions and involvement in innovating public sector projects for the European Union enables them to stay in this market and let the clients profit. The Working Tomorrow program at Logica focuses on innovative projects and developing prototypes and demonstrations of new concepts and the work presented in this thesis was carried out within the context of this program.

1.3 Problem statement

For the Watch-Over project Logica needed to develop a prototype wearable device for the vulnerable road user. This task was wrapped in a WT assignment because of its innovative character and the lack of hardware based knowledge within Business Competence Unit. In the following subsections the research questions and the deliverables for this assignment are mentioned.

1.3.1 Research Questions

There is already an initial wearable device manufactured according to the Watch-Over specifications. The research questions will discuss some of the weaknesses of this implementation, so we can use these lessons for the improved prototype. The following research questions were stated.

1. An initial version of the wearable device uses CSS modulation technique from Nanotron as the communication medium and for ranging between the devices. Tests have shown that it works but not that well. Are there better technologies available that can be implemented instead?

2. Which extensions can be added to extend the usability of the wearable device?

Beside the Watch-Over project, this prototype for the wearable device could also be used within a CVIS application to show the possibility of integration of third party solutions in the CVIS FOAM framework. So a third assignment was:

3. How can the for the vehicle developed on-board module be integrated into the open service environment of CVIS? The on-board module is the whole in-vehicle system that initiates the communication to the vulnerable road user, performs the determination of the situation and informs both the vulnerable road user and the vehicle driver of the possible danger.

in Chapter 3, these questions and their solutions to the questions will be discussed. As most of the accidents with VRUs happen at urban areas [12], we limit our scope to these areas.

1.3.2 Main Deliverables

This assignment has also two deliverables.

1. A working prototype of the wearable device with which Logica can demonstrate the possibilities of current technological state for cooperative road safety solutions.
2. A CVIS application using the prototype in a cooperative framework.

1.4 Thesis framework

The layout of this thesis is as follows. Chapter 2 gives the background information that was needed for this project. In Chapter 3 the research questions stated in Section 1.3.1 will be discussed and conclusions will be drawn to improve the initial Watch-Over wearable device prototype. In the next chapter, Chapter 4 the implementation of these improvements will be described. In this chapter is also the implementation of both deliverables described. Chapter 5 describes several tests that are performed and the conclusions that can be drawn from these tests. Finally, Chapter 6 contains the conclusion that can be drawn from this project, presents an evaluation and ends with recommendations for further research on this subject.

2 Background information

Just like vehicle drivers, the current sensor technologies cannot see behind obstacles. So there is a need for location information from other road users / road side units or from the vulnerable road uses themselves. The Watch-Over project focuses at providing location information by the vulnerable road users themselves, by using a wearable device to communicate with in-vehicle systems. The European funded projects PROTECTOR [23] and SAVE-U [33], have also been working on the prevention of accidents involving vulnerable road users. Both projects have been investigating systems based on in-vehicle sensors. These systems can be combined with the Watch-Over approach to improve the usability in those scenarios were the vulnerable road user is not hidden by obstacles. In Section 2.1 the wearable device for the vulnerable road user will be discussed and in Section 2.2 we will look into the CVIS project and their implementation of an open framework within the in-vehicle systems.

2.1 Watch-Over wearable device

The Watch-Over wearable device is a small device which could be integrated within other equipment a road users already carries with him, like a mobile phone. It should evolve in a simple and low cost on-board system with a flexible and open architecture [32].

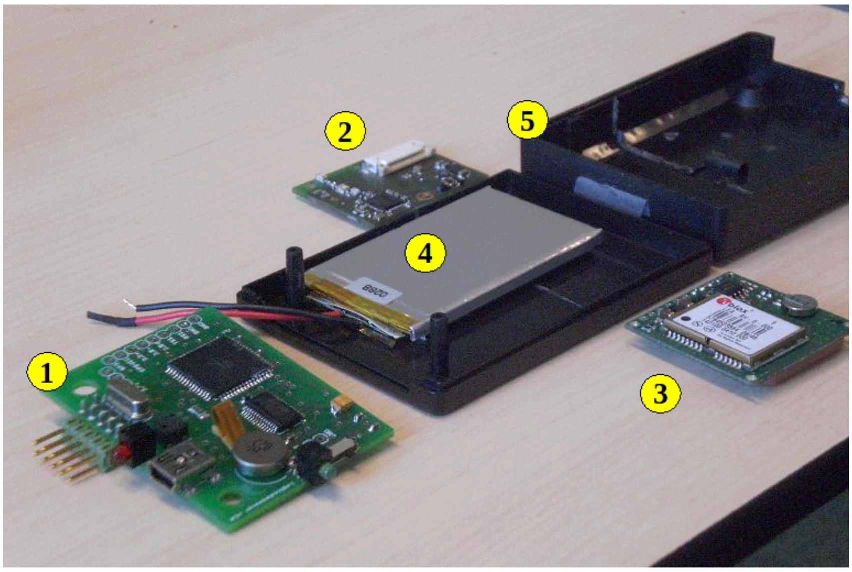


Figure 2.1: Initial prototype of the wearable device; With Circuit board (1), Communication device (2), GPS receiver (3), Battery (4) and Casing(5)

In Figure 2.1 we have a picture of the initial prototype of the wearable device. The device is constructed according the specification of the Watch-Over project [29]. In Figure 2.2 we have an overview of the whole system with both the wearable device for the vulnerable road user and the in-vehicle on-board unit.

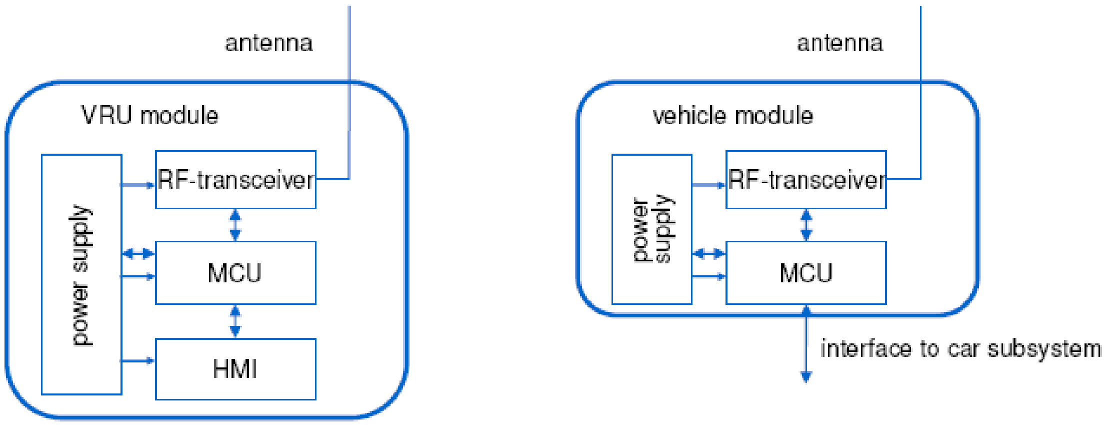


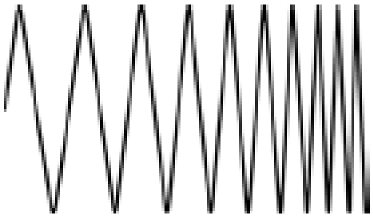
Figure 2.2: System architecture of Watch-Over modules

2.1.1 Communication

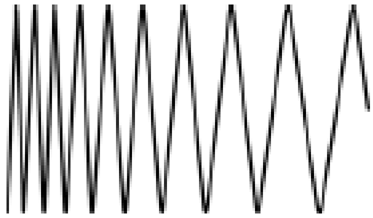
The Watch-Over system uses communication devices from Nanotron [50]. These devices are based on a Chirp Spread Spectrum [CSS] technology [13]. This technique makes it possible to do ranging measurements while communicating.

CSS CSS is an Ultra-wideband based technology within the IEEE802.15.4a specifications. It is an adaptation of the Multi Dimensional Multiple Access [MDMA] communication method. MDMA consist of a combination of Amplitude Modulation, Frequency Modulation and Phase Modulation. MDMA is suitable for low power requirements with up to medium data ranges. The actual information is embedded in the phase so that the amplitude of the signal is constant. The Frequency Modulation is used for making the signal more robust against disturbances. It is possible to vary the amplitude to reduce the transmission power, for less important data. The CSS technology from Nanotron operates in the 2,45 Ghz band and is therefore somewhat similar to ZigBEE [46], but with less protocol overhead and different signal modulation. CSS is, similar to other MDMA communication methods, based on the use of chirps. A chirp is a linear frequency modulated impulse with a large time-bandwidth product. There are up-chirps and down-chirps, they are depicted in Figure 2.3.

Larger time-bandwidth products give better resistance against disturbances during transmission. The duration of these chirps is fixed at 1 microsecond, together with a effective bandwidth of 64 Mhz for the signal, the gain of CSS should be around 17 dB. The range of the Nanotron implementation is specified at 100 meters, but this is only in optimal conditions and with normal large antennas. In the wearable device smaller



(a) Upchirp



(b) Downchirp

Figure 2.3: (a) upchirp and (b) downchirp

antennas are used, therefore we have to cope with smaller ranges. Nanotron technologies uses an enhanced CSS, called a chirp modulation which combines chirp-signals with differential phase shift keying. Called DBO-CSS, where four sub-chirps form one chirp and four up or down sequences of sub-chirps form a set of four chirp symbols. These four different modulated chirps help to avoid the interference of nearby neighbouring nets.

Communication Protocol The Communication between the wearable device and the on-board unit is based on a proprietary mac based communication protocol. Every vehicle module and wearable device should have its own unique mac address. For now these have to be manually specified. There are three types of messages; normal data, broadcasts and ranging requests. There is a list of data and broadcast commands and answer length specified within the Watch-Over documentation [47]. The NanoLOC tranceivers use the Portable Protocol Stack [PPS] [11] from Nanotron.

2.1.2 Localization

The watch-over in-vehicle prototype can use two different methods to acquire the location of a vulnerable road user. The first method is to request the GPS coordinates from the wearable device. The second method is to use the ranging functionality of the NanoLOC device, with two or more receivers on a fixed location in the car a relative location can be acquired.

2.1.2.1 GPS

The GPS module, an Antaris 4 from u_blox is used to acquire the location [9]. This receiver has a passive antenna, which makes it slightly more difficult to acquire a good location fix. The error is stated between the 2 and 10 meters. It sends NMEA data over the serial connection to the microprocessor which just picks out the coordinates and sends it to the car or request. The location errors for both the GPS receivers in the vehicle and in the wearable device can be partly the same resulting in less error for the relative location of both. This is due to the errors in the satellite's atomic clocks, inconsistencies of atmospheric conditions and errors in the satellite trajectory. These errors will be the same for both the GPS receiver in the vehicle as well as the GPS receiver in the wearable device.

2.1.2.2 Direct distance determination with NanoLOC tranceiver

The NanoLOC communication modules uses Symmetrical Double Sided Two Way Ranging [SDS-TWR] [8] for their distance measurement. A calculation process based on propagation time of the communication messages. It does two measurements one from the in-vehicle device and one from the wearable device. This resolves the problem of clock drift and other inaccuracies. It takes approximately one nanosecond to the measurement [14]. The two way ranging is depicted in Figure 2.4. For a relative location

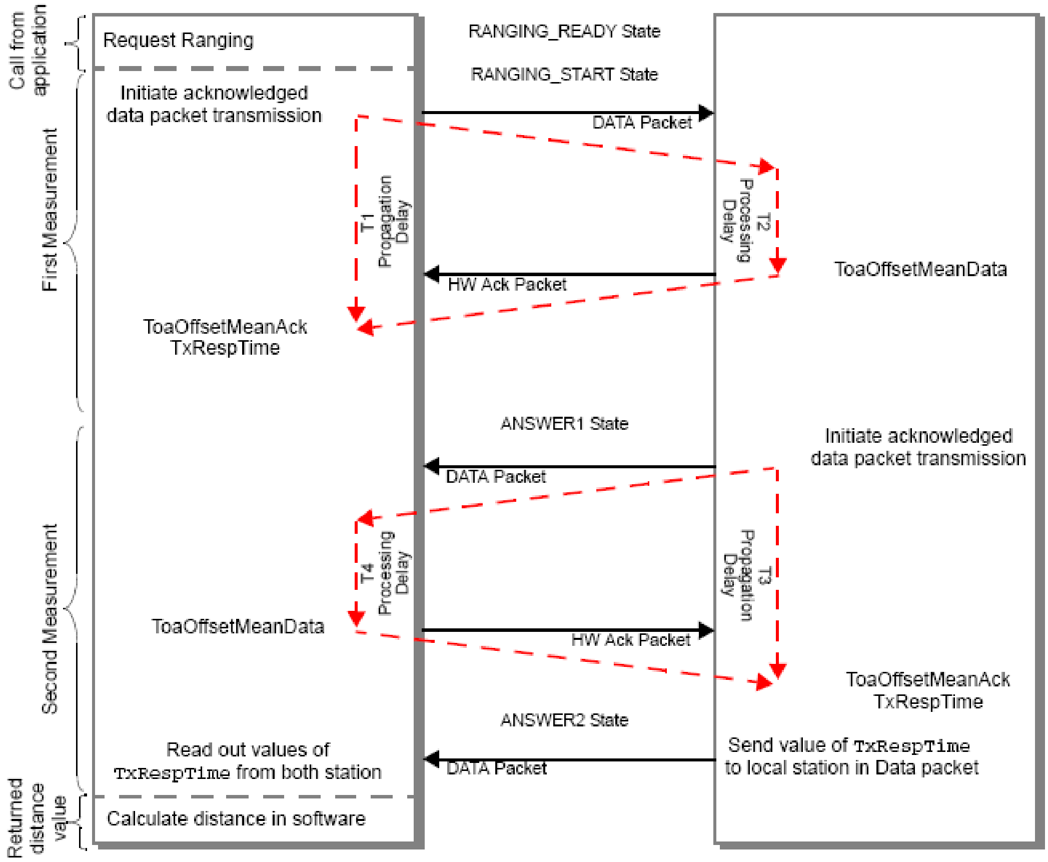


Figure 2.4: Symetrical two way ranging

estimation we need at least two NanoLOC transceivers in the car. With help of triangulation we can estimate the location. The error can be smaller than with GPS location especially if we get more NanoLOC transceivers spread over the car.

2.2 CVIS

The European CVIS project [19] is coordinated by European Road Transport Telematics Implementation Coordination Organization ERTICO [20]. It is a large project where many new innovative ideas can be wrapped within one more or less universal framework.

It provides both the framework and communications layers in both software and hardware for these new ideas to be developed. The key objectives are:

- to create an unified technical solution allowing all vehicles and infrastructure elements to communicate with each other in a continuous and transparent way using a variety of media and with enhanced localization;
- to enable a wide range of potential cooperative services to run on an open application framework in the vehicle and roadside equipment;
- to define and validate an open architecture and system concept for a number of cooperative system applications, and develop common core components to support cooperation models in real-life applications and services for drivers, operators, industry and other key stakeholders;
- to address issues such as user acceptance, data privacy and security, system openness and interoperability, risk and liability, public policy needs, cost/benefit and business models, and roll-out plans for implementation.

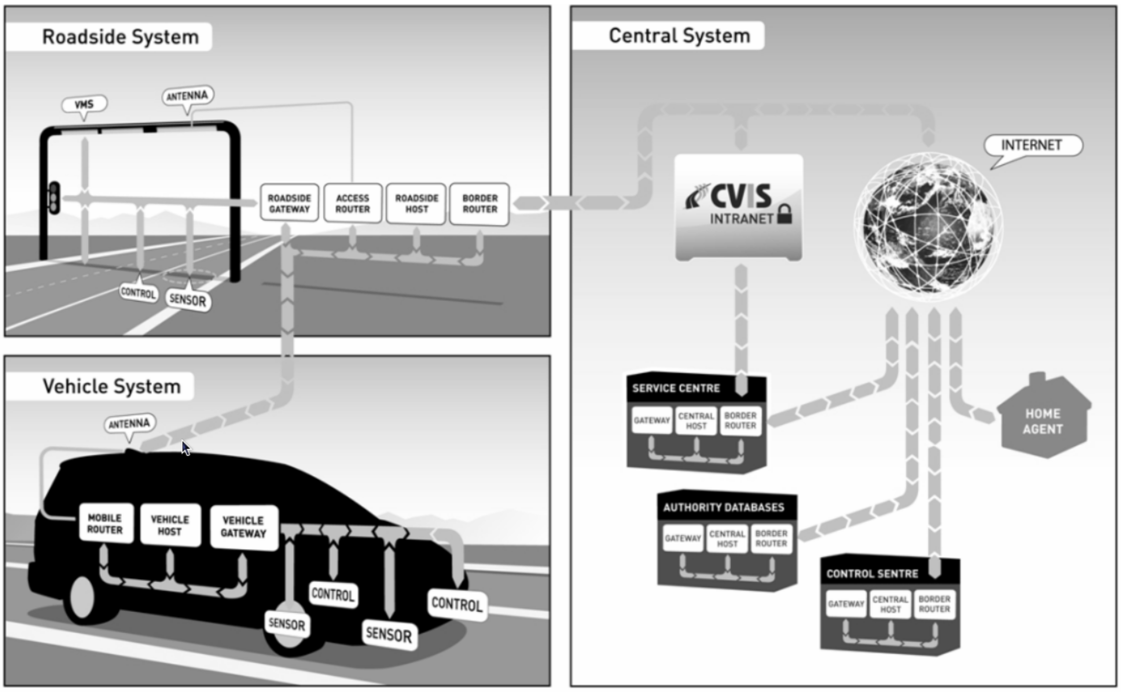


Figure 2.5: Overview of the CVIS architecture

The CVIS platform provides a way of communication between all involved parties, in Figure 2.5 the three parts are shown; vehicles, road-side systems and central systems [38].

The European Telecommunications Standards Institute [ETSI] [21] is defining standards for vehicular communications such as cooperative systems, electronic fee collection and interoperability. Their open systems strategy fits nicely with the goal of the CVIS project to create an open framework for these cooperative vehicular systems. These Intelligent Transport Systems [ITS] include all kind of communication between all kinds of transportation means. Besides CVIS there are two other e-safety projects; SAFESPOT and COOPERS. Al three of them aim at the development of cooperative systems for road safety improvement [51]. With the CVIS project we will focus more on road transportation and especially between vehicles together and road side systems.

CVIS has its own solution for location and localization services, the positioning and mapping [POMA] sub-project [44]. With enhanced positioning algorithms that provide mapping modules also an advanced positioning system and includes open Application Programming Interfaces (API). The main advantage over just enhanced GPS location is that it uses geographical information and Geo Info System (GIS) systems for mapping enhancing the location and mapping it on the local dynamic map [51]. For example using the maps of the road network. Furthermore the GPS location is enhanced with the aid of EGNOS [24] correction system. Instead of receiving this data from satellites it requests the whole database over the internet so that it can be used right away. The last method of enhancing the location is the use of on-board sensors gyrators and the already in the vehicle available data like wheel spinning speed and steering angle.

Communications and Networking [COMM] is another technological sub-project of CVIS. It focuses on providing a communication infrastructure to the CVIS project [45]. This infrastructure makes it possible to communicate from vehicle to vehicle but also vehicle to roadside unit and vehicle to back-office and vice versa. It will provide a range of possibilities regarding communication techniques, data speeds and their costs.

An third technological sub-project of CVIS is the Framework for open application management [FOAM] [25]. This FOAM sub-project aims at creating an open end-to-end application framework, connecting in-vehicle systems, roadside infrastructure and back-end infrastructure. It is the heart of the CVIS application development in Section 2.2.1 this open framework will be further discussed.

2.2.1 FOAM

FOAM is an open framework architecture, conform the ETSI open systems strategy. It supports CALM vehicle-to-vehicle, vehicle-to-infrastructure and infrastructure-to-infrastructure information and transaction exchange. This is achieved by providing APIs to the communication system developments on one hand and offering the functionality of this development as JAVA OSGI services to any other applications on the other hand. The Api's help application development activities in CVIS, and supplies client side run time environments for both, rich java clients as well as embedded native clients. Giving an unified application interfaces for applications, sensors and actuators and creates a so-called binding to specific technologies in order to create a fully functional system. The whole environment is based on java and OSGi and runs on top of a Linux operating system. The OSGi framework is based on a Knopflerfish implementation with additional modules for interfacing the hardware and an unified communication layer which chooses the most suitable way of communicating available at the time.

2.2.2 CVIS and SAFESPOT event for cooperative systems on the road

On the CVIS and SAFESPOT event for cooperative systems on the road in Helmond we have shown the current state of the CVIS project to the European Commission members and the press. This event was held from 11 till 14 May, around the Helmond Castle. Besides the annual review for the CVIS and SAFESPOT projects this event was also mend as showcase for the current state of art in cooperative road safety possibilities. We planned to have the the second deliverable, the CVIS application, ready for this event.

Figure 2.6: Helmond test event

Discussion on research questions

3

In this chapter we will discuss the research questions stated in Section 1.3.1. The first research question will be discussed in Section 3.2.

1. An initial version of the wearable device uses CSS modulation technique from Nanotron as the communication medium and for ranging between the devices. Tests have shown that it works but not that well. Are there better technologies available that can be implemented instead?

The second research question will be discussed in Section 3.3.

2. Which extensions can be added to extend the usability of the wearable device?

And the last research question will be discussed in Section 3.4.

3. How can the for the vehicle developed on-board module be integrated into the open service environment of CVIS?

Before we can discuss the research questions we have to specify the requirements, this will be done in Section 3.1. The conclusion that can be drawn from this research will be summarized in Section 3.5.

3.1 Requirements

The following requirements are either discussed on a brainstorm session or mentioned in Watch-Over specification.

- The wearable device has to be wearable, therefore it should not exceed the following dimensions; 10 by 7 by 3 centimeters.
- The wearable device has to run for at least one day without charging.
- The wearable device should contain a rechargeable Lithium-Ion (or similar) battery.
- The working range should be up to 100 meter. [29]
- The system position accuracy should be within 15 meters both Longitudinal and Lateral. [29]
- It should be possible to implement the improvements with custom of the shelve available hardware.

3.2 Communication medium

Besides choosing the communication technique it is also important to look at the available frequency band [30]. There are several allowed frequency bands in Europe and we will look into the most common ones. 2.4 Ghz is used for short range defined protocols, like ZigBee, Bluetooth, Nanotron and other ZigBee look-a-likes. The advantage of this range is that it can be used worldwide, so there are a lot of COTS modules available for it and it has a wide allocation, allowing higher data rates. The disadvantage is however that it has a high loss per meter, even worse in bad weather like rain and a low penetration through buildings compared to the lower Mhz frequency bands. 868 Mhz and 433 Mhz are also both allowed to use throughout Europe. The 433 Mhz frequency band is more widely used with a lot of COTS modules. There are less 868 Mhz frequency modules available, but still enough if you look for them. It has a more complicated band plan than the other frequency band. ZigBee modules can use a single channel in this frequency band as well. In the next paragraphs we will discuss several possible replacements for Nanotrons NanoLOC.

Ultra Wide Band [UWB] is a generic denomination and does not relate for a specific technology. The prevailing definition comes with two preconditions to be met to call a technology UWB [42]:

- The used bandwidth is larger than 500 Mhz, or
- The used spectrum is greater than 20 percent of the center frequency.

There is a large frequency band reserved for UWB signals. So, UWB is used for all kinds of technologies that are transmitting information spread over a large bandwidth. It has the advantage of allowing low transmit power with a large channel capacity and the possibility of a simple transceiver architecture [36]. The wideband nature allows UWB signals to easily penetrate through obstacles and provides very precise ranging capabilities. The power restrictions dictate that the devices can be small with low power consumption. For this research we are looking to specific communication techniques that can be implemented within the current hardware with custom of the shelf components. UWB as a generic technology is not yet available on the marked as custom of the shelve component, therefore UWB drops out.

Zigbee [46] is the only technology that uses both 2.4 Ghz and 868/900 Mhz. It is targeted at low and ultra low-power wireless devices, therefore it has only a small range of up to 30 meters. It is relatively slow with an average data rate of 128 kbits/s and uses Direct Sequence Spread Spectrum technology. The protocol is designed for short messages, so the device can go quickly to a lower power mode. The shorter range in the 2.4 Ghz frequency band makes it less suitable for our purposes. If we use the 868 Mhz frequency band the range will be slightly better however we can use only one channel in this band, so the data rate will be much smaller. The packet size [28] of messages in the ZigBee protocol is larger than with some of the proprietary protocols. Due to the small range in the ZigBee specification will not be a wise choice as replacement for the NanoLOC.

Miwi [34] is a reduced version of ZigBee with less protocol and for smaller networks but also less capacity. Being a reduced and simplified version ZigBee does not increase the range, therefore MiWi is also not suitable as replacement for the NanoLOC communication device.

The range of Bluetooth and passive RFID devices is too small to be useful for our purposes. WiFi and WiMAX are not developed for low power devices, however with the adaption of WiFi both in mobile device as well as for Wireless Access in Vehicle environments it can be an interesting alternative.

There are several transceivers in the 868 Mhz bandwidth running a proprietary protocol that are approved by ETSI and have range specifications of over 300 meters. These transceivers are widely available as COTS components. The only downside is that some of these transceivers have higher power consumption than some of the earlier mentioned transceivers. Another department had a development kit from Aerocomm with two AC4868-250 [2] tranceivers. These transceivers are certified to deliver up to 250 mW of output power, given us the best options for reliable data transmission. We decided to test this development kit to see if it could solve the small NanoLOC range issue at a affordable power consumption. The tests are described in Section 5.1, the results were excellent even after we reduced the max transmit power by three quarters. We have chosen to go for this Aerocomm AC4868 transceiver because of three reasons:

- The test results with the development kit looked real promising
- The availability of the development kit gives us the advantage of not having to look at an on-board unit, because these boards can be connected easily onto the in-vehicle computer.
- The possibility to lower transmit power consumption if the whole system would not met a certain minimum uptime.

3.3 Extensions to the prototype

Several brainstorm sessions lead to the following list of improvements and extensions for the initial prototype of the wearable device.

- There should be some kind of battery management. Sometimes, the radio module does not work anymore, but there is still power left to power the micro-controller. Not knowing if the device works degrades the usability of the wearable device and the whole system.
- It should be possible to disguise the wearable device by making the (alarm) messages available to the user through a some wireless connection
- The range of the radio module is very limited when using a small antenna, even more when the vulnerable road user is not in a line of sight of the vehicle driver.
- The self-localization of the device is not accurate enough to always be usable.

3.3.1 Battery management

To ensure proper battery management we need both measurement of the remaining power and some way to visualize this to the user. The first issue will be tackled by adding some hardware to the circuit board and make its data available to the micro-controller. To visualize the battery status we could either use a multicoloured led or a display. We have chosen for the Dallas DS2782 [6] Standalone Fuel Gauge IC, which will keep track of the lithium-ion battery and inform the micro-controller of its status. There will be both an three coloured led and a display be available for notifying the user of the battery status.

3.3.2 Disguise of wearable device

If we want to create the possibility to disguise the wearable device in for example a backpack or even in the frame of a bicycle we need to add some wireless link to make the alarm and other messages available to other personal digital assistants. The chosen wireless protocol should be supported by the majority of devices, short-range and has to be a low-power consumer. The best option for this is bluetooth because this is supported by most mobile phones, pdas and developed for short-range low power communication. The bluetooth device can be connected with a serial connection to the micro-controller. There are several bluetooth chips available, we have chosen for the BGB203 [4] a bluetooth chip from Philips Semiconductors. This is an all in one package with just a serial connection and handling the bluetooth protocol stack for us.

3.3.3 Radio communication range

This is already discussed in Section 3.2 with the different communication techniques

3.3.4 Localization

At the moment the wearable device is equipped with a standard GPS receiver, in Section 2.1.2.1 there is more information about this current implemented GPS receiver.

There are three most commonly used location technologies; stand-alone, satellite-based and terrestrial radio-based [55]. Beside these three technologies there are several options to improve the self-localization of the wearable device, but most of them are not very usable in our situation. For vehicle navigation systems there are map matching algorithms used to improve the localization. This option will consume additional power and the need of better maps with this information available for pedestrians and bicycles. Another possibility is to extend the prototype with additional hardware like a gyroscope, magnetic compass or accelerometers to improve the calculation of the actual path and with this information the current location. An inertial measurement unit [IMU] [35] is a combination of multiple gyroscopes and accelerometers. And is used for example in aeroplanes and in-vehicle installed guidance systems. Using an IMU to improve the location determination brings however new constrains, they are dependent the place on the body where you wear them [49], and the factors are different for bikers and pedestrians. So for our more generic case they are less usable. If we want to use a magnetic compass it is better to add a gyroscope, because the magnetic compass can determine the bias of the gyro and the inertial orientation. And the gyroscope can derive the change in azimuth due to the magnetic perturbation [39, 40]. And so they can compensate for the errors created with by the other system. However we have to make sure the gyroscope only measures motion in the direction we want. This technique will most likely give us the accuracy we want, but at the cost of a too large increase of wearable device size.

With a High-sensitive [HS] GPS receiver you can still get a signal 20-25dB below normal GPS threshold [54]. However there is also a downside of using HS-GPS receivers, the accuracy will be worse than with a normal GPS receiver. So for our case where we are seeking for best accuracy these receivers are not preferable to use. Another way to improve GPS localization accuracy is by using EGNOS, We need a capable GPS receiver and be able to process this additional data. It takes a up to 15 minutes before all the correction data is available to the system [44].

Galileo [24] is the GNSS system of the Europe, it is an project of the European Union and the European Space Agency. It is complementary to the American GPS and the Rusian GLONASS system. With 30 satellites it claims an accuracy of up to 1 meter, which would be fine for our purposes [52]. However for this accuracy will only be reached if we can use the Commercial Service. Another option is to use the Public Regulated service with local improvements on the signals.

Besides improving the self-localization it is possible to improve the relative location by using the communication system. We can either do the measurements and calculation on the wearable device or on the vehicle side.

There are several location determination techniques based on the time it takes for signal to travel over a certain distance. These time of flight [ToF] systems need some way of synchronized clock between the devices or we need two way communication. If we have two way communication we can take the time the communication packet travels from the host to the client and the time of the reply of the client back to the host. In this way we do not need a synchronized clock between the host and the client. However we have to make sure the time the client needs to prepare the answering packet is always the same, so that when the client is busy the distance is changing. The disadvantage of the system is when we have only one host and one client, because the best we can do is a distance measurement. If we have more than one host, we have to find a way to combine these measurements to create a two dimensional relative location. For the determination of the location using only the transmitted packet we need to know the exact time of transmission and reception of the packet. Therefore both the client and the host should use the same synchronized clock. If we have multiple time synchronized hosts we can use a time difference of arrival system. With this system we take the time difference measured between two signals from different hosts, with more than two different host station we can create a two dimensional location.

Instead of using only ToF between one antenna and the wearable device to gather the distance, we can use Angle of arrival [AoA]. If there are multiple antenna's on the car the accuracy mismatch will be below 2 percent [37]. For AoA we need to have either an antenna array or a directional antenna at the receiving end were the location calculations are done [43].

Combining this angle of arrival with the time of flight of the data we will get a fairly accurate relative position of the VRU. It gives us even a way to improve the determination in non line of sight [NLOS] situation [53].

The Location determination can of course be done at either side of the communication. If there are several vehicles and other fixed points with a known location the determination could better be done in the wearable device. Just like a GPS reception is better with more satellites in view, this will also hold for multiple equipped vehicles in view. However it will be difficult to fit an antenna area in the wearable device so it makes sense to just use time of arrival based techniques if we want to do the calculation in the wearable device.

Due to our choice for the Aerocomm transceivers, it will be difficult to implement localization based on the communication channel. It is not supported right away, so we should either use additional transceivers only for the localization or add additional hardware directly onto the Aerocomm chips for signal measurement. It is not possible to use accurate time of flight measurements because this part of communication is handled by the transceiver. It takes to long to receive the Egnos correction database by using a GPS receiver, therefore this is not a good solution either. The Galileo project however looks promising, however it is not there yet. The in-vehicle on-board system uses the same GPS receiver as the wearable device, as stated in Section 2.1.2.1 there will be a smaller error between to receivers that are close together. In 5.2 are the overall test results and the GPS based localization accuracy. Our recommendation is to use the Galileo based commercial version when it is available and until then the normal GPS receiver that is already build in. Although augmented GPS with inertial sensors and a magnetic compass would give a good improvement in accuracy, but this would lead to a to large increase of size of the wearable device.

3.3.5 Power management

The new radio module and the additional components mentioned in the above subsections demand additional power. The regulator on the initial prototype had a maximum of 2 times 150 mW, this will be not enough for all the new components:

- The Aerocomm transceiver uses up to 250mW for transmitting [2].
- The display consumes 80mA and an additional 23mA for blacklight [5].
- The bluetooth module needs 20mA [4].

Therefore we have to replace the regulator as well. We have chosen for an one ampere regulator from Sipex [1], to make sure we have enough current available for all the components. Besides the regulator we also have to make sure the battery can deliver enough energy for normal operation. Table 3.1 describes the components and there energy needs. Our battery has a maximal continuous discharge current of 2000mA [7], so that should not give any problem. The capacity of the battery is 1250 mAh, so even with this higher load the new prototype should be able to work for several hours.

Component	Power consumption
Micro-controller	50mA
Transceiver receiving	36mA
Transceiver transmitting	240mA
Display	103mA
Bluetooth	20mA
Vibrator + logic	50mA
Buzzer + logic	80mA
Several other chips	30mA

Table 3.1: Power consumption of components

3.4 Integration within CVIS

The CVIS host system is depicted in Figure 3.1, the operating system is in our case based on debian linux. The hardware is a car-pc with a Pentium M processor, hard disk, mini-pci card slot, four usb ports and three serial COM ports. This car-pc is named e-box within the project, and specially produced by CVIS COMM partners. There are two versions of the e-box; the host and the router. The router is mainly

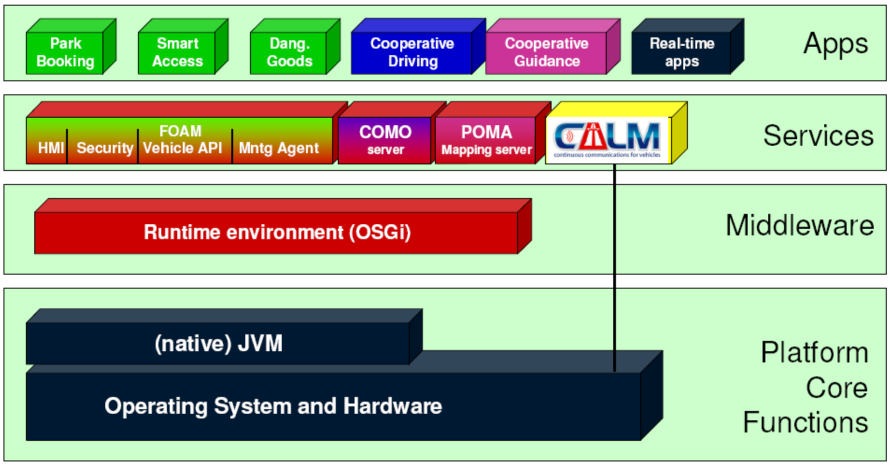


Figure 3.1: Overview of the CVIS system [31]

meant for communication and is usually extended with an additional PCI card with CALM hardware; two CALM M5 communication boards, a GPS receiver and several acceleration sensors and a UMTS receiver for communication with the internet and home-office. The host is used for serving the user interface and the applications.

The CVIS FOAM provides us with extensive development platform with the on OSGi based java environment Knopflerfish. The whole user interface called the HMI, is already defined and there are several service interfaces for communicating with the CALM communication layers and for retrieving sensor data [41]. Within the specification there are even services for the serial interfaces [16].

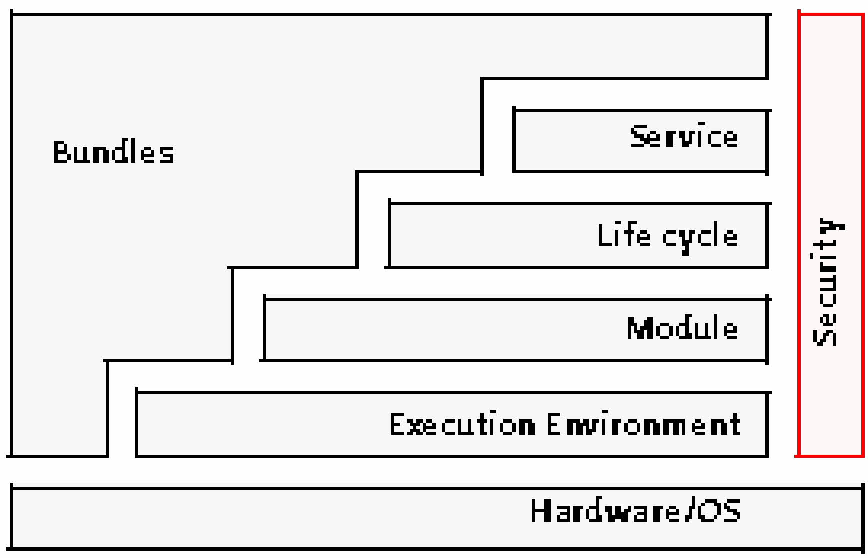


Figure 3.2: Layering of OSGi Framework

The OSGi Framework is divided in five layers; Security, Module, Life cycle, Service and the bundles with the actual services. In Figure 3.2 they are depicted [25].

The interaction between the bundle with the actual service and the Framework is depicted in Figure 3.3. These bundles can be started and stopped independent from other bundles and it is also possible to run multiple bundles in the HMI at the same time. The status is either communicated through status icons or the application can request focus if it has urgent messages.

The deployment of bundles within the framework can be done from a service center or manually, either by adding it to the start sequence or by running it manually from the development environment.

We think the CVIS FOAM environment is suitable for integration the Watch-Over on-board unit into a bigger road safety systems. Both projects have common goals and the CVIS e-box systems give us enough possibilities of connection with the communication development boards. The FOAM Framework give us the tools for a complete application which can be integrated into other safely driving applications as well.

3.5 Conclusions

In Section 3.2 alternative communication methods and techniques were discussed. The Aerocomm AC4868 comes out as an interesting alternative giving a huge increase of the possible range. Tests with this transceiver have shown that this can be a good replacement for the NanoLOC. There were several improvements and additions suggested in Section 3.3. To prevent strange behavior of the wearable device due to almost empty battery a remaining battery measurement chip will be added to the design. An additional bluetooth module will be added to the design as well. This module enables us to

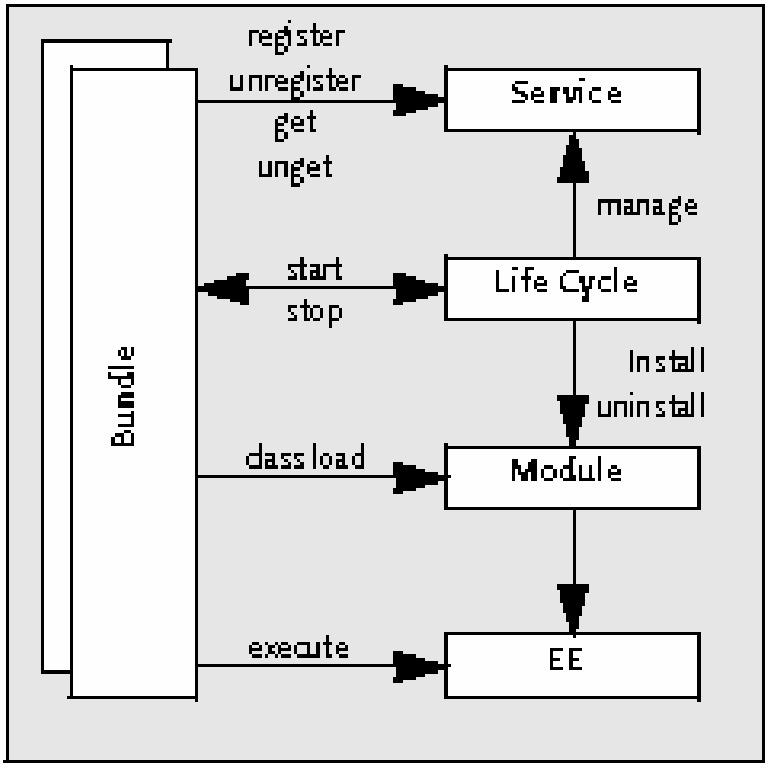


Figure 3.3: Interactions between the OSGi Framework layers

disguise the wearable device and still make the warnings available to the user through other available equipment, like mobile phones. We will not add additional modules to improve the self-localization of the wearable device. Most alternatives will not make the improvement we would like to see, therefore we decided to wait for the Galileo project and there commercial service with an accuracy of at least 1 meter.

In Section 3.4, the integration of the Watch-Over wearable device and on-board unit into the open service environment of CVIS was discussed. The CVIS project with its FOAM Framework and e-box systems give us a good opportunity of integrating these parts of the Watch-Over project into a bigger safe and efficient driver system.

4 Implementation

This chapter describes the implementation phase of the prototype development and the software development for the open service environment. We start with the hardware design and assembly in Section 4.1 followed by Section 4.2 describing the embedded software for the wearable device. The last section, Section 4.3 describes the software written for the open service environment of the CVIS project.

4.1 Hardware

For the new version of the wearable device prototype, we started with the schematics of the initial version. The design was no longer usable for our version due to the new components that had to fit on the circuit board as well. In the following subsections each step of the creations process of the wearable device will be described.

4.1.1 Schematics

For the design of the hardware Eagle Light was used, which is a free to use tool for designing printed circuit boards from CadSoft Computer, Inc. This is only freeware for non-profit and evaluation purposes, which is exactly the case in this project. It is non-profit and for me it is for evaluation purpose as well. To really get to know a program like this you have to create your own circuit board. As long as the components you use are in the library, it is a rather straightforward job. You just have to pick the components and connect the components by wiring. It is important to check every component with their data sheet, sometimes you have to add additional components like resistors and capacitors. Some of the used components were not available in the library nor on the internet. These had to be created manually, this is a time consuming process with a lot of checking the data sheet. It is important that the sizes are exact and that the pins are labeled correctly on the exact right spot. The schematics of the wearable device are depicted in Figure A.1 and can be found in the Appendix.

4.1.2 Circuit board

Now that the schematics were constructed the actual design of the board had to be made. The eagle software has the possibility to do the wiring for you, however you have to manually place the components first. There are several aspects to take into account when placing the components. First you have to choose if you want to use both sides of the board for components and how many layers you want for the interconnections between the components. We have chosen for a two layer board, it saves us almost halve the space and we need at least two layers for the wiring otherwise the cannot cross each other. It is possible to use more layers but there is not much gain in size. This is mainly because of the size of all the components together already covers most of the both sides of the board. One of the things to take into account is the place of your interconnections to your programming device, power switches and other external connections. To make final assembly easier we had chosen to put these at at one side. Another thing to think about is the thickness of the components and interconnects. To reduce the required space for the board within the casing all the thick components and interconnects are placed on the same side and the thinner components on the other side. So after placing these interconnects to the outside world and other thicker components, you mainly follow the bunch of temporary air-wires and try to place the components with a lot of interconnection close to each other. As mentioned before, the eagle software has the possibility to auto route the wiring for you. However this is not even near optimal, so you have to remove wires manually and route them different to get a fully routed design. The process of placing and routing was an iterative process of adding components , auto wiring, removing wiring moving components to end up with an optimal covered circuit board. In Figure A.2 in the Appendix the final design is depicted. After the design was completed, the necessary ground plan files were send to a manufacturer were the circuit board was fabricated. This took a couple of weeks, the price depends strongly on the time you have before you need it.

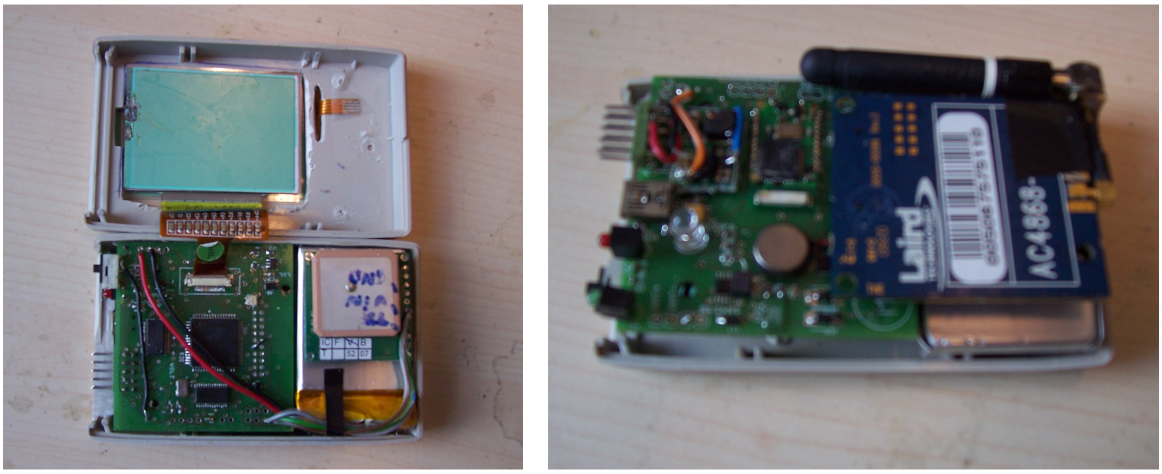
4.1.3 Components

The list with all the used components on the circuit board is stated in Table A.1 which can be found in the Appendix. Most of the components are Surface Mounted Devices otherwise it would not fit on the circuit board. All the components we used are custom of the shelf available, they can be bought easily on the internet. An Atmel ATmega128 micro-controller [3] was chosen for the embedded system. Mainly because it was already used on the initial prototype and it provided enough possibilities for the interconnection of the additional parts. The ATmega128 has two UART ports, a SPI port and enough available pins for a parallel display as well as needed for the other additional parts. We needed three serial connections, therefore an additional SPI to serial converter was added to the design. In the end we experienced problems with this SPI connection so it was better if we had replaced it with another micro-controller with more serial ports.

4.1.4 Assembling

The assembly of the circuit board was a time consuming difficult job, everything had to be assembled by hand. Especially making sure all the tiny components were connected thoroughly, this meant a lot of checking. Furthermore we had to make sure none of the components broke during the process. Because we had not checked proper functioning of the additional added parts before starting assembling the new prototype, we did not know if it all would work as expected. That was probably why we run into several problems. The new power regulator did not work as expected even though the additional circuitry was exactly as described in the data-sheet. To make sure we did not had made a mistake in the design process, the regulator and additional circuitry were rebuild on another circuit board. However this did not resolve the issue, it still did not work properly. Additional research and checking did not lead to any other conclusion then that the data-sheet was wrong. In the end we replaced the whole regulator and circuitry with another one of a different brand as you can see in Figure 4.1(b), and this resolved our problems. However it had cost us quite some time trying to find an error or an explanation, therefore we had not much time left for the rest of the implementation.

Additional care has to be taken when fitting all the components in the casing. To make sure the wearable device is good wearable the case should be as small as possible. However some components should have a clear view to the outside world and should not be blocked be other components or shielding. The GPS antenna for example should no be disturbed by the communication antenna nor be blocked by for example the battery or some other components[48] as depicted in Figure 4.1. Unfortunately the power con-



(a) Top side

(b) Bottom side

Figure 4.1: A closer look inside the wearable device (a) top and (b) bottom side

nectors have broken of the display after fitting it in the case. We tried to fix this with soldering but that did not hold. Due to the short time that was left before the Helmond event, it was not possible to replace it in time. Because the Helmond event was focused on the in-vehicle systems rather than the vulnerable road users itself it was not worth the risk of braking it all while trying to replace it.

4.2 Embedded Software

As stated before we have used an Atmel128 micro-controller. The next step was to test if all the components did what they were expected to do. Therefore we had to write several small test programs. Atmel has its own programming environment for windows: Atmel AVR studio 4 [18]. And this was used for developing the software and programming the micro-controller.

The test programs are just like the rest of the embedded program written in a C based programming language. We have written test programs for the lcd screen and for communication with the spi2uart chip that we needed for the communication with the bluetooth transceiver, because there were not enough available serial ports on the Atmel micro-controller. We were able to print characters and graphics to the screen, so the next step would be to integrate it into our main program. The communication with the SPI chip did not succeed, therefore we were not able to get through to the bluetooth chip. We have tested SPI communication between two atmel micro-controllers and that did work as expected. We also test the SPI communication with a development board of the spi2uart chip, but that did not work either. So the best solution is to replace the spi2uart chip with one of another brand, or maybe change the micro-controller with one that has more serial pins available. We did not had time to make a new design and order a new circuit board, therefore we cannot use bluetooth with our prototype.

Due to the problems we had encountered with the power regulator we did not manage to make the embedded software for the battery measurement chip. Because the run-time was still sufficient for the demonstrations, we decided that the software for the battery status measurements would be skipped. This could still be done later on, because the hardware is already available within the prototype.

An important lesson was learned; never trust a datasheet, and make sure you test the components before ordering your final circuit board. So there is still room for improvement on the prototype.

4.3 Integration within CVIS

As mentioned in Section 3.4 the Open Service Environment of CVIS is written in Java. This FOAM framework is based on the open source OSGi implementation Knopflerfish. The preferred language for applications development is Java, however the OSGi environment supports applications written in other software languages as well. Therefore we have chosen to develop the our applications in Java as well. An advantage was that we could more easily connect to other already available services for the interconnection with the host systems hardware. For our applications we had to communicate with the

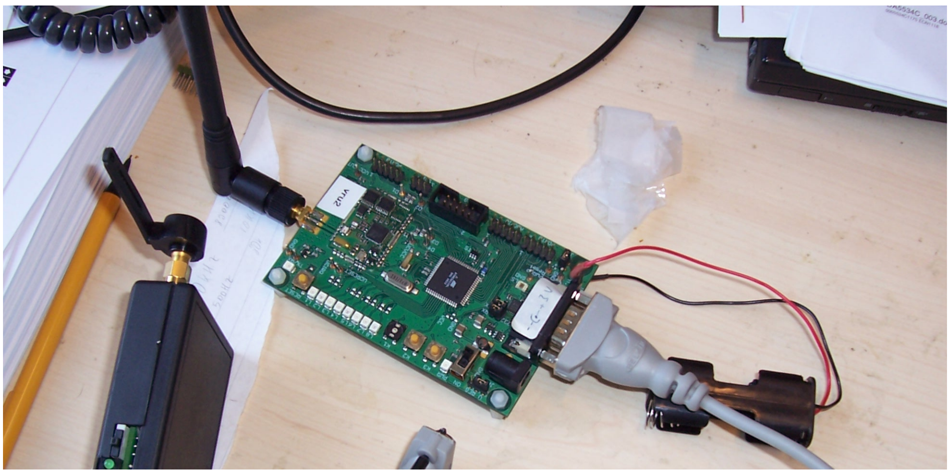


Figure 4.2: Development board Nanotron

development boards as depicted in Figure 4.2. This image shows us the NanoLOC communication device and antenna which can be connected to a computer. In our case this can be done via a serial I/O port of the e-box. According the specification the OSGi environment should provides us with services for the interconnection with the host serial I/O hardware port. However this does not work in our situation, due to time constrains we did not find the cause. We have chosen to use the serial I/O API from rxtx[17] for the communication with the on-board unit antenna. This API did work for us and is not difficult to install on new e-box host systems.

4.3.1 Implemented services

We developed two applications for CVIS, one is based on the NanoLOC ranging technique of the first prototype and the other one is based on relative GPS location and both the 868 Mhz and the NanoLOC communication modules. The first one is called collision avoidance, it is a driver aid for alerting that there is a dangerous situation ahead and the car should brake. In Section 4.3.2 we will describe this application in more detail. The second one is called radar, and shows the relative location of nearby vulnerable road users wearing a wearable device on the screen. In Section 4.3.3 this application will be described. For these applications the e-box host system has to be equipped with the development board containing the antenna and the communication module. To get ranging data from the wearable device we had to send a sequence of commands to development board. The whole specification of commands is mentioned in the Watch-Over documentation[47]. The commands we needed are stated in Table 4.1, all commands start with 7F and end with 8F. The implemented applications should be

ID	Description	Command
1	Exploration request	92
2	Open socket	86 'MAC'
3	Ranging request + warning	91 AA 'socket ID' AB CD 00
3	Ranging request + medium	91 AA 'socket ID' AB CD 10
3	Ranging request + high	91 AA 'socket ID' AB CD 20

ID	Response Command
1	02 'message ID' AND 11 00 'MAC address'
2	86 'socket ID'
3	12 AB CD 'socket ID' 'distance in cm' 'signal strength' 'GPS Location'

Table 4.1: NanoLOC communication specification

able to work next to the already developed CVIS applications as depicted if Figure 4.3. In this figure we see the CVIS interface with several applications and the connector to the back-office. The icons right below show the connection status of the CALM API. Knopflerfish has provided us with some sample program containing the basic procedures and actions for starting and stopping the service and communicating with the HMI. This program contains an Activator class which is called by the framework when the application is launched. And a View class containing some basic methods for displaying data on the screen. It is possible to leave the applications running even when they do

Figure 4.3: CVIS HMI with applications

not have focus anymore. You can use the status icon to inform the driver of the status.

4.3.2 Collision avoidance

The Collision avoidance application uses the NanoLOC ranging technique used in the first prototype for determination of the distance to the vulnerable road user. It warns when road users are too close to the vehicle, determined by a predefined threshold. This application can be used for example in trucks covering the dead angels right in front of the truck or at the sides of the truck. Or in sub-urban areas to just warn for nearby vulnerable road users. It is aimed at the real nearby situations from 0 to 5 meters around the vehicle. Analogue to other CVIS applications we have made an activator class. This class will be called from the CVIS framework when the application is started. In this class we defined what we wanted to start-up; the user interface of the application, a thread for the serial port communication. And what should be stopped when we close the application. The serial port communication is handled by a different thread than the rest of the program. The ranging data will be passed on from the serial port thread to the main view of the program. Even when the application is running in the background the driver will be warned if a vulnerable road user wearing a wearable device is too close by. This is done either by an overlay over the whole HMI of the CVIS framework or by just requesting focus back to the application. This is depicted in Figure 4.5 where we see the Brake overlay on the CVIS HMI.

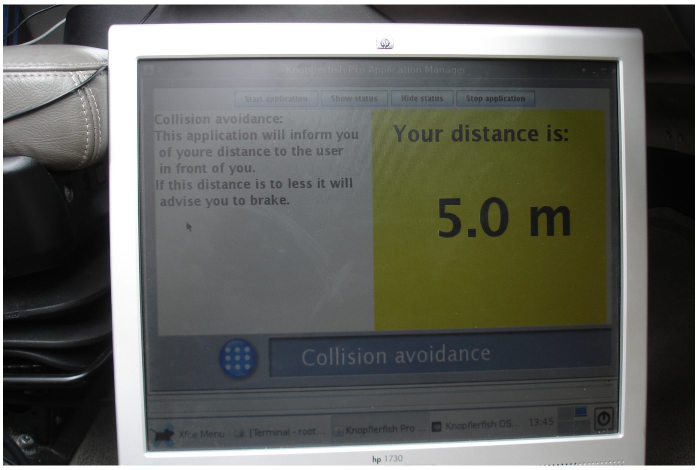


Figure 4.4: Collision avoidance application

Figure 4.5: Brake overlay on Collision avoidance application

4.3.3 Radar

The second application was build specific for the Helmond event, to show the different advantages of the developed wearable devices. The Radar application uses relative GPS positions from the wearable devices and the vehicle own GPS system. It displays all the vulnerable road users wearing a wearable device on the CVIS HMI. For simplicity is chosen to show it on a radar image, however the same data could easily be reused on the local dynamic map. And the vulnerable road users are plot on the real time street map. For this application we used the developed Collision avoidance application as basis to build further on. The serial communication thread had to be extended to make communication possible to both development boards at the same time. So we are able to communicate with both types of wearable devices. Besides receiving the locations of the vulnerable road users we had to know the location of the vehicle as well. Instead of using the location services already available with the CVIS poma bundles we decided

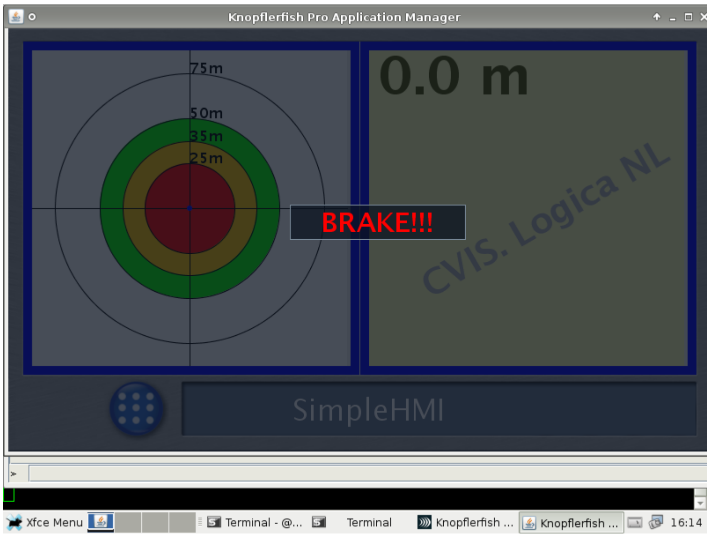


Figure 4.6: Radar application

to use an external GPS receiver, the same one as used in the wearable devices. This had as advantage that we could use the same raw GPS positions as we received from the wearable devices, without enhancements made by the POMA bundle. Another advantage was that this way we did not need the full CVIS host router setup with antenna setup, as depicted in Figure 4.7 for demonstrations but just the CVIS host e-box.

We needed also a way to convert the GPS positions to relative positions, unfortunately you cannot just subtract to positions from each other to get the relative positions. However there are coordinate conversion scripts available to convert the raw GPS. After conversion it is possible to calculate the relative position of Vulnerable road user and vehicle by simple subtraction of the two positions.

4.4 Conclusion

This chapter described the creation of the wearable device and the implementation of two applications for the CVIS environment. We did succeed in the creation of the new prototype, however due to the encountered problems we did not manage to implement all the improvements mentioned in Chapter 3. Their hardware parts have been added to the design and soldered to the circuit board, however not all their functionality is available to the micro-controller.

The applications for the CVIS environment are implemented and as long as there is a development board available as on-board unit these can be used on the e-box, to add vulnerable road user location awareness to the CVIS HMI.

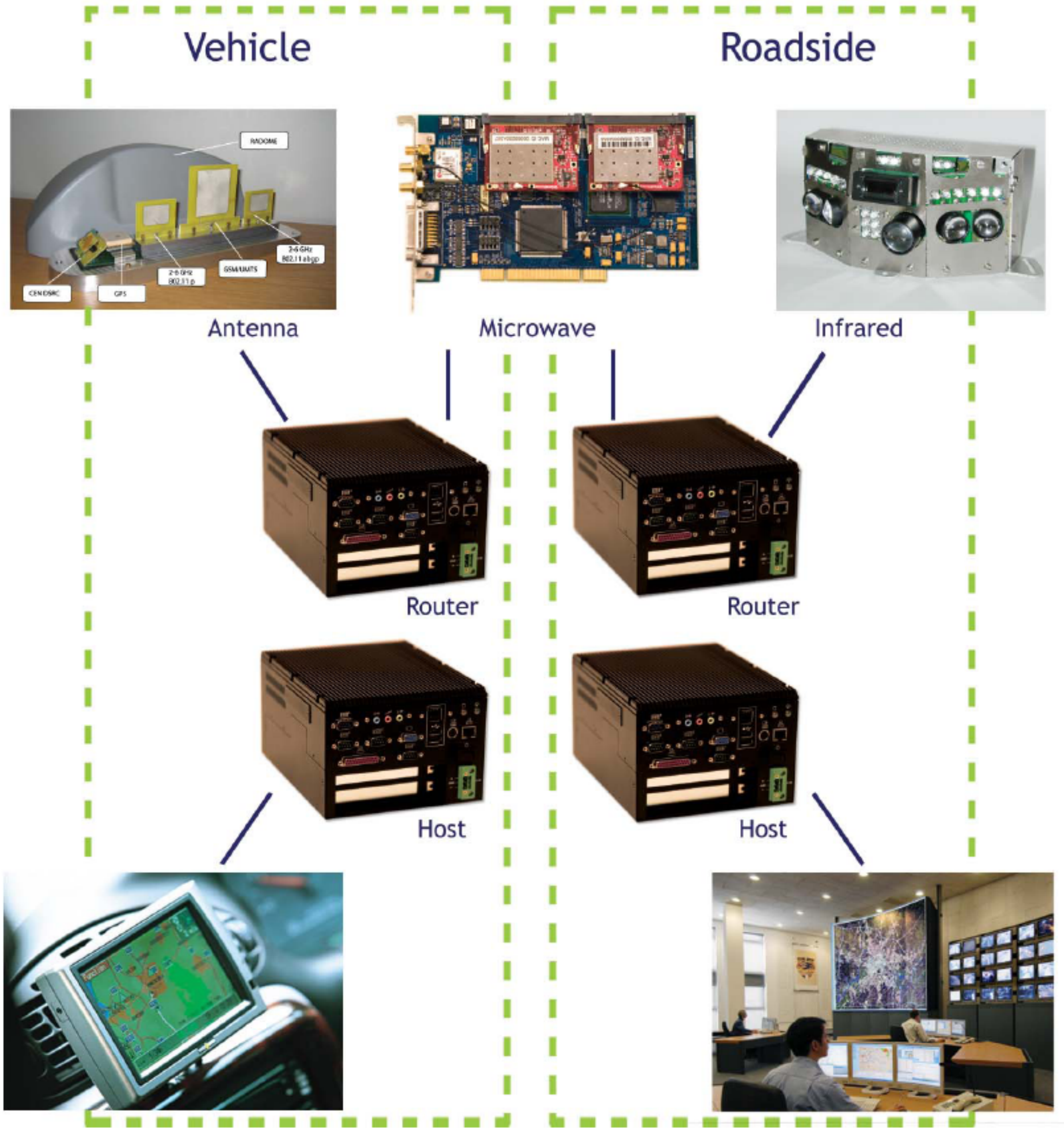


Figure 4.7: Full CVIS e-box host-router setup

Experimental evaluation 5

In this chapter we will discuss the results of several experiments performed to test the performance of hardware components and the overall prototypes. We start in Section 5.1 were we the tests that are performed regarding the range of the communication and the link quality. In Section 5.2 we describe our tests and findings concerning the overall performance.

5.1 Link quality

We performed several tests regarding the link quality and the possible operating range with both the initial NanoLOC transceiver and the replacement, the Aerocomm AC4868 tranceiver. First we will describe the test environment and the test setup and then the results of these tests. We will finalize with an evaluation of these results and draw some initial conclusions.

5.1.1 Experimental environment

All the experiments were performed outside in the open air, where we tried to mimic normal operation conditions. The first two experiments were performed outside the Logica building on the open car park at the other side of the street. There were a lot of cars parked there, so there could be a lot of reflections and distortions. In Figure 5.1 we have an image of the car park. The car park was at the moment of testing already bigger than in this picture, but there are no more recent aerial pictures available at the moment. The third experiment was performed on the streets around the Logica building, this was to mimic a normal operation situation.

5.1.2 Test setup

In the first experiment, the on-board unit was connected to a laptop in a driving car and the initial prototype of the wearable device was on a fixed location. The development board and antenna were mounted on the roof to make sure the car did not block any reception.
The second experiment was with two borrowed Aerocomm AC4868 transceivers on development boards both powered with 9 volts batteries. One was again connected to a laptop the other one was stand alone and configured to send every incoming message back. The stand-alone receiver was carried around the parking lot. Both transceivers were initially configured to a maximum transmitting power of 250mW, the stand-alone transceiver was reconfigured during the test to a lower maximum transmitting power.
The third test was performed with both the initial prototype and the second prototype.

Figure 5.1: First test area; the open car park

So using both the NanoLOC communication and the Aerocomm communication modules. The corresponding on-board unit were connected to a laptop, but only one at a time. The laptop was in the car, which was parked on several potential dangerous locations while the wearable device was carried around. These were amongst others scenarios were a person comes from behind a car blocking the view, or when something else was blocking the view. The Aerocomm development board transceiver was running on a maximum transmitting power of 250mW while the wearable device transceiver was running on a quarter of this maximum power.

5.1.3 Test results

The first test confirmed the earlier results with this kind of communication devices. Between cars the reception was very bad, most of the time there was no reception at all. In line of sight it was slightly better, then we could reach up to 8 meters. Another outcome of this test showed that the ranging measurement of the NanoLOC was far from accurate. At exactly the same position it could vary up to three meters and with a lot of distortion the mismatch could be up to 5 meters. Averaging several measurements could give a slightly better ranging results, with only a mismatch of two till three meters.

The second test, with the borrowed Aerocomm AC4868 boards was more successful. We could cover the whole parking lot and even between cars there was still a good connection possible. But this was at full transmitting power, which is quite a lot more than the NanoLOC boards. The test was conducted with the development kit antenna's, which will be bigger than the one we will be using in the wearable device. Even after reducing the transmitting power with three quarters on the stand alone development board, the results were quite good. In line of sight we could still cover the parking lot which was almost 100 meters and most of the time we had also reception between the vehicles as well.

The third test confirmed our findings with the first two tests. At every non line of sight situation the initial prototype setup failed or performed at least unstable, but the developed prototype stayed transmitting. So even the smaller antenna used in this setup did not made the wearable device lose connection with the development board.

Another test performed at the Watch-Over review with the initial version showed that in bad weather conditions this was even worse. In a dense fog there was even in clear line of sight no communication possible over more than two meters.

5.1.4 Test result evaluation

The tests gave us a clear view of the advantages of the chosen new communication transceivers. They outperformed the NanoLOC transceivers but at the cost of losing the ranging capabilities. With the new prototype we were able to reach the required range of up to 100 meter [29] of the Watch-Over project.

5.2 Overall Performance evaluation

There were two events were we did a performance evaluation. The first one we performed around the Logica building and the second one in Helmond, during the CVIS and SAFESPOT showcase event. This section describes first the requirements followed by our findings and finalize with an evaluation.

5.2.1 Requirement summary

The requirements that were specified for this project are stated in the following list.

- The wearable device has to work for at least one day without charging.
- Both applications have to work in the CVIS HMI, running on the CVIS e-box.
- The working range should be up to 100 meter. [29]
- The system position accuracy should be within 15 meters both Longitudinal and Lateral. [29]

5.2.2 Test results

The initial prototype had a range of up to 15 meters however if the range was more then 8 meters the reliability became a factor to take into account. With the distance measurement of the NanoLOC the inaccuracy at ranges below the 2.5 meters became far too large to be usable. Overall the inaccuracy of the localization was around 5 meter.

The improved version of the prototype with the Aerocomm transceiver had a range of up 125 meter. The reliability did not decreased substantially at bigger distances, nor when something blocked the line of sight. The inaccuracy of the relative GPS location determination on good reception was around the 2-3 meters, however in bad conditions this was up to 8 meters.

Fully charged batteries worked the whole day, no need for additional recharging.

Both applications could easily be started from the CVIS HMI, however we suffered just like some other project partners from java heap space errors when the OSGi environment was running to long. This could be partly solved by increasing this heap space.

5.2.3 Test result evaluation

The second prototype performs better considering the working ranging, however the NanoLoc with its ranging is slightly more accurate in its ranging. On good reception the relative GPS location has an inaccuracy of around 2 meters, however in bad conditions this can be up to 8 meters. Were the NanoLOC ranging has an inaccuracy of only 2 till 5 meters, but this in direct distance only, so with multiple NanoLOC on-board units this will be improved due to triangulation. The applications perform well enough for demonstration purposes and the wearable devices keep on running the whole day without losing performance.

5.3 Conclusion

Tests have shown that the improved version of the wearable device have reached the minimum requirements as stated in Section 5.2.1. The integration within the CVIS framework had also succeed, as we were able to demonstrate the applications at the Helmond event.

Conclusions 6

This thesis project discussed the cooperative approach on vulnerable road user protection through the European Union co-funded projects Watch-Over and CVIS. A wearable unit was to be constructed and an on-board unit to be configured. First, the background information over the Watch-Over and CVIS projects was provided. Second, the research questions were discussed and choices for the implementation were made. Third, the solutions were implemented, a new prototype was made and the on-board unit was programmed. And finally the whole system was showed on the CVIS and SAFESPOT event for cooperative systems on the road in Helmond.

6.1 Summary

This section presents a summary of the research questions and solution selection, implementation phase and the experimental evaluation.

6.1.1 Research questions

In Chapter 3, the research questions were discussed and solutions for improvement of the wearable device were selected. We have looked at a replacement for the NanoLOC transceiver with its ranging capabilities. Our main concern was to improve the work range, e.g. the distance over which the communication still worked sufficient enough for communication. We chose for a different technique on a different frequency band, instead of the busy 2.4 GHz frequency band we chose for 868 MHz band. For the new transceiver we have chosen for the Aerocomm AC4868, one of the advantages of this transceiver is that it is possible to easily change the maximum transmitting power. But the paramount factor was the availability of a development kit with another Logica division in Rijswijk, and the good test results we had experienced with this kit.

We have also looked at possible additions to the wearable device to extend the usability. By either adding WPAN capabilities to make it possible to put the wearable device out of sight, or give the user more information about the current state of the device, for example the battery status. Furthermore we have looked at ways to improve the relative localization of the wearable device and on-board unit.

We have chosen for a simple graphical display to inform the user about the current state of the wearable device and give more information of current threads. By displaying arrow symbols indicating the direction of the thread and displaying current battery levels. For the measurement of the battery level an additional chip was added to the design. Besides using the graphical screen the vulnerable road user can also be warned through a visible, audible or feel-able signal about its potential dangerous situation. An third way of informing the user was by using the intended WPAN capabilities, which can best be achieved by adding bluetooth communication to the wearable device. Most cell phones and personal digital assistants are bluetooth enabled and support serial communication through a bluetooth link. Unfortunately none of these additions are fully functional in the prototype. For the localization we have looked into several different options, from either localization based on the communication signal, improved GPS localization and augmented GPS localization with inertial measurements and magnetic compasses. Due to the choice of the Aerocomm transceiver relative localization based on the communication channel will be difficult, because the chip does not support it. GPS localization can be improved several ways but neither seem sufficient at the moment. However the Galileo project gives us the possibilities to do an absolute localization with a maximum mismatch of 1 meter. The only problem is that it is not fully operational yet. Augmented GPS by means of adding inertial measurements and magnetic compass looks promising, however this would cause an increase of the size of the wearable device which is not desirable.

And finally we have looked at the possibility to integrate the Watch-Over co-operational vulnerable road unit protection ideas with the wearable device and on-board unit system into the open service environment of CVIS. The CVIS project lend itself quite good for integrating other projects into it. The FOAM Framework gives us the possibility to communicate with our development board and inform the vehicle driver with the relevant information through the HMI.

6.1.2 Implementation

The Implementation of the main deliverables stated in Section 1.3.2 was discussed in Chapter 4. The first deliverable was made with the improvements discussed in the research questions. However due to encountered problems the battery measurement and possibility to communicate warnings and messages to another personal device which the user might carry with him are not implemented in the wearable device embedded software. The necessary hardware was added to the design and is available for the programmer.

There were two CVIS applications developed; the radar application and the collision avoidance application. The collision avoidance application uses the ranging capabilities of the initial prototype to measure the distance between the CVIS equipped vehicle and the vulnerable road user wearing a wearable device. The distance is used to warn the driver when there are vulnerable road users to close by, which he might have missed. For example a cyclist or pedestrian in the dead angel of a truck, or behind the truck when it is driving backwards. The radar application uses the GPS locations of all wearable device equipped vulnerable road users and the GPS location of the CVIS equipped vehicle to show the relative positions of the vulnerable road users around the vehicle. On the CVIS HMI you can see and track the vulnerable road users and take measurement before a potential dangerous situation can occur.

6.1.3 Experimental evaluation

We have put our developed deliverables to the test, in Chapter 5 the tests and results are discussed. First we have looked at the possible replacement chip for improving the communication range. The replacement transceiver showed a big improvement of possible range. This was the major advantage of the new developed wearable device, but at the cost of a decreased localization accuracy. Both developed applications and the wearable devices were demonstrated at the CVIS and SAFESPOT event for cooperative systems on the road in Helmond.

6.2 Project evaluation

This section evaluates this project by revising the original project description and goals and by evaluating the main contributions.

6.2.1 Project description and project goals

The original project goal was to develop a wearable device for a vulnerable road user for the Watch-Over project. When I started with the project there was already an initial version of the wearable device developed, because the Watch-Over project was to end December 2008. Therefore the project goal was extended with the improvement of this initial wearable device and with the integration of the Watch-Over cooperative approach into the CVIS project.

6.2.2 Contributions

The main contributions of my master project were;

- Improved work range of the wearable device.
- Integration of the Watch-Over hardware and ideas into the CVIS project.
- The development of two applications for the CVIS project.
- Assisted the CVIS team with releasing their potential at the Helmond Event.

6.3 Future research

This project has shown that a cooperative approach has a potential to aid sensor based vulnerable road user detection, increasing the detection of vulnerable road users before dangerous situations occur. Besides making the other parts of the added hardware work, the following recommendations are given for future research;

- Integration of the wearable device capabilities into a cell phone, so that the user does not have to carry additional devices with him.
- Integration of the radar application into the local dynamic map of the SAFESPOT project, so that vulnerable road users can be plot into this map.
- Improve localization, the accuracy should be within a meter, if possible without increasing the size of the wearable device.

- Adding path recognition to the on-board system, to make sure there is only a warning when there is a real chance on a dangerous situation.

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A Hardware

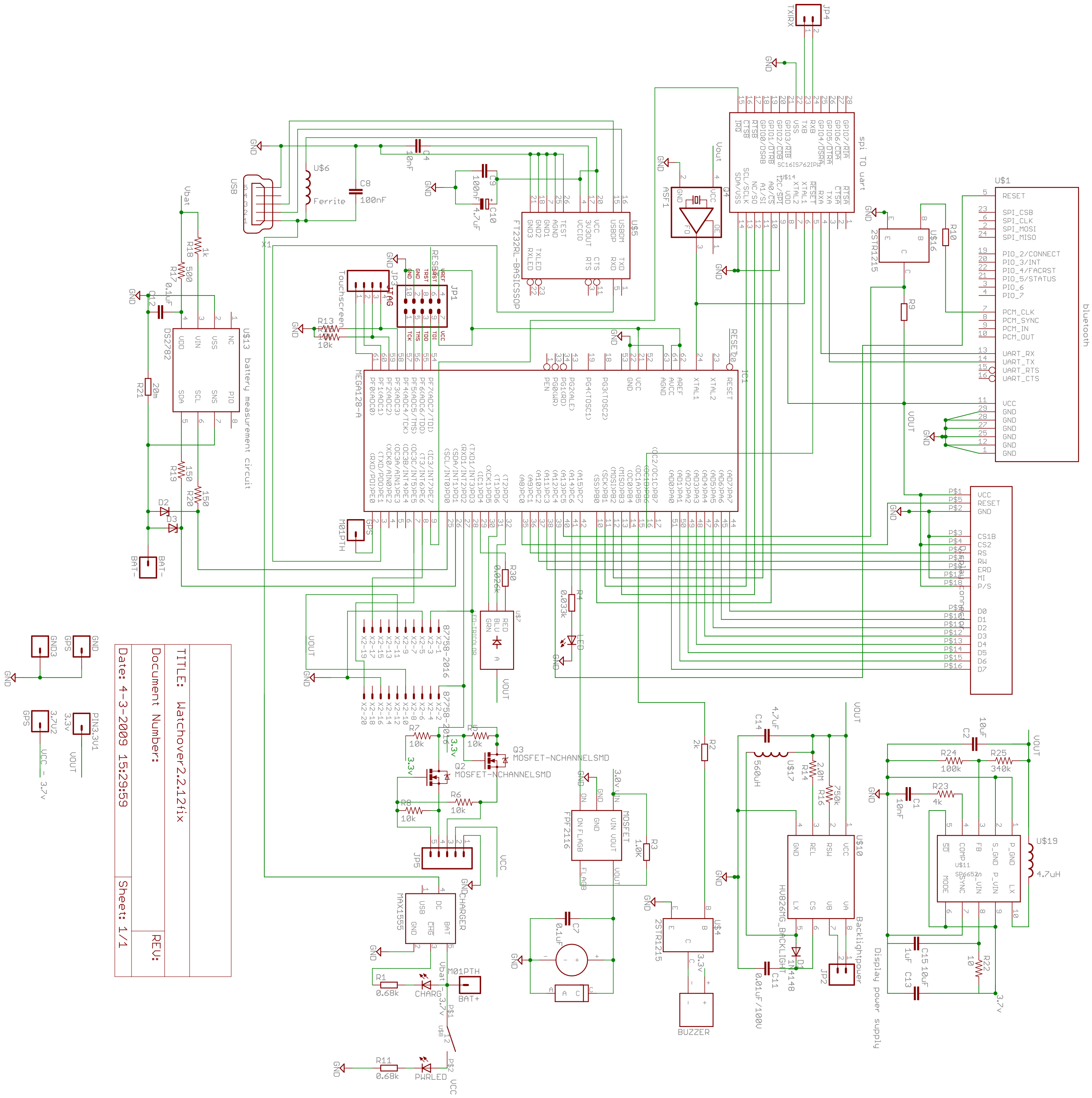

Figure A.1: Schematics of the wearable device

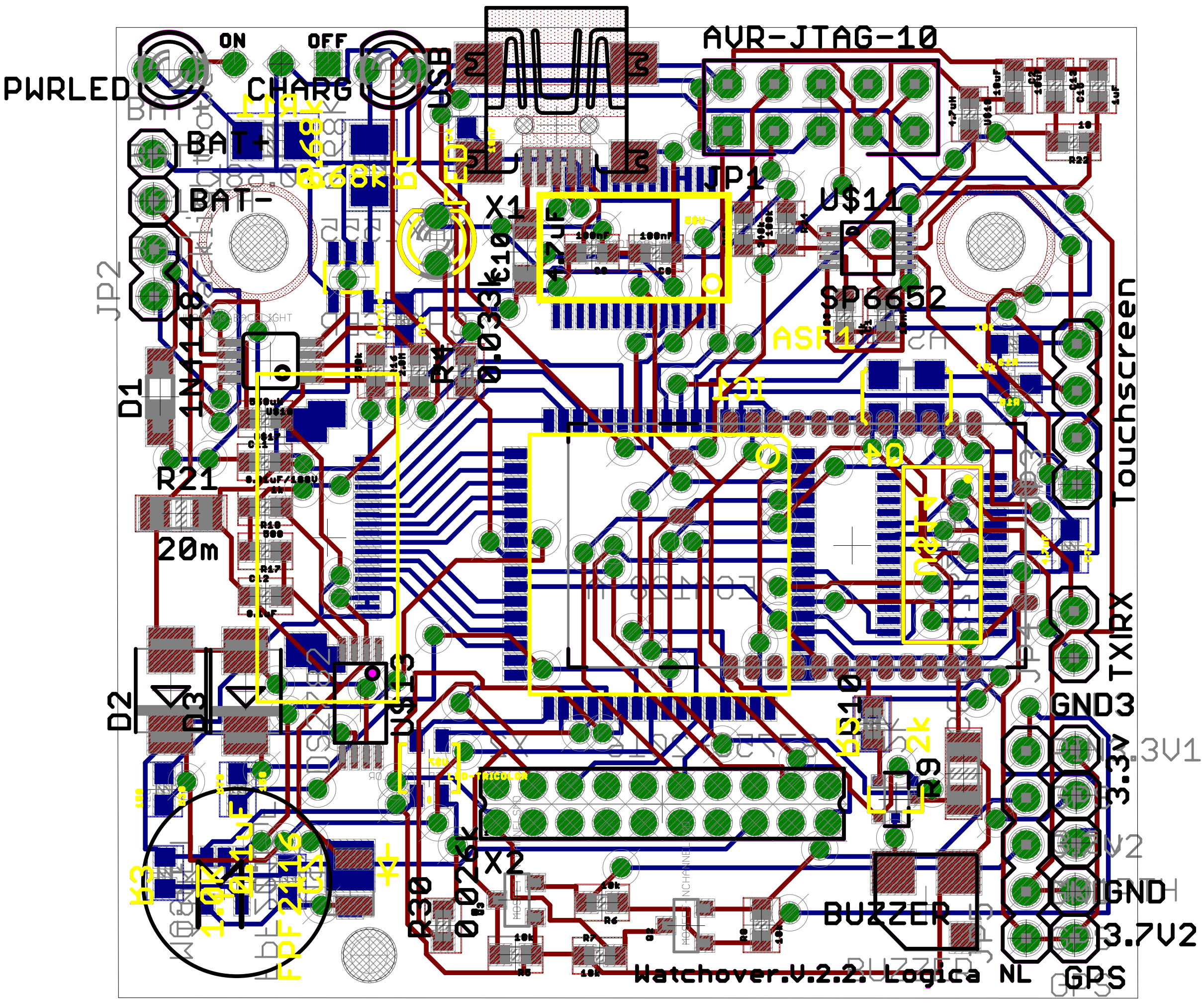

Figure A.2: Full design of the circuit board (both sides)

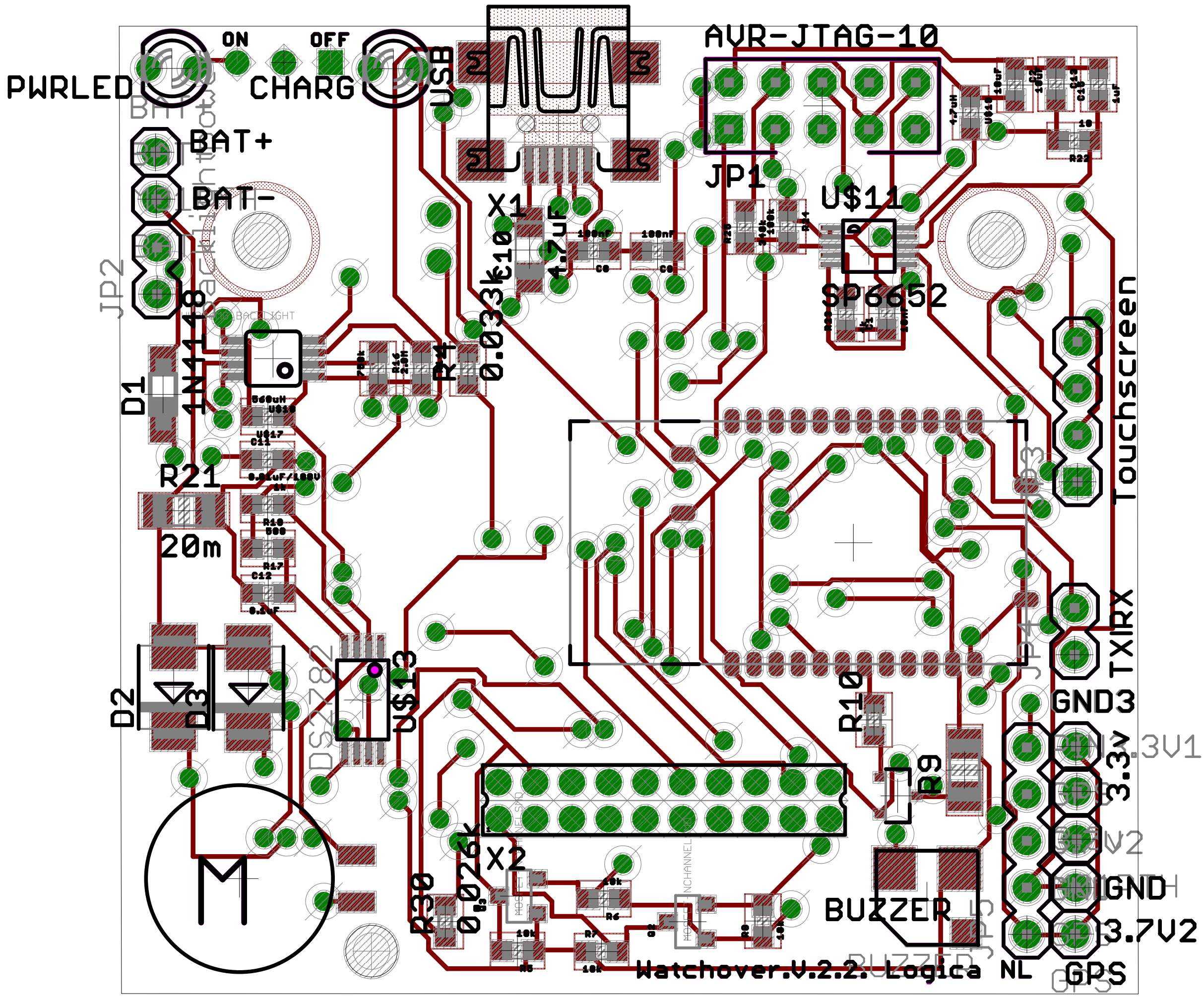

Figure A.3: Design of the circuit board front-side

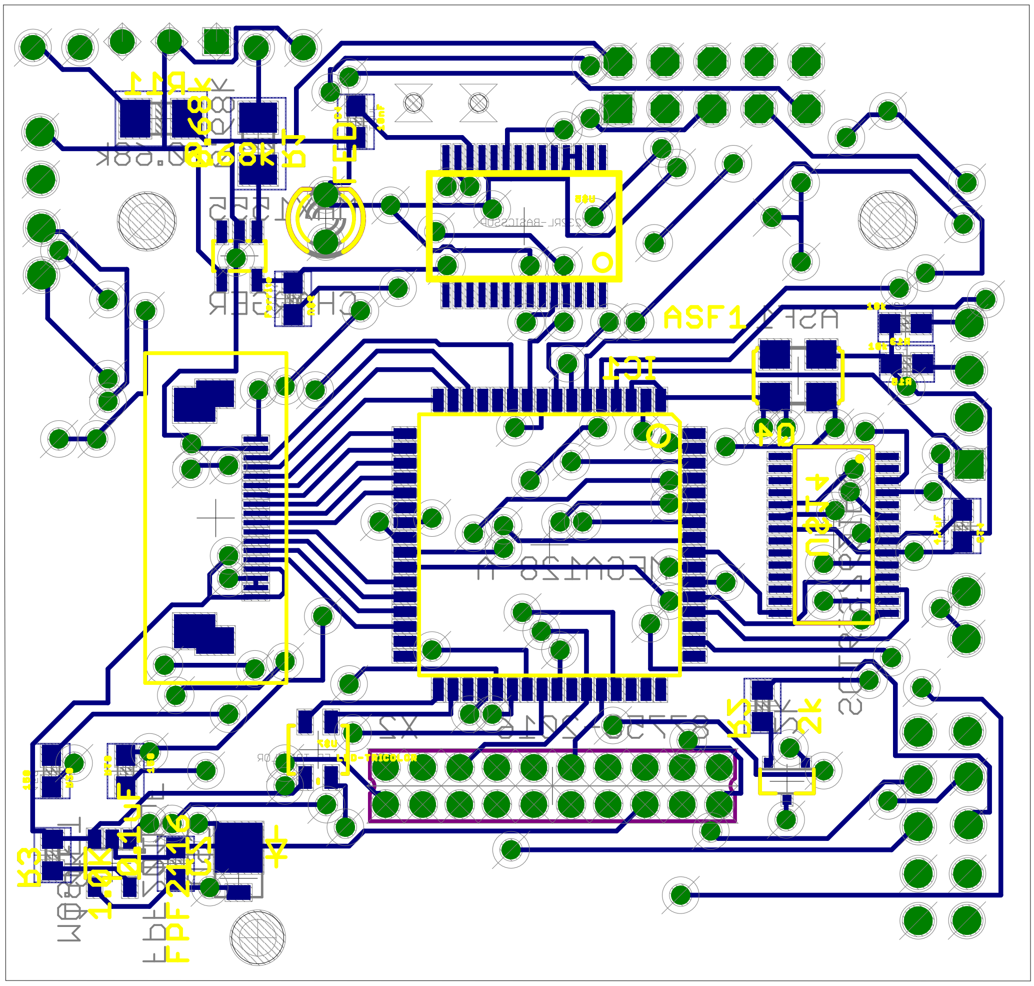

Figure A.4: Design of the circuit board back-side

Component	Description	package	nr:
ATMEL ATMEGA128L-8AU	8Bit 128k Flash MCU	TQFP64	1
AVR-JTAG-10	connector	thru hole	1
BLUERADIO_BR-C40A	bluetooth radio module	SOT863-1	1
C & K PCM12SMTR	slide switch	ultra miniture	1
EL Backlighting HVCMOS	HV826MG	MSOP8	1
EXAR SP6652EU-L	1A regulator	MSOP10	1
FAIRCHILD SEMICONDUCTOR FPF2116	MOSFET	SOT-23-5	1
FTDI FT232RL	USB to UART chip	SSOP28	1
KEMET B45025B1069K757	Capacitor 10uF	CASE B	2
KEMET C0603C103K2RAC	Capacitor 10nF	0603	3
KEMET C0603C104K4RAC	Capacitor 100nF	0603	4
KEMET T491B475K016AT	Capacitor 4,7uF	CASE B	2
CFAX12864CP1-WGH-TS	128x64 graphical display		1
LED-TRICOLOR	LED	SMD	1
LUMBERG 2486 01	mini USB socket		1
MARL 103-305-01	LED RED	PCB, 3mm	1
MARL 103-314-01	LED GREEN	PCB, 3mm	1
MAXIM DS2782E+	IC	TSSOP8	1
MAXIM MAX1555	USB charger	SOT-23	1
MULTICOMP MC 0.063W 0603 1% 100K	Resistor 100kR	0603	1
MULTICOMP MC 0.063W 0603 1% 10K	Resistor 10kR	0603	6
MULTICOMP MC 0.063W 0603 1% 26R1	Resistor 26.1R	0603	1
MULTICOMP MC 0.063W 0603 1% 340K	Resistor 340kR	0603	1
MULTICOMP MC 0.063W 0603 1% 4K02	Resistor 4.02kR	0603	1
MULTICOMP MC 0.063W 0603 1% 750K	Resistor 750kR	0603	1
MULTICOMP MC 0.063W 0603 5% 10R	Resistor 10R	0603	1
MULTICOMP MC 0.063W 0603 5% 150R	Resistor 150R	0603	1
MULTICOMP MC 0.063W 0603 5% 33R	Resistor 33R	0603	1
MURATA BLM18PG300SN1D	Ferrite bead	0603	1
MURATA LQH43CN4R7M03L	Inductor 4,7uH	0603	1
MURATA LQH43MN561J03L	Inductor 560uH	0603	1
ON SEMICONDUCTOR MMSZ4690T1G	Diode	SOD-123	1
OPTEK OVLBR4C7	LED, RED	45deg,3mm	2
PHYCOMP 223824613663	Capacitor 1uF	0603	1
PHYCOMP 232270260102	Resistor 1kR	0603	3
PHYCOMP 232271161681	Resistor 680R	1206	2
SAMTEC - CLT-110-01-L-D	connector	thru hole	1
SC16IS762IPW	spi2uart nxp	SOT-361	1
SEMICONDUCTOR BSS138	MOSFET N	SOT-23	3
SMD Clock Oscillators 7.3728MHz 3.3V	Oscillator 7.3728MHZ	ASF1	1
STAR MICRONICS NFT-03C	Buzzer		1
STMICROELECTRONICS 2STR1215	transistor NPN	SOT-23	1
Coin type Vibe Motor	Vibration unit		1
VISHAY DALE CRCW06032K00FKEA	Resistor 2kR	0603	1
VISHAY DALE CRCW06032M00FKEA	Resistor 2MR	0603	1
VISHAY DALE CRCW0603499RFKEA	Resistor 499R	0603	1
VISHAY DRALORIC - 0603, 0R, 1%	Resistor 0R	0603	1
VISHAY SEMICONDUCTOR 1N4148W	Diode 1N4148	SOD-123	1
VISHAY SMP11-E3/84A	Diode	SMP11	1
WELWYN ULR3-R002FT2	Resistor 20m	2512	1

Table A.1: Component list of wearable device circuit board

Curriculum Vitae

Daan Mastenbroek was born in 's Gravendeel, the Netherlands, on August 4th, 1980. He obtained his HAVO diploma in 1997 and his VWO diploma in 1999 both at the Revius Lyceum in Doorn. He did his bachelor in Electrical Engineering at the Faculty of Electrical Engineering, Mathematics and Computer Science of the Delft University of Technology. He joined the Computer Engineering department of Delft University of Technology in September 2004. He did an internship at Bitbybit Information Systems from 2007 to 2008. He did his thesis named *WATCH-OVER; A co-operative approach on vulnerable road user protection* at Logica Netherlands B.V. at their Working Tomorrow program and under the supervision of Arjan van Genderen. Daan will graduate from the Delft University of Technology in 2009.