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Person Following in an Autonomous Suitcase

Diploma Thesis in Computer Science

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Abstract

This thesis presents the development of a new approach for building a person following robot that is able to operate in an unknown environment facing real life situations. Infrared receivers are used to identify and locate a target person, who is equipped with infrared diodes. This approach has the following advantages: reliable identification of the target person, cheap design and good noise tolerance.
The process of implementing the new person following strategy revealed several inherent restrictions of the existing platform, which thus had to be revised. Therefore the approach could no be implemented completely. Nevertheless it is still promising and should be pursued in continuation of the RoboSuitcase project.

Zusammenfassung

Diese Arbeit stellt die Entwicklung eines neuen Konzeptes für einen Roboter vor, der Personen in einer unbekannten Umgebung folgt. Infrarotempfänger ermöglichen die Identifikation und Lokalisierung einer mit Infrarotsendern ausgestatteten Zielperson. Vorteile dieses Ansatzes sind: die zuverlässige Identifizierung der Zielperson, der einfache und kostengünstige Aufbau des Systems und eine geringe Störanfälligkeit der Sensoren.
Während der Realisierung dieser Strategie wurden einige technische Mängel der bisherigen Plattform entdeckt, die daraufhin überarbeitet werden musste. Dadurch konnte das Konzept nicht vollständig umgesetzt werden. Nichtsdestotrotz ist es nach wie vor vielversprechend und sollte weiter verfolgt werden.

Contents

1 Introduction

Imagine an ordinary day at the main station in Zurich. Commuters rush through the hall. Voyagers are waiting for the departure of their train - when suddenly a common-looking suitcase shows up. Moving independently, it follows its owner while weaving through the pedestrians and neatly avoiding dustbins and ticket machines.

Robots supporting us in daily life is no longer a crazy idea of science fiction authors. There are service robots assisting clients in supermarkets [5], grass mowing robots in our backyards [1], [32] and autonomous vacuum cleaner in our flats [17], [15]. And this is definitely just the beginning. Researchers are developing robots for all thinkable and unthinkable applications. A walking robot with big arms and a teddy bear head is created for rescuing injured soldiers out of combat zones [28]. A cute little robot called Phyno is built to act as an interface for the inhabitants of an ubiquitous computing home [26] and automated self-cleaning cat litter-boxes make cat keeping a little more comfortable. And these are just some selected examples out of a capacious diverse field.

To equip a conventional everyday item with some autonomy and therewith creating robots that support humans in every day life, this is basically the aim of the RoboSuitcase project. And doing this not by building robots from scratch, but getting inspired by everyday products. Maintain their specific functions, add some sort of autonomy to them and build thus robotized daily items. This idea is explained in more detail in section 2.1.1.
The idea of taking a suitcase originates from an inspiring moment of Andreas Fischer while reading the Dani Futuro comic strip: "Le cimetire de l'espace" [11]. Picture 1.1 from this comic strip shows three space travelers with their "teletransportable" suitcases flying behind them. Back in reality, Andreas Fischer created the idea of an autonomous suitcase driving on the ground and following its owner independently.

Before this assignment, previous work has been done on the RoboSuitcase project. An overview on this work is given in section 2.1.2 and 2.1.3. To complete the chapter 2 on the preconditions and head directly for the central issues of this thesis the task of the assignment is presented in section 2.2.
In chapter 3 some related projects are presented and the similarities and differences to the RoboSuitcase project are highlighted. The main part of the assignment is then following in chapters 4 to 7.
The actual work began with the identification of the requirements for the sensory system in order to achieve a tracking and following behavior of the RoboSuitcase. Then an evaluation of different kinds of sensors was done and finally the most suitable sensory

system for the RoboSuitcase was chosen. This is documented in chapter 4. Chapter 5 then outlines the working process of integrating the sensors into the system and illustrates this with some selected issues. The extended system including all components and the interaction between them is in detail explained in chapter 6. Including section 6.2 which outlines the technical boundaries of the system. Some ideas on possibilities for the implementation of a controlling entity for the RoboSuitcase are presented in chapter 7. Due to the severe technical boundaries of the RoboSuitcase's setup and the temporal restrictions of the assignment, it has not been possible to implement and test any of these strategies. Therefore the conclusion follows directly in chapter 8.

The last part of this thesis consists of an outlook on future work on the RoboSuitcase project. Possible solutions to the encountered problems discussed and ideas for future developing and improving the system are proposed then in the second part of the chapter.

Figure 1.1: The inspirational source for the RoboSuitcase project [11].

2 Preconditions

Beginning with an explanation of the RoboSuitcase project in general, this chapter will present the preconditions of this assignment. The basic idea of the project and its previous development are described in the first part whereas the second part will focus on this particular assignment and outline its specific task.

2.1 The RoboSuitcase Project

The RoboSuitcase project is based on the idea of robotized daily items which is explained in detail in section 2.1.1. Then section 2.1.2 states shortly about the development of the project and describes the design of the system as it was in the beginning of this assignment.

2.1.1 Idea: Robotized Daily Items

The underlying idea of the RoboSuitcase project is to redesign everyday things and equip them with a, to a certain extend, autonomous behavior i.e. to build an autonomous agent inspired by an everyday object.

The concept of autonomy is frequently used in the context of artificial intelligence and robotics. Pfeifer and Scheier [31] state, that the term *autonomy* refers to a freedom of external control i.e. to an independence from the environment and other agents. Furthermore they explain, that the concept of autonomy is not an all-or-nothing issue but a gradual property.

If we have a look at the items that surround us in everyday life we notice that their characteristics are mostly passive e.g. they just react on direct physical intervention. Take a chair for example, one has to pull or push it in order to move it. Considering their behavioral possibilities one can classify these objects into different groups, which are illustrated in figure 2.1. However this classification is meant as an illustration of the idea and not to be exclusive or complete for all existing objects.
Be group one the pure stiff objects like bookshelves, cups or screwdrivers which can move as a whole or break if the force applied on them is strong enough, but they can not perform any other action.
More sophisticated objects like an umbrella, a suitcase or a bicycle would form group number two. They possess one or more mechanical degrees of freedom and parts can be moved independently from each other. But they have to be moved i.e. they still need a direct physical force in oder to move itself.

The third group of objects would be more sophisticated mechanical or even electrical items. They are equipped with some sort of user interface consisting of buttons or remote control. Reacting on inputs they execute some defined behaviors but they would not change their behavior without the interaction over a defined user interface or direct physical intervention. Examples of this category would be mixers, lamps or coffee machines.
The fourth group would consist of autonomous objects, which would adapt their behavior autonomously to the environment without direct physical interaction. Therefore they need to be equipped with sensors in order to be able to perceive their environment. Examples of such objects are the self cleaning litter boxes or the autonomous vacuum cleaner presented in chapter 3.
Looking at this classification, the aim of the project consists of taking an object out of group one, two or three and changing it in a way it gets some kind of autonomous behavior and therefore belongs to group number four. With the essential condition of maintaining the main functions of the object and in order to generate a high user acceptance to keep also the appearance of the object as far as possible.

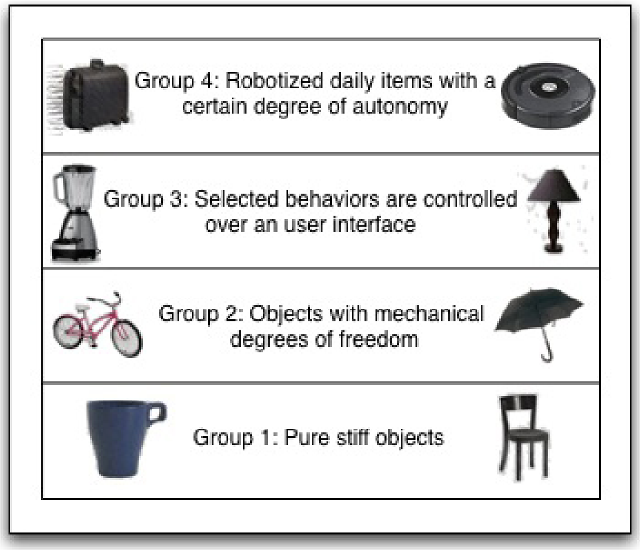

Figure 2.1: A classification of everyday objects regarding their possibilities of interaction with their environments.

So what are the advantages of having a suitcase acting autonomously? Regarding the classification just made, a suitcase is basically an object from group two. It has several degrees of freedom, one can open it or close it and it can be pulled. A person has to apply physical force on it in order to move it. Equipping it with an autonomous driving behavior would free the suitcase owner from the activity of pulling it. So far it would be a nice application for simplifying travelers life or another tool to enforce the lack of agitation of some persons. But the application of a person following robot can also be an important contribution to the support of elderly and disabled people, especially in our aging society.

2.1.2 History

The primary inspiration of the RoboSuitcase project origins as already mentioned in the introduction from the Dani Futuro Comic Strip "La cimetire de l'espace" [11]. The first prototype was then built in 2006 by taking away the cover of a remote controlled car and fusing the remaining components with a common suitcase. The result was a, not that common anymore, RoboSuitcase, which was controlled by a remote device. Regarding the groups of objects introduced in section 2.1.1, the RoboSuitcase would at this moment belong to group number three, an object controlled over a defined user interface. The goal however was to change it in a way it belongs to number four and possesses an autonomous behavior. Therefore it had to be enhanced further.
An electronics engineer was then assigned to extend the suitcase with some micro controller for controlling the motor and the servo. For an easy development of the system, the micro controller was built as a wireless server, which can send data and receive commands from an external device.
In order to achieve a first autonomous behavior, a student was assigned a diploma thesis [18] for implementing autonomous motion and obstacle detection.
In cooperation with the electronic engineer he added another micro controller board and four ultrasonic sensors for obstacle detection. Then he implemented a Java program running on an external computer, which was connected through a wireless network to the RoboSuitcase.
The RoboSuitcase was then able to run autonomously down a floor and avoid obstacles on its way.
And this is the point where the actual assignment started with the task of implementing a person following behavior.

2.1.3 System Overview

After the outline of the RoboSuitcase's life so far. This section will give a more technical overview on the system at the beginning of this assignment. However the individual components are just explained in such detail as it is necessary to show the level of development of the project and to get an understanding for the system. All the components are described in more detail in chapter 6 where the final overview on the new system is presented. Starting with the hardware we will then proceed with a short overview on the software components of the system.

Hardware

The shell of RoboSuitcase consists of a quotidian black hard shell suitcase, see picture 2.2 d. The inside is equipped with a motor and a servo for the drive and the steering.

Further it contains two development boards each with a PIC micro controller. To preclude misunderstanding they are named the I/O board and the WLAN board. While the I/O board provides a programmable interface for the sensors, the WLAN board, shown in picture 2.2 a., acts as web server for the communication over the wireless network. Four ultrasonic sensors are controlled by the I/O board and used for obstacle avoidance. A web cam and four infrared sensors, see picture 2.2 c., are also part of the RoboSuitcase but not used for the autonomous behavior.
Sensory data are transmitted over the wireless connection to an external computer where the steering commands are calculated and sent back to the RoboSuitcase.

To keep the original appearance, the wheels of the RoboSuitcase are still the original. The motor axles lay directly on the back wheels of the RoboSuitcase. As the axles do not have a good grip on the hard plastic wheels, they are equipped with some rubber mantel in order to increase the grip and optimize the force transmission, see picture 2.2 b. The servo is connected to the left front wheel and moves in a degree of approximately $\pm 30°$.
The ultrasonic sensors are a combination of an ultrasonic emitter and a receiver, for a photo see picture 2.2 e. They determine the distance to the closest objects by emitting ultrasonic waves and measuring the time until the emitted wave comes back and is received by the ultrasonic receiver. These sensors are positioned in the front of the suitcase. As outlined in graphic 2.3 the sensors point $\pm 20°$ respectively $\pm 50°$ away from the middle axis of the RoboSuitcase.

Software

There are three programmable hardware components contained in the system: Two PICs on the I/O and the WLAN board and the program on the external computer. The two PICs are programmed in C whereas the program on the external computer is developed in Java. In the following three paragraphs a short description of each one is given.

The I/O board acts as the interface to the sensors. It triggers the ultrasonic sensors in a way they can not interfere with each other and measures the answering time which is then standardized to a number in the range of 0 to 255 which in turn corresponds to the distance of the closest object in the range of one ultrasonic sensor. The collected data is then transmitted over an I2C connection to the WLAN board.

The WLAN board acts as a wireless web server. It uses the ChipWeb software from Iosoft Ltd. [16] which provides a customizable web server. The original source code has been adapted to the aims of the RoboSuitcase. It provides a simple HTML site containing tables filled with the sensory data, which can be queried over the wireless network by an external computer.
The steering commands are transmitted from an external computer to the RoboSuitcase contained in the query string. The WLAN board forwards these to the adequate address

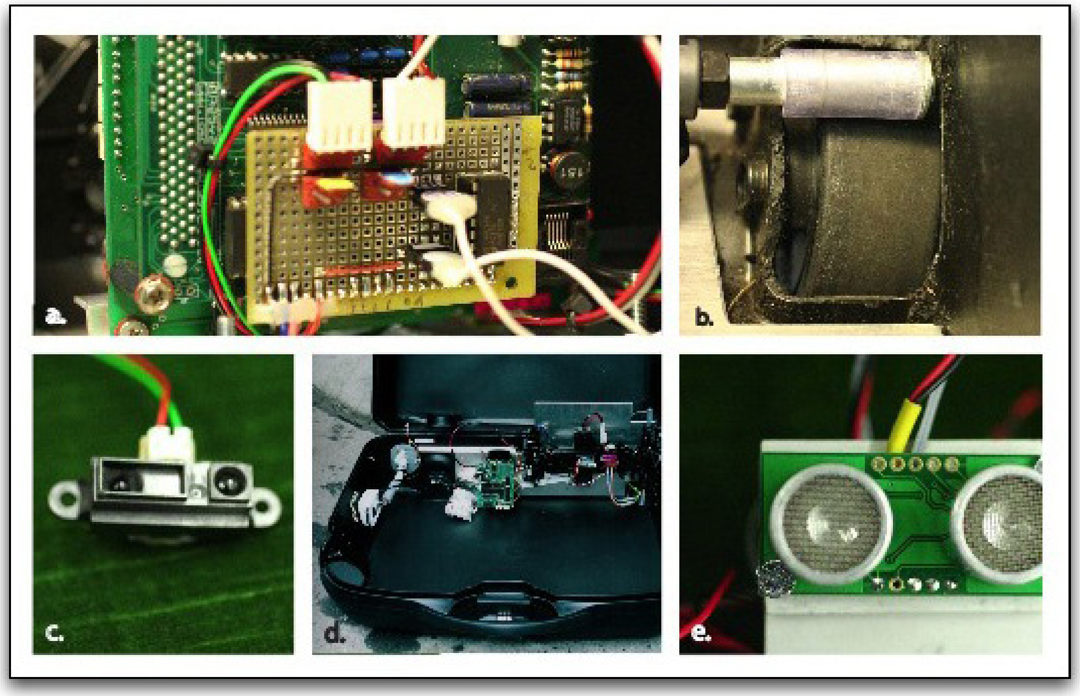

Figure 2.2: Photos of details of the RoboSuitcase's hardware: a. the WLAN board, b. the original wheel with the motor axle, c. an infrared distance sensor, d. the shell and inside of the RoboSuitcase, e. an ultrasonic sensor.

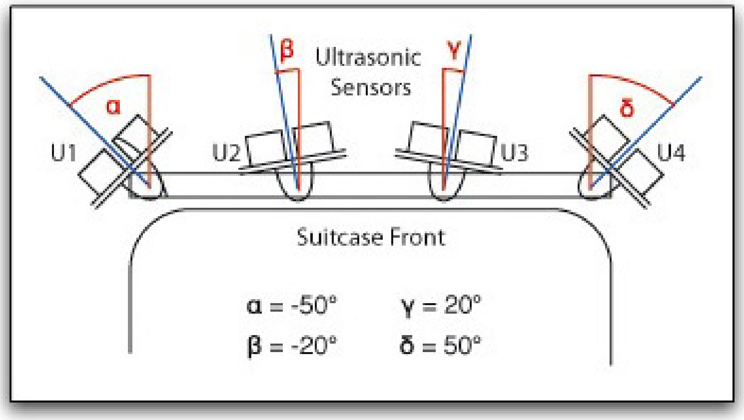

Figure 2.3: The positioning of the ultrasonic sensors on the RoboSuitcase.

i.e to the motor or the servo.

The Java program runs on a MAC OSX computer. It provides a modular framework for a relatively easy development of different algorithms for the control of the RoboSuitcase. Basically it sends requests to the WLAN board parses the received HTML code and extracts the sensory data. Then it processes the data and calculates the new commands for the RoboSuitcase. These steering and speed commands are then sent back to the WLAN board contained in the new request.

2.2 The Task

The task of this assignment is to augment the capabilities of the RoboSuitcase. It should be able to follow a given person in an unknown environment and avoid possible obstacles on its way. Conditions are given by the situation. The RoboSuitcase has to be able to follow a person in walking speed. Obstacles are either fix like dustbins, walls or pillars or they move like other people, animals or other autonomous suitcases.

The desired behavior consist therefore of: Sensing and identifying the RoboSuitcase's owner, determine his relative position and move the RoboSuitcase in such a way that it follows its owner while not bumping neither into obstacles nor into its owner.

This task is divided into the following subtasks:

2.2.1 Evaluation of a Convenient Sensor System

At first a sensory system should be chosen. Therefore different sensors should be evaluated regarding the aim of following a person in walking speed. Relevant properties are e.g price, weight, size, robustness or failure resistance. The most convenient one(s) are then chosen.

* Which similar applications and know-how exist already?

* Which sensor systems can be used for this specific application?

2.2.2 Positioning of the Sensors

The arrangement of the sensors on the RoboSuitcase have a great impact on its functioning. Thus an evaluation of different arrangements is necessary.

* How should the sensors be positioned and aligned?

2.2.3 Implementation of the Controller

The existing software needs to be extended and changed in order to be able to process the new sensory input. Different algorithms for the person following should be implemented and tested. The best strategy has then to be optimized.

* Which strategies exist in literature?
* Which strategies are suitable for this application?
* How can different algorithms be evaluated and compared to each other?

The assignment bases on the work done by past assignments. The new functions have to be integrated in the already existing platform.

This chapter showed that the aim of the project is to equip a suitcase with an autonomous behavior in order to make traveling easier and to support elderly and disabled people. The RoboSuitcase is at this point able to drive around autonomously and avoid obstacles.
Imagine your suitcase in the hall of an airport driving around autonomously avoiding all obstacles on its way, including you. This will not support you in any way but complicate traveling a lot.
The last section outlined the goals of this assignments which indicate the direction to an useful autonomous behavior that is able to support the RoboSuitcase's owner and not complicates his life. The next chapter will introduce some work that is related to this goal in one way or an other.

3 Related Work

The specific task of this assignment is a quite complex one. It is actually a combination of several fields of research e.g. ubiquitous computing, identification of persons, path planning or obstacle avoidance. And the given combination is rare to find. Anyway there is some work that is related in at least some points to this assignment. First two products are introduced which illustrate perfectly the idea of robotized daily items. These are self cleaning litter boxes for cats e.g. the Litter-Robot™ and autonomous vacuum cleaners e.g. the iRobot Roomba®. Then a paper about the topic of robotized daily items is presented which has mainly the same idea as the RoboSuitcase project but differs in the technical approach. To conclude this section the person tracking robot ApriAttenda is presented, which implements some of the behaviors that are desired for the RoboSuitcase too.

3.1 Self Cleaning Litter Boxes

Self cleaning litter boxes for cats are quite a good example for illustrating the basic idea of this assignment. Inspired by an everyday object a robotized item is created. The basic function of such a litter box is to serve as a toilet for cats. To decrease the unpleasant handling of the litter boxes, the self cleaning litter boxes were invented.
The litter boxes on the market work in a quite similar way, but look a little different. The two examples shown here are the Litter-Robot™ [4], which is shown in graphic 3.1 a. and LitterMaid™ [14] in graphic 3.1 b..
Both of the boxes work with clumping litter, which allows the easy separation of clean and dirty litter by a rake. The two of them contain sensors to perceive the presence of an animal and once an animal left in the litter box, the box will automatically start to clean itself. That is separating the litter a rake and put the clumped litter in a separate dirt box. The clean loose litter stays in the litter box and the cat can enter again. The cat keeper has to empty the dirt box only once in a while.
As these are examples for the general idea and not for the technical approach of this assignment, the technical details of the systems are not presented here. The interested reader will find details on the respective websites of the companies [4], [14].

3.2 Roomba®

Roomba® is another example for the idea of a robotized daily item and probably the most famous one, see picture 3.2. In this context it stands for a great bunch of similar

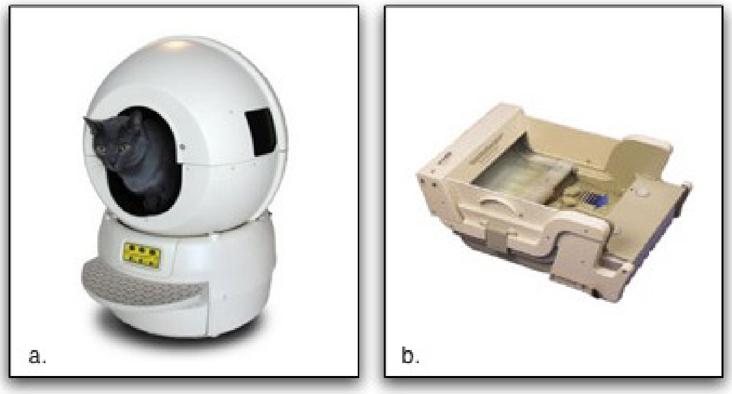

Figure 3.1: Two versions of self cleaning cat litter boxes: a. Litter-Robot™ [4] b. LitterMaid™ [14].

products. Be it other autonomous vacuum cleaners or grass mower, which work accordingly to the same principles.

In general these systems work like this: Having a flat surface that has to be treated in some way, e.g. vacuum cleaned or mowed, the robot moves around randomly. Doing this long enough the robot once will have treated the whole surface.
The robot is round and can turn on the spot in order to be able to leave any corner that it was able to enter before. It drives straight on until bumping into or sensing in an other way some kind of obstacle then it turns around and continues its work. The obstacles may be walls or furniture, but also stairs or artificial borders specially set up for the robot.
One can distinguish three approaches for generating the desired behavior in these systems. For the navigation algorithm a random behavior is implemented. An enhanced environment helps the user to restrict the application area and the low level sensors like bumpers and infrared distance sensors are used to enable the robot to react on its environment.

While maintaining the main functions of a common vacuum cleaner as in the Robo-Suitcase project, in this case the appearance of the product has been changed in order to optimize the product in its functioning.
An additional feature of these systems is the self sufficiency. They come with a charging station, which is frequented by the robot as soon as it runs out of power.

Figure 3.2: The vacuum cleaner iRobot Roomba® 500

3.3 Robotizing Daily Items

In the paper called "A Study of Robotizing Daily Items For an Autonomous Carrying System" [29] Nishimura et al. present their approach of equipping daily items with an autonomous behavior.
They introduce the idea of an attachment-and-detachment system for equipping various items like a chair, a desk or the shopping cart which they develop as a prototype. The desired behaviors of their robot are quite the same as in this assignment: Person following and obstacle avoidance.

The design of the shopping cart is as follows. A stereo camera is mounted in the front of the cart to detect the target person and determine the distance to it. The identification of the person is done by a classification of the color of the person's clothes. Close objects are detected by a laser ranger and a velocity sensor measures the driving velocity of the cart. From the laser ranger's and the velocity data an obstacle map from the environment is generated.
While the person following is an autonomous behavior of the system, the obstacle avoidance is implemented to be remote controlled. The two control mechanisms are implemented compatibly into the system.

In contrast to the goals, the technical approach is quite different to the one used with the RoboSuitcase, which may be caused by the different requirements imposed on the project. While the RoboSuitcase is meant to run in a real and unknown environment, the shopping cart system is designed more for the use in a controlled office surrounding. The identification of a person by the color of his/her clothes may work in a controlled environment with a selected test person. But in a train station cloth colors will in general appear on more than one person and the system would then follow just any of the persons wearing e.g. a gray jacket. This would not meet the requirements for the RoboSuitcase to identify the target person reliably.

3.4 AApriAttenda™

The person following robot ApriAttenda™ is developed by the Toyota Corporation and the Tokyo University of Science. In ”Development of a Person Following Robots with Vision Based Target Detection” [37] Yoshimi et al. and Mizoguchi present the idea and the design of the system.

The aim of developing ApriAttenda™ is to create a robot that supports humans in daily life and to achieve symbiosis and interaction between robots and humans. They state that for this aim the target criteria are the ability to recognize individuals and to perform save movement around humans.
For the person recognition they use two sensory systems. Stereo vision for identifying persons by registering color and texture of their clothes and speech recognition. For obstacle detection ultrasonic sensors are used.

Figure 3.3: ApriAttenda™ (on the right) with ApriAlpha™

The implemented behaviors are: finding a person, following it, avoiding obstacles on the way and trying to resume contact to the person when lost. To achieve the following and obstacle avoidance behavior a potential field algorithm was implemented which calculates repulsive forces from obstacles and an attractive force from the target person. These vectors are then combined to the final moving direction.
The idea of repulsive forces generated by obstacles is also implemented for obstacle avoidance in the RoboSuitcase. The extension to a combined following and obstacle avoidance algorithm is certainly a strategy to be tested for the RoboSuitcase too.

In this chapter some related work to the RoboSuitcase project was presented. The diversity of the examples shown here represent the amplitude of research fields which are relevant for the development of the RoboSuitcase.
Section 3.3 stated that the definition of the requirements of a system, be it restrictions resulting from the task or its environment, are a highly relevant issue for the development of a robotic system. The next chapter starts with the definition of the requirements for the RoboSuitcase, respectively for its sensory system, to perform the desired behavior.

4 Sensor Evaluation

This chapter first discusses the requirements for the sensory system. Then several types of sensors are evaluated considering these requirements and their application in related work. Based on this evaluation a decision is made and the chosen sensors are shortly introduced.

4.1 Requirements

The meta principle on the design of autonomous agents introduced by Pfeifer and Scheier [31] says that designing autonomous agents involves three constituents. The design of the agent itself, the task and desired behavior of the agent and its ecological niche. They state that for designing a, to a certain degree, autonomous agent these three constituents have to fit each other i.e. the requirements for one of the constituents can be deduced from the given characteristics from the other two. Relating this to the RoboSuitcase system one has to consider the RoboSuitcase itself, its task and desired behavior and its destined environment in order to establish the requirements of the system.
The agent is already given by the previous assignment [18] see section 2.1.3 for a detailed overview. It should now be extended concerning the sensory system and the controller while the morphology and the underlying system should be maintained.
The task and the aim of the sensors are described in detail in section 2.2.
The environment of the RoboSuitcase is given by the designated use of it: Follow its owner autonomously through halls of train stations or airports. This implicates the environment of the RoboSuitcase to be basically flat grounds in halls and corridors, a lot of obstacles e.g. dustbins, walls, baggage pieces or moving people to avoid and the specific person whom to follow.
To achieve the desired behavior it has to be considered whether the person whom the RoboSuitcase has to follow should be marked in some way. By all means this depends strongly on the sensory system chosen.

The requirements deduced from the definitions of the three constituents are the following:

Identification of a Person

The RoboSuitcase is meant to work in environments like train stations and airport halls. Typically there are a lot of people in these places and the system has to know exactly whom to follow. A reliable identification of the target person is therefore definitely a must-have for the RoboSuitcase. It has also to be considered that once there may be several RoboSuitcases acting in one place. They should therefore be able to distinguish their owner from other RoboSuitcase owners.

Determination of the Relative Angle to a Target Person

As the RoboSuitcase has to follow somebody it needs to sense this person somehow. And it needs to be able to determine the relative position of the person to itself. Therefore it needs sensors that are able of delivering adequate data.
The desired behavior is to follow somebody i.e. the person is supposed to walk in front of the suitcase and he will walk in curves or zigzag sometimes too. Therefore a detecting angle of about 180° in the front of the robot can be considered as the minimal detection angle necessary. As there is a constantly interaction with a human, the human will probably adapt to the RoboSuitcase up to a certain point too. E.g. he will understand that the RoboSuitcase can not see behind itself, because this is quite familiar to a human. And then it can behave accordingly and stand in front of the RoboSuitcase when he wants it to follow him. Anyway, for a more sophisticated behavior the RoboSuitcase should be equipped with more sensors in order to be able to detect its owner in the whole range of 360°.

Distance Estimation

The RoboSuitcase is supposed to follow a person without bumping into it. Thus it has to be able to estimate the distance to the person. The measurement does not have to be exact, but accurate enough to avoid collisions with persons and to maintain a security distance to them. The system should be able to detect a proximity to the person closer than a defined security distance in a stable manner. The security distance can vary in different following algorithms. E.g. if the RoboSuitcase follows right behind the person a security distance of 70 cm up to 1 m would be appropriate depending on the length of the footsteps one takes. Thinking about an algorithm that makes the RoboSuitcase follow a little inclined on the right side of the person as dogs do, the security distance could be minimized to 30 to 50 cm.
The security distance is measured here as the distance on the floor from the position of the RoboSuitcases front to the position of the back of the person.

Temporal Resolution - Driving Velocity

The RoboSuitcase is supposed to follow a person walking in normal walking speed, which is considered to be around 5 km/h which is about 1.4 m/s. At this velocity the controller has to be able to get the sensor data and process it in an amount of time which allows the RoboSuitcase to react fast enough to the environment's challenges e.g. people crossing their way.
A certain amount of temporal redundancy increases the stability of the system. In other words if we have three data sets in a row showing an obstacle on its way it is more

probable that there is really an obstacle and not only noise in the sensory data.
Most sensors normally just need time in the range of milli or even micro seconds in order to return their data. Thus the reaction time of the system depends mostly on the algorithm and on the processing of the sensory data.

Computational Power

The final implementation goal, even if it is not part of this diploma thesis, is to perform all the calculations on a microchip located in the suitcase itself. Hence it is necessary to consider this in the selection of the sensory system regarding the computational power needed to process the sensory data.

Integration in Existing System

The agent's design is proposing some restrictions as well. The sensors should fit in to the existing design concerning size, weight and power and should not interfere with the existing sensory system for obstacle avoidance.

Costs

In section 2.1.1 the idea of redesigning everyday things was explained. The object should be redesigned but maintain its main functionalities since it is meant to be used afterwards for the same purpose as before. The RoboSuitcase should thus be affordable in order to be used.
When selecting the sensory system one should keep in mind the cost-benefit ratio of the respective technologies.

In summary there are basically three tasks which a suitable sensory system should be able to fulfill and several additional restrictions.
First, the sensory system has to be able to reliably identify a specified person in a basically unknown environment. Second, the relative position of the RoboSuitcase to the person has to be specified. Third, the distance to the person has to be estimated.
The computational power needed for the data processing should fit the computational resources of a microchip. The system should be able to work while driving in walking speed and the sensors should fit the RoboSuitcase regarding size, weight and other sensors. Finally, the cost-benefit ratio of the sensors should be considered when deciding on the sensory system in order to keep it affordable.

4.2 Sensor Technologies

As showed in the previous section the sensors have to fulfill mainly three tasks under some restricting conditions. There is quite a large research field on the topics of person tracking , determination of relative angles and estimating distances to specified objects.

The largest amount of research in person identification and tracking systems is made in vision based technologies. Therefore this section will start analyzing vision technologies regarding to its suitability the RoboSuitcase project. Subsection 4.2.2 will then address the global positioning system GPS. A wide class of technologies which include emitters and receivers to transmit signals can be used for several distinct aims. Section 4.2.3 will give an overview and have a look at the different technologies from this class. The last section then refers to environment scanning technologies e.g. laser scanner.

4.2.1 Vision

A lot of research is done in the field of person identification and tracking with visual systems. Mainly they use one or two cameras and do image processing, e.g. feature [37] or motion detection [9], in order to extract the relevant information.

For the identification of persons in visual data there exist many different approaches. The identification of faces [9] is certainly an interesting field but for the aim of the RoboSuitcase to follow behind a person it is not suitable, because people would have to walk backwards in order to enable the RoboSuitcase to follow them. Other approaches focus on identifying human shapes in the camera images [27], [23], but they do not identify specific persons which is required for this assignment. More promisingly are approaches as tracking the back view of a person and identify him/her by a registered texture and color of his/her clothes [13], [37]. Anyway it is highly doubtable that this technique would work in practice, because the designated environment including the people and their clothes is unknown and therefore it is impossible to select a color and texture which will be certainly unique in the environment. For several RoboSuitcases in a shared environment it will be even more complicated. Additionally humans are not likely to agree in wearing extremely colorful and eye-catching clothes just to use the RoboSuitcase.
An other approach is to mark the target person with an infrared emitter, which can not be seen by humans but which can be recorded by a camera. But the problem of the uniqueness appears here too. One can not exclude the possibility of other infrared emitters being around on public places.
The second big restriction with the use of vision is the amount of data. Imagine a camera with a temporal resolution of 12 fps and 640 x 480 pixels each frame, which is quite low quality. This would already lead to 3'686'400 pixel data per second which would have to be processed within milli seconds in order to be able to react on suddenly appearing obstacles. This clearly contradicts the restriction of low computational power.

We conclude that a reliable identification of a person's back view in an unknown environment is not possible, because one can not assure an unique back view. The two remaining tasks namely the determination of the relative angle and the distance, require a reliable identification of the target person in the visual data. Thus they can not be executed either. Adding the computational power needed to process the camera images, vision can be excluded as suitable sensor technology for the RoboSuitcase.

4.2.2 Global Positioning System (GPS)

A GPS system would be at first sight a possible solution for the relative angle and the distance estimating tasks. The RoboSuitcase itself and the owner could determine their global position through GPS. With an additional communication channel e.g. a radio transceiver they could exchange the data and then the relative angle and the exact distance could easily be calculated. At a second glance one will notice that there are some severe restrictions on this technique. The most striking is the fact, that GPS works only outdoors. Some optimizing approaches try to increase the availability with super sensitive sensors [34]. But still the availability which is necessary for a continuous following behavior is not guaranteed. Another difficulty with using GPS for the given task would be the accuracy of the measurement.
Due to the restricted availability of the GPS it is not suitable for the use in the RoboSuitcase.

4.2.3 Emitter-Receiver Communication

A bunch of sensors come in pairs i.e. an emitter and a receiver to transmit some kind of signals. These sensors are used e.g. for remote controlling the TV set by infrared signals or to synchronize a mobile phone to a computer by bluetooth i.e. radio waves. With a data transmission system the identification of an emitting unit by a receiving unit can be easily made by adding an identification key to the sent signal. As the medium will be air there exist basically three medias that can be used for data transmission: Light, radio waves or sonic signals.

Light

Data transmission with modulated light signals are made with different kinds of light. The two most common ones are infrared and ultra violet light. Both of them are invisible for humans and can be modulated in order to transmit data.

The most used light for data transmission is infrared. An often stated disadvantage of this technology is the need for a direct line of sight (LOS). However this could be a decisive advantage in this project considering that the need of a LOS can be used to determine the incident angle of the signal, when using different receivers with different receiving angles [25], [2], [20]. The remaining task is the estimation of the distance from the RoboSuitcase to its owner. Possible approaches would be to analyze the intensity of the signal or the horizontal incident angle of the signal or to use another sensory system in combination with the infrared sensors.

Ultraviolet (UV) light is invisible for humans and has a wavelength of 1 to 400 nm. Although ultraviolet waves can be modulated and used to transmit data it is normally just used in wires. And this for a plausible reason. UV waves can cause severe injuries to humans and animals. On longer exposure skin is harmed and appearing in lower wavelengths it can even cause blindness. These characteristics make UV an unsuitable technology for the RoboSuitcase.

Radio

Radio wave, e.g. technologies like bluetooth or RFID, would do a good job for identifying purposes. However, radio transmission is not restricted to a LOS. Whereas for simple data transmission this is a plus, in this task it complicates the tracking of the target person. Relative angles could be determined by triangulation on the signal strength. Which means the signal strength is measured on two opposite points on the robot. By analyzing the signal strength one can calculate the relative angle of the emitter to the two receivers by simple geometry. And with this approach obviously also the distance to the person could be measured. However, considering the width of the RoboSuitcase of about 20 cm and the expected distances to the person of one to three meters, the distance estimation would need an accuracy of at least some centimeters, which can not be done by usual affordable sensors.

Sonic

The already implemented system for obstacle avoidance is based on ultra sonic sensors. An ultra sonic emitting device for identifying the person to be tracked would interfere with the obstacle detection system.
Apart from the interfering problems sonar signals reflect a lot on any kind of surfaces. This makes a reliable determination of the relative position to the person extremely difficult.

4.2.4 Laser Scanner

In high end robot navigation systems laser scanner are used quite often, because of their accuracy and richness in data.
The use of a laser scanner can be compared to the use of a camera. The only difference is that the laser scanner returns less sensory data and no color but distance information. The problems that occur with this type of sensor are quite the same as with using a camera. A reliable identification of one specified person is hard to do and would imply some labeling of the target person that could be identified by the laser scanner. Considering the fact that the specified person moves a lot while walking and the laser scanner is simply able of detecting forms of objects, this is really hard or even impossible to do. The same as in the case of the camera, the determination of the relative angle and the distance would be relatively easy, given the fact that the laser scanner measures exactly these two things: the distance to objects and their relative angle to itself.
For object avoidance the laser scanner is perfect, and in combination with other sensors it would be an interesting source of redundancy data to work on. For example once detected the relative position of the target person the laser scanner could deliver the information of the distance to it.

Other reasons against the use of laser scanners would be the price, laser scanner cost in the range of several thousand swiss franks each, or the required computational power to process the sensory data.

The summarized result is the following: Vision can not be used because there is no reliable strategy to identify specified persons, anyway the amount of data a camera produces can not be processed by a simple microchip. Global positioning is only fully usable in outdoor areas, for a continuous location indoors it is no suitable practice. Transmit data by modulated light is not practicable with UV light because of its external effects. But using infrared sensors would be a possibility. It has the advantage of needing a LOS from an emitter to a receiver in order to transmit a signal, which allows to deduce a relative angle if the sensors are placed accordingly. For the distance determination several approaches exist that would have to be tested in practice. Radio waves offer a reliable way to identify a person if he/she wears an emitter, but there is no practicable way of determining a relative angle with this approach. Sonic signals would interfere with the implemented obstacle avoidance system and laser scanners are not able to identify specific persons properly and are in addition beyond the budget for this assignment.

4.3 Selection

Looking at the previous section one realizes that it is not an easy task for one sensory system to accomplish with all the requirements of this assignment. However the clear favorite is the infrared data transmission strategy. Which therefore is chosen to be tested.
For the implementation the TSAL4400 infrared emitting diode is chosen in combination with the TSOP2238 infrared receiving modules. They are produced by the Vishay Electronic GmbH and optimized for the use in remote control systems. They offer a communication range of up to 35 m in optimal conditions. A great noise resistance is achieved by a sophisticated signal filtering in the receiver module. Only signals with a defined carrier frequency of 38 kHz and a burst length of more than ten cycles a burst are captured. Therefore ambient light and constant infrared signals can be identified as noise and filtered out.

5 Working Process and Selected Issues

This chapter deals with the process of integrating the chosen sensors into the already existing system, its adaption and extension. At first we will explain shortly the idea of how to use the selected sensors in order to achieve the desired behavior. Then an overview on the working process is given, which is then in section 5.3 illustrated with details about some selected issues from the working process.

5.1 Idea

In section 4 it was shown that there is no reliable method to identify a specific target person without marking him/her in some manner. The use of the infrared sensor implies the equipment of the person with an emitting device and the attachment of the infrared receivers on the RoboSuitcase.

The convenience of using infrared communication is the requested line of sight from the emitter to the receiver. For the task of identifying the relative angle of the target person this can be used as follows.
Each receiver module has a defined receiving angle. When one of the modules is measuring an infrared signal, the emitting source of the infrared signal is placed within this specified angle. See 5.1 for an illustration.
For determining the distance to the target person, this approach is also a possibility to be tested. Taking a receiver and let it point to the sky. This sensor will only receive a signal if the target person is close enough and the incident angle of the signal steep enough.

Basically we receive two kind of data from these sensors. First, the information, whether a signal is received or not, which results in a boolean value for each sensor. Second, the actual data transmitted, which can be one or several bytes.
For the determination of the relative angle the first kind of data is used. The second can transmit additional data as start or stop commands or changing to different modes. This is actually not used but possible uses of this kind of data are discussed in the outlook in chapter 9.

5.2 Process

The next step after having chosen the sensors, was to set up a small test environment to get insights about how to build the electrical circuits for the two sensor modules.

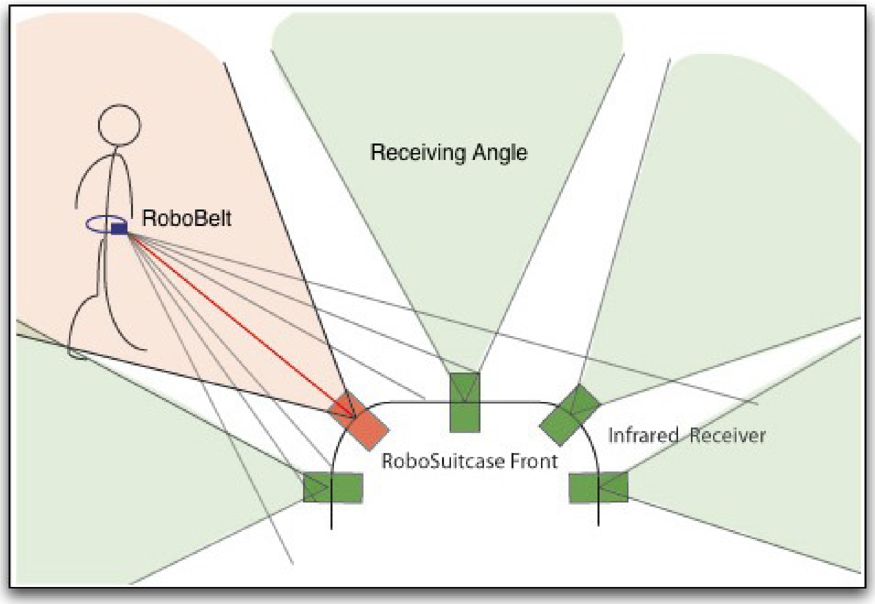

Figure 5.1: The idea of the infrared sensors. If the target person is located within the receiving angle of an infrared receiver, it gets the signal and the relative angle of the target person can be deduced.

The details of this setup are described in section 5.3.1. Once the receiver modules were able to receive the signal sent by the diodes, the next step was to think about how to integrate the sensors in the RoboSuitcase system.
One part of this task was to build a device that is worn by the person and emits constantly infrared signals. The other part consists in integrating the receiver modules in the RoboSuitcase itself.
Latter means defining the number of receivers needed and attaching them to the RoboSuitcase in a convenient way. Details about the positioning of the sensors can be read in section 5.3.2. Then all the receivers have to be connected to a power supply and to the I/O board, which in consequence had to be adapted in order to control all sensors and read them correctly. The device for equipping a person with the infrared diodes is built on a belt. Considerations about the needed number and positioning of the diodes and the detailed setup of the RoboBelt are outlined in section 6.1.2. The moments of first testing of the new sensors with the whole system made appear some weaknesses of the system, which are outlined in section 6.2. The most outstanding problem was the performance of the wireless connection. In consequence some steps were then taken in order to improve this. For details of this process see section 5.3.4.

5.3 Selected issues

After the rough overview on the process of developing the RoboSuitcase in the previous paragraphs. This section will explain some selected issues in more detail.

5.3.1 Test Setup for the Sensors

As both, the infrared emitter diode and the receiver need an electrical circuit in order to work a test setup was built on breadboards.

Section 4.3 described the noise resistance of the TSOP2238 receiver. It is immune to ambient light and most technical infrared sources, because the receiver has an integrated filter that admits only specially modulated signals. The signal is supposed to have a carrier frequency of 38kHz and the burst length has to be at least 10 cycles a burst.

The electrical circuit for the receiver module is quite simple. Its three pins are used for voltage, ground and data output. For connecting it to a power supply and a micro controller only one capacitor and one resistor are needed. See picture 5.2 b.

The circuit for the diode, see illustration 5.2 a., is a little more sophisticated, because of the requirements of the receiver. The signal has to be generated in an adequate way for the receiver to capture it. There are two sources of signal waves. The data signal generated by a C++ program running on a laptop and the signal with the carrier frequency that is generated in a 555 timer placed directly on the breadboard.
The data signal from the laptop is transmitted over the data transmission pin of the serial interface to the electrical circuit of the diode. There it is merged with the carrier

frequency of the 555 timer and then provided to the diode.
The 555 timer circuit is presented as only one module in picture 5.2, to point out the composition of the electrical outline. Actually the 555 timer needs a special circuit in order to generate a given frequency. This circuit includes a power supply of the timer and appropriate connections of its pins. The requested 5 volt are supplied by the USB hub of the laptop, which also generates the data signal. To manipulate the frequency of the output signal the capacitance of two capacitors can be varied.

The main challenges building the electronic setup was to understand the requirements of the infrared receiver and to find the right components in order to modulate the signal in the appropriate way.

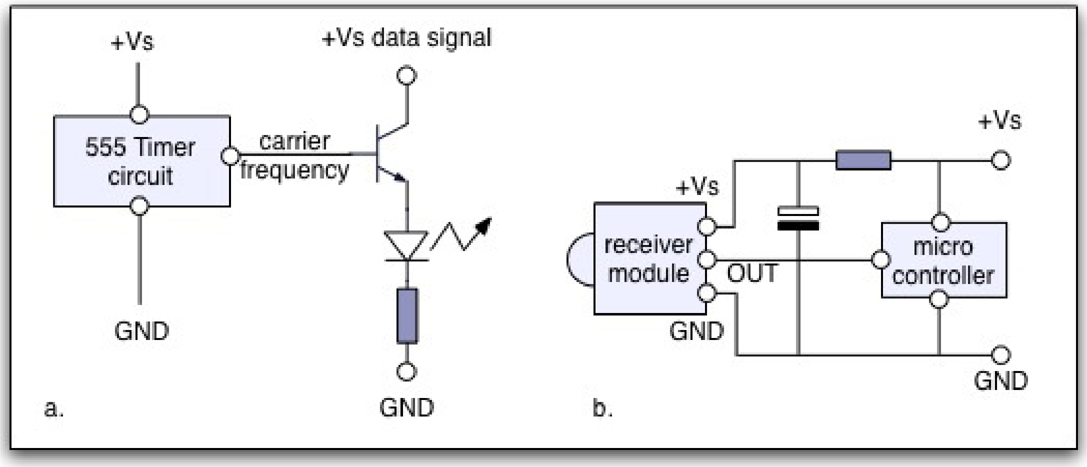

Figure 5.2: The electrical circuits of the infrared emitter (a.) and receiver (b.).

5.3.2 Positioning of the Sensors on the RoboSuitcase

The positioning of the sensors on the RoboSuitcase has a great impact on the acquired data and therefore on the behavior of the RoboSuitcase.

For an adequate positioning the characteristics of the sensors and the required information have to be considered.
The receivers have a receiving angle of about 90° horizontally and vertically.
For the desired behavior of the RoboSuitcase information about the relative angle of the target person has to be known in order to steer the RoboSuitcase in the adequate direction. Additionally the distance to the person has to be determined.

Section 5.1 explained how the relative angle can be determined by the receiving angle of the sensor. Varying the receiving angle of the sensors, one can define the resolution of the sensory data. The smaller the receiving angles and the more sensors are used the higher the resolution of the data. But higher resolution also means more data to process and more sensors to handle.
To have some redundancy in the sensory data it would be useful to overlap the perception areas of the sensors. This would also increase the resolution of the data by adding the overlapping areas as distinguishable regions.
As the aim of the RoboSuitcase is to follow somebody, it should always optimize its direction according to the location of the target person. In other words, the RoboSuitcase will always turn to the target person and try to keep him/her right in front of it. The adjustment of the steering angle would therefore be larger the more the desired direction differs from the actual one and smaller and more precise the smaller the correction needed. Therefore the information of the desired direction if it is close to the actual one needs to be quite precise, compared to the information needed in the other case, where a simple turn left or turn right information would be enough.
A varying resolution, higher in the front of the RoboSuitcase and lower on the sides would address this issue.

So what would be an appropriate resolution for the RoboSuitcase? Generally it has to know, whether it has to drive right ahead, turn left or right. This would be three sensors.
Considering the demand for redundancy and the varying resolution following positioning of the sensors was made: Five sensors keep track of the relative angle to the target person. They are aligned as shown in illustration 5.3. With the angles of 0°, ±45° and ±90° and a restricted receiving angle of about ±22.5° horizontally. For determining the relative position of the target person the sensors should have a restricted horizontal and a wide vertical angle. Because the vertical incident angle of the signal varies according to the distance of the person.
This fact can in turn be used in order to determine the distance. For this purpose a sixth sensor was placed on top of the RoboSuitcase which could if required be complemented with more sensors.
The sensors used for the relative angle determination are fixed in a height of about 45 cm from the ground which is the highest possibility to fix them on a plane surface.

This actual outline of the sensors is a first approach and is meant to be adjusted to the selected algorithm and its specific requirements. As the implementation of a controlling algorithm could not be addressed in this assignment due to different reasons, read chapter 8 for details, this outline was maintained till the end of this assignment.

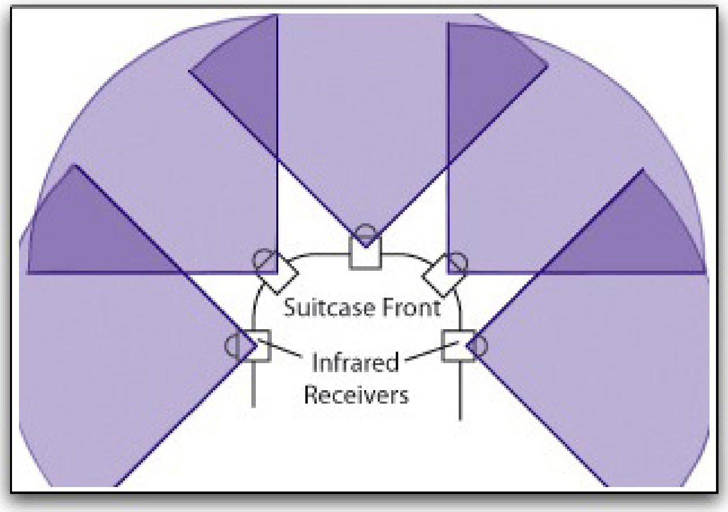

Figure 5.3: The positioning of the infrared receivers on the RoboSuitcase. They are aligned with angles of 0°, ±45° and ±90° respectively and have a receiving angle restricted to ±22.5°.

5.3.3 RoboBelt

The idea of the RoboBelt is to equip a belt with infrared diodes and transmit a signal, which can be identified and located by the infrared receivers on the RoboSuitcase. In section 5.3.1 the setup of a single diode and a single receiver is described. But as a single diode just has a range of just 20 to 25 degree several diodes are necessary to cover a reasonable range.
But what is a reasonable range? To answer this question some information about heights, distances in the expected situation are required.
The average body size of Europeans is 169,9 cm [8]. A belt is normally worn on about half the full body size. The RoboSuitcase measures 55 cm in height. Therefore it is assumed that the height of the diodes, which are worn on a belt is higher than the height of the receivers placed on the RoboSuitcase. Considering this one can say that the angle of the line between the RoboBelt respectively the diodes and the RoboSuitcase respectively the receivers is not getting bigger than 90° in any situation. The angle decreases whenever the agents get closer and increases when distance gets larger. It even converges to 90° with an increasing distance, but it can not grow to more than 90°. Therefore the reasonable space is already limited in the vertical dimension to 90°. Graphic 5.4 a. illustrates this considerations. For the horizontal space the emitting angle should be ideally 360°. Because for a person who is followed by an autonomous suitcase it is quite natural to turn once in a while to look if the suitcase is still following or stand still and turn around to wait for the RoboSuitcase to come. For maneuvers like these the RoboSuitcase would loose the signal from the RoboBelt and would not be able to

determine anymore where the person is standing.

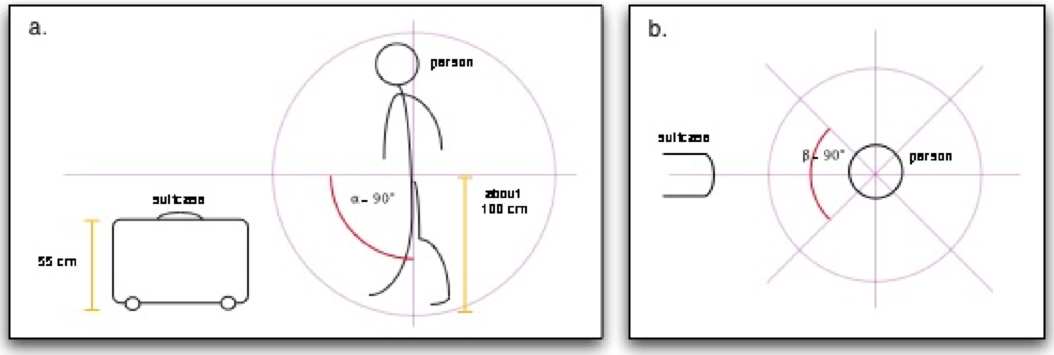

Figure 5.4: The required angle for the signal emitting diodes to cover the in the vertical range (a.) and in the horizontal range (b.).

Lets take a spheric to represent all possible directions in which the infrared signal could be sent. In graphic 5.5 a. we see the reasonable ranges we just defined colored. It is simply the lower hemisphere of the spheric.
For the first test setup of the suitcase anyway it is not necessary to include already the complete features. For developing and testing the following behavior of the RoboSuitcase in a first step, it will be sufficient to cover a limited range of about 90° which is shown in graphic 5.4 a. in the top view and 5.5 b. on the base of the spheric.

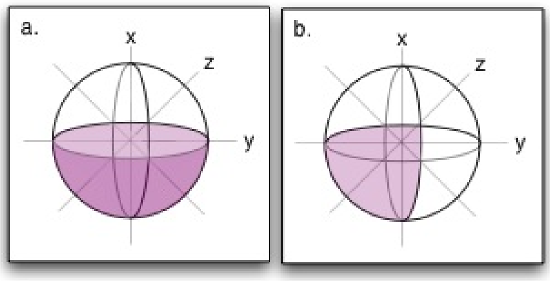

Figure 5.5: The spheric representations of the reasonable ranges (a.) and the restricted ranges for the first testing (b.) to be covered by the infrared emitting RoboBelt.

This is implemented with 4 x 4 infrared diodes adjusted in the right angles and fixed on the RoboBelt. This can be seen in picture 6.1 from chapter 6.
It was already mentioned above, that the first test setup on the breadboards was with one diode and one receiver. Concerning the electrical circuit the generation of the signal and the powering of the 555 timer by the laptop was maintained. But as 16 diodes need more amperes than one, the circuit had to be extended with a battery in order to provide the necessary power.

5.3.4 Performance

Once the sensor setup was done and tested for the first time, a delay in the sensory data was noticed. Therefore the performance of the system was analyzed with surprisingly results. The wireless connection was only able to transmit three times a second the complete sensory data. This is a really bad performance and not enough for a smooth real-time navigation. To solve this problem several steps have been taken.

The initial situation was as explained in section 2.1.3: The WLAN board acting as a server is implemented with a customizable framework for a web server in C whereas the WLAN client is integrated in the Java program on the external computer. The connection to the WLAN server was established by the call of the function *openStream()* from the Java class URL and closed again after each transmission.

In order to establish a continuous connection between the two devices, a TCP socket was generated in the Java program over which the sensory data and commands should be transmitted without closing the connection after every data transmission. But anyway the connection was closed by the system after every reading of the sensory data. The reason was not clearly identified, but a possible explanation would be the implementation of the network functions in Java, since Java has a high level of abstraction and is not meant to be used for manually implementing network issues.

The next approach was to try to implement the WLAN client in C++ and test if the network has a better performance. Therefore a test client was implemented, which effectively exhibited a better performance of about 8 to 12 data transmissions a second. As the framework for the data processing still was implemented in Java, the two programs had to interact somehow and exchange the data. Hence a Java Native Interface (JNI) was implemented to achieve the integration of the C++ code into the Java program. This worked well regarding the data transmission and the integration of the two codes. But one problem remained. The wireless connection has the nature of aborting once in a while and the problem of handling the errors occurred in the Java Native Interface JNI and the reestablishing of the connection has not been able to be solved .

A third approach was to reduce the amount of transmitted data. Instead of sending a whole HTML code, just the sensory data were sent by the WLAN server. This increased the performance again up to 20 transmissions a second.

Finally the performance of the wireless connection could be improved with the different approaches. But the connection lacks now in stability.

This chapter presented the working process of this assignment, respectively the way from the RoboSuitcase at the beginning of this assignment to the actual state of it. A lot of the problems encountered on this way were solved. But some still remain. The following chapter will now give an overview on the actual system and show the major problems still remaining.

6 System Overview

The RoboSuitcase is now extended with the new sensory system and completed with the RoboBelt. This chapter gives now a description of the system as a whole. The first section focuses on the technical outline of the RoboSuitcase and the second on the technical limitations and remaining problems of the system.

6.1 RoboSuitcase

This section will give an overview on all the components present in the RoboSuitcase's system and their interaction. Section 6.1.1 will present an overview of all the individual components directly associated with the RoboSuitcase. Then in section 6.1.2 the RoboBelt will be explained in detail. Section 6.1.3 will finally describe the data flow in the RoboSuitcase and the external computer.

6.1.1 Components

In the following section all the components of the RoboSuitcase and the most crucial facts about them are presented.
The RoboSuitcase contains the following components:

Four *ultrasonic sensors* of the type SRF05. Each of these sensors contain an ultrasonic emitter and a corresponding receiver. By means of measuring the time between sending and receiving an ultrasonic signal, these sensors determine the distance to the closest object in a particular direction. The sensors have a range of approximately three to four meters.

Six *infrared receivers* of the type TSOP2238 produced by Vishay Semiconductor GmbH. These sensors are built for infrared remote control systems. To receive data from an infrared diode, the wave lengths have to correlate and the requirements for the transmitted signal, see section 5.3.1, have to be fulfilled. The data transmission is highly resistant to noise and interferences e.g. from ambient light or other infrared devices. Details about the TSOP2238 infrared receiver modules can be found in section 4.3.
Five of the sensors point horizontally away from the RoboSuitcase in order to determine the relative position of the tracked human, respectively the belt. One of them points upside in order to determine the distance to the tracked person. Details of the positioning of the sensors are described in section 5.3.2.

Four *infrared distance sensors* of the type GP2D120 produced by Sharp. These sensors measure distance to objects and work similarly to the ultrasonic sensors mentioned above. They are not used in the actual state of the RoboSuitcase project, because of their limited range of around 30 cm and their susceptibility to noise.

The *I/O-board* is a PIC developer board from ETT Co. Ltd. equipped with a PIC18F452 micro controller from Mircochip Technology Inc. The main task of the micro controller is to control the sensors whereas the developer board provides the necessary periphery for the correct operation of the micro controller. From the standard interfaces included in the developer board, only one is used to establish an I2C connection to the wireless board.

The *WLAN board* is an ER25 wireless development board from Isoft Ltd that is also equipped with a PIC18F452 from Microchip Technology Inc. It comes with the Chip-Web wireless source code package, which was adapted to the requirements of this specific project. The WLAN board mainly operates the wireless LAN connection to the external computer.

For the drive mechanism a *motor* is required. It is taken from a remote control car and has been integrated into the suitcase. The specification of the motor is not available anymore. The control chip has been exchanged due to overheating. It is now a V12 XR from Modelcraft Inc.

A *servo motor* steers the RoboSuitcase by turning its front wheel. Originally also taken from the remote control car it has been exchanged several times due to damages.

A remote control car motor can obviously be controlled by a remote device. This feature was meant to be maintained. Therefore the *antenna* was also built into the RoboSuitcase. Because of some interferences, probably from the wireless card, the remote control from the original control device is not used at the moment.

Two *rechargeable batteries* supply the RoboSuitcase with power. One for the two boards and the other for the motors. The batteries are 7.2 V Ni MH X-packs with 3300 mAh.

A special feature is the integrated AXIS 206W *Wireless Network Camera*, which can be accessed directly through wireless LAN. The camera is not used for the obstacle avoidance or person following algorithms due to the problems explained in section 4.2.1, but it is integrated in the user interface of the Java program, which allows the user on the external computer to look where RoboSuitcase is driving.

The external computer, which is not directly contained in the RoboSuitcase is the data processing entity of the system. It takes the sensory data it receives, applies an algorithm on it and calculates thereby the new motion commands for the RoboSuitcase.

It can generally be any computer equipped with wireless LAN. But so far it is tested on Mac OSX operating systems only.

6.1.2 RoboBelt

The process of building the RoboBelt was described in detail in section 5.3.3. Figure 6.1 shows what the belt looks like. In the schematic representation its main components are labeled.

The *serial connection* is attached to a laptop, which generates the signal for the infrared communication. The serial interface is connected to the *electrical circuit* on the RoboBelt.
The *electrical circuit* powered with 5 V from an USB connection generates the carrier frequency of 38kHz required by the receiver and modulates it with the data signal from the serial connection. Its detailed outline is described in section 5.3.1.
As the USB connection does not supply enough current for all diodes a 9 V *battery* is integrated to provide the necessary power.
Finally sixteen TSAL4400 *infrared emitting diodes* arranged in four rows emit the generated signals as modulated infrared light.

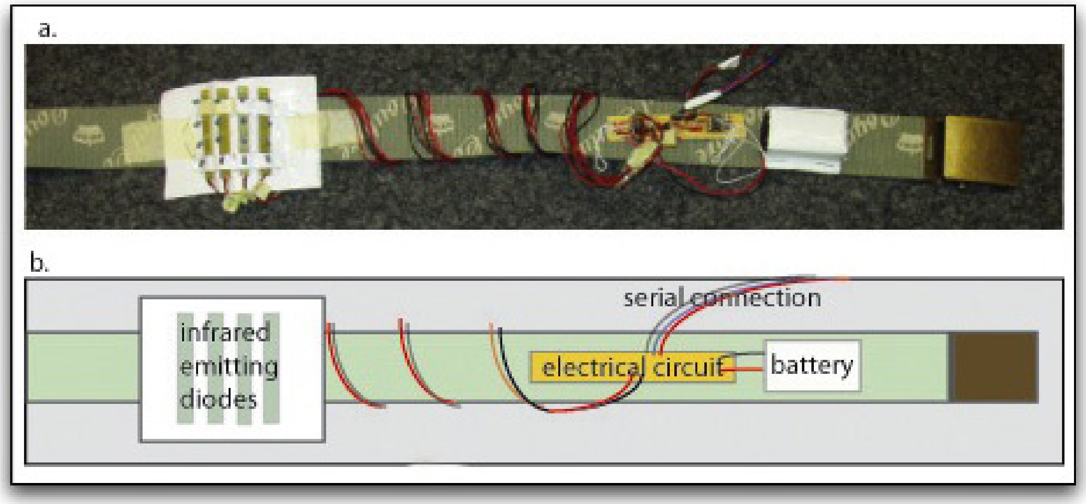

Figure 6.1: A photo (a.) and the corresponding schematic representation (b.) of the RoboBelt and its components.

6.1.3 Data Flow

After looking at the hardware components of the RoboSuitcase's system, we will now have a look at how these components interact and exchange data. Figure 6.2 illustrates the data flow.

The details of the processing of the sensor data and the calculation of the motion commands are left out in this chapter. This matter will be discussed in chapter 7.

The sensory data about the environment is collected by the infrared receiver and the ultrasonic sensors, which are attached to respectively integrated into the RoboSuitcase's shell. They are controlled by the I/O board, which determines the sequential triggering of the sensors. The collected sensory data is transmitted over a I2C connection to the WLAN board. Acting as a WLAN server, it sends the data to a WLAN client whenever it receives a request to do so.
The external computer regularly sends requests to the WLAN board in order to get the newest sensory data. Once received, the data is processed and new speed and a steering commands are generated. For transmitting the new commands to the RoboSuitcase they are inserted in the next data request for the WLAN board.
The WLAN board parses the request in order to extract the commands and then sends them to the corresponding motors. In addition it requests the newest sensory data from the I/O board and sends them back to the external computer.

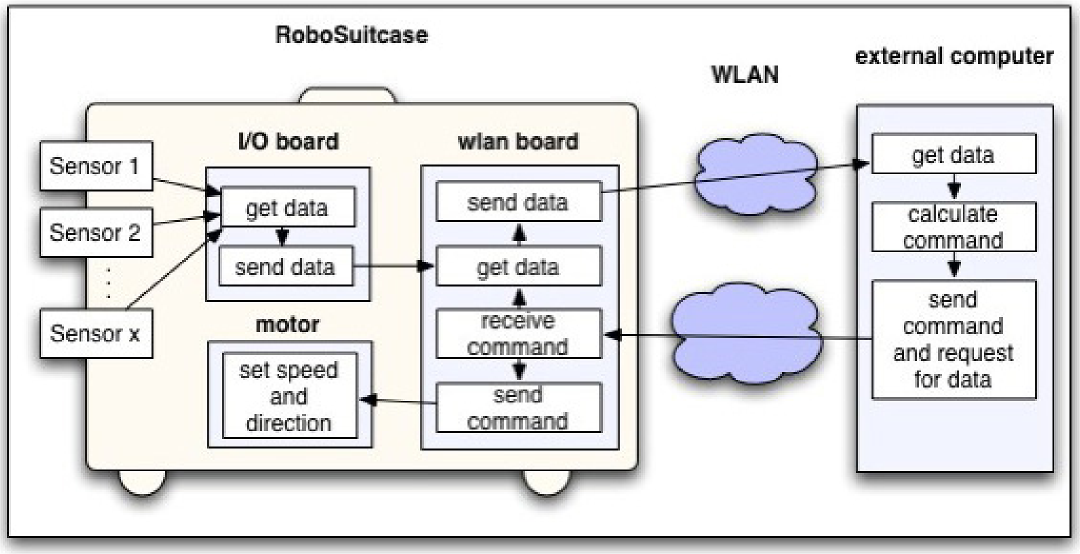

Figure 6.2: The data flow in the RoboSuitcase and the external computer.

6.2 Technical Limitations

The RoboSuitcase as outlined in section 2.1.2 has evolved over quite some time. Components were added continuously and many different people worked on the project mostly independently and with little coordination. For this reason the RoboSuitcase project suffers from several kinds of problems. It is not optimized and lacks in performance and maintainability. Sources of emerging errors or irregularities are notoriously hard to identify. And there is no general documentation, but the information has to be aggregated with some effort from different kinds of sources.
Additional problems have emerged during this assignment but there was simply not enough time to solve them. The problems belonging to the first group of inherent boundaries are outlined in section 6.2.1 the main problem emerged from this assignment in section 6.2.2.

6.2.1 Inherited Technical Problems of the RoboSuitcase

Looking at the outline of the hardware components in section 6.1.1 and the dataflow diagram on picture 6.2 one will notify the complexity of the system. Mainly the amount of different communication channels between the components is unnecessary for the system. One of these connections poses the biggest technical boundary on the system, the wireless connection. Section 5.3.4 presented the efforts taken on this topic and the improvement achieved. But still the performance is not stable enough for a reliable performance of the system.

The integration of the two boards with the RoboSuitcase is done in an improvised way. The interface to the I/O board provides space for connecting 16 input or output devices. This is just a part of all output/input channels offered by the PIC micro controller.
The attached devices are powered directly by the micro controller, which is not meant to supply so many devices with power. This could be a reason for an additional problem that appears with the I/O board. It crashes regularly every two seconds and then restarts. During this time period obviously it can not control the sensors nor deliver sensory data. This causes an interrupt in the time line of the sensory data of 200 to 300 milliseconds every 2 s, which is 10 to 15% of the time.

Another problem of the RoboSuitcase platform is the actuation. The contact of the motor axles to the wheels of the RoboSuitcase is not given permanently and the power transmission is not always equal on both wheels. Speed and steering angle can therefore differ from the given commands, which impedes the evaluation of a navigation algorithm.

6.2.2 New Technical Problems Related to this Assignment

In the scope of this assignment the main technical task consisted in the integration of the new sensory system in the RoboSuitcase. The electrical setup and the physical in-

tegration were carried out successfully. The remaining problem is the reading of the sensory data on the I/O board.
The detection of whether there was a signal received or not can be easily made. For each sensor a time slot is reserved in which the respective input pin of the micro controller is observed. But when it comes to read out the transmitted data, timing problems appear. Especially the fact that the signal changes its burst lengths depending on the distance to the signal emitting device, makes this task difficult to solve. One can measure the voltage level of the pin in predefined time intervals, but as these are variable in the received signal, this approach is not working correctly.

The Infrared Data Association (IrDA) [3] introduced standard communication protocols for infrared communication. Using this protocol would simplify the reading of the data. There exist special integrated circuits for creating and reading data according to this standard [7], which could be integrated in the existing electrical circuits of the infrared diodes and receivers. Due to the restricted time of this assignment this approach has not been implemented yet.

In this chapter the technical outline of the RoboSuitcase and the RoboBelt were shown. An overview on the interaction of the individual components was given and in the end the remaining problems were presented. The technical challenges appeared to be really demanding and time consuming. The further development of the RoboSuitcase was therefore not accomplished and the next chapter instead of introducing the implemented and tested algorithms for the RoboSuitcase presents now some theoretical considerations and ideas.

7 Sensory Motor Coupling - Algorithms

Due to the encountered technical boundaries described in the previous section and the time spent on this topics, there was no time left in the scope of this diploma thesis to implement and evaluate different control strategies for the person following behavior. Nonetheless there were some theoretical considerations made, which are outlined in this chapter.

7.1 Obstacle Avoidance

There's a huge research field in the development and evaluation of obstacle avoidance algorithms. The development of an obstacle avoidance behavior is not explicitly part of this assignment but was the task of the previous assignment [18]. Nevertheless, the obstacle avoidance algorithm developed in the previous diploma thesis should be integrated in the person following algorithm and hence the reflection on this subject is implicitly part of this assignment too.

First the implemented object avoidance algorithm is presented and evaluated in the context of a person following behavior. Then an other simple but interesting strategy in relation to the actual task is presented.

7.1.1 Square Repulsive Force Algorithm

The final choice of the previous diploma thesis was the square repulsive force algorithm [18].
A repulsive force is a virtual force, which represents the tendency of the RoboSuitcase to drive away from obstacles. Therefore a close object would generate a greater repulsive force than an object standing in some distance.
Repulsive forces are represented in vectors containing information about the distance to an object and its relative angle to the RoboSuitcase. The distances are taken from the sensory data and the angles result from the positioning of the sensors, which is given.
To weight to the strong repulsive forces more than the weak ones, the algorithm uses the squared values of the forces. This makes strong forces i.e. long vectors much longer, and weak forces i.e. small vectors remain relatively small.

The test environment for this algorithm was an office floor equipped with some obstacles, like plastic boxes and the task was to drive along the floor avoiding walls and obstacles.

The performance of the RoboSuitcase with this setup was not yet satisfyingly as the RoboSuitcase was not able to turn fast enough around facing a wall or to stop adequately facing a close object. Therefore special cases were introduced to detect these situations and react adequatly. Details about the implementation of the algorithm can be found in the corresponding diploma thesis [18].
Given a person whom the RoboSuitcase follows, the implemented special cases of facing a wall are superfluous, because it is quite improbable that the person will walk into a wall. The person would turn and avoid the wall and the RoboSuitcase would do so too, just by following the person. Much more probable would be e.g. the case of a second person crossing the way of the RoboSuitcase.
In general this strategy focusses more on the autonomous moving than on the situation of facing an obstacle and drive around it. Therefore it is perhaps not quite ideal for the assignments purposes.

7.1.2 Wall Following

In some cases obstacle avoidance or driving around obstacles can be realized by wall following behavior [6].
An adequate special case for the situations the RoboSuitcase will most probably encounter, would be the case of a person crossing the way of the RoboSuitcase or even stopping in front of it. The suitcase could then not detect its owner anymore. One promising approach in this case would be to implement a simple wall following mode. Once detected a person and having lost the signal of the infrared emitters the RoboSuitcase would change into the wall following behavior and drive along the obstacle and drive around it this way.
This approach would also hold for other objects like dustbins, pillars or pieces of luggage. Algorithms including the direction of the last appearance of the target person are promising too, but need reliable information about absolute directions, which are in the moment not available on the platform.

7.2 Person Following

The RoboSuitcase will in practice share its environment with humans. An interesting point to look at is therefore how the RoboSuitcase should behave in order to create a maximum acceptance among humans. Section 7.2.1 will deals with this matter. Then section 7.2.2 presents three selected strategies of implementing a person following behavior.

Given the sensory system chosen in chapter 4 the information for the person following algorithms is basically an array of bits of zeros and ones. One meaning the corresponding sensor received the signal, zero respectively no signal was received. In other words, one knows which of the sensors have direct line of sight to the target person. This allows determining the relative position of the person to the RoboSuitcase.
The distance can roughly be determined by one or two horizontally placed receivers,

which only receive some infrared signal when the emitter is close enough i.e. the incident angle is steep enough. For details about the use and positioning of the sensors have a look at section 5.1 and 5.3.2 respectively.

7.2.1 Human Robot Interaction

The field of human-robot interaction deals with the questions of how natural and effective interaction and communication between humans and robot can be created and which requirements and expectations humans do have when interacting with robots.
In general on can say that humans are more likely to accept robots in their surrounding if they act in a natural and understandable way. For humans a natural and understandable behavior is basically one that is similar to their own behavior [12].

Considering now the RoboSuitcase, the related aspects are mainly the acceptance of different strategies of person following approaches and the interaction of moving robots and humans crossing their way.
. For the human following, there are two basic ways of following behaviors. The path following and the direction following. I.e. the robot can follow the human on exactly the same path the human is walking and therewith profit from the safety of the human's path. Or it does not follow the exact path, but just steers in the direction of the human and therewith creates its own path. Comparing these two behaviors regarding the people's trust and comfort with the robot, it turns out that the direction following behavior is rated more natural and human-like [12].

In direct interaction meaning facing a human, the robot should perform a behavior that expresses awareness of the person and safety in motion. This includes classically respecting the human's personal or intimate space and the pro-active avoidance of a person [30]. Another less submissive approach would be not to pro-actively avoid the person, but to push it gently in order to let him/her know that he/she should please move to the side. Regarding the human-likeness of this behavior this is not less plausible than the pro-active avoidance.
The two strategies could also be combined and the second one could be applied if there is no way to surround the person somehow.

7.2.2 Strategies

So how can the sensory data be processed in order to get some reasonable commands and a reliable person following behavior. Some strategies to be tested would be the following.

Potential Field Method

The potential field method introduced by [21] implements a field of artificial forces in which the robot moves. There are repulsive forces from obstacles and attractive forces from the position to be reached respectively the target object. From this general idea different algorithms have been derived. E.g. the vector field histogram, the virtual force field method [22] or the evolutionary artificial potential field method [35]. One of the algorithms inspired by the potential field method, the square repulsive forces algorithm has been implemented in the RoboSuitcase and is introduced in section 7.1.1. As this algorithm is created for obstacle avoidance only, the repulsive forces have been implemented. Hence it would be possible to extend this algorithm with the attractive forces from the target person.

Fuzzy Logic Approaches

Fuzzy controlers are widely used for machine and robotic control, especially concerning real world applications [24], [33]. These approaches base on the fuzzy logic, which adds to the classical boolean logic based on *yes* (1) and *no* (0), all the continous values like *maybe*, 0.5 or *probably*, 0.9. Fuzzy sets are accordingly sets whose members have degrees of membership instead of belonging completely to a set or not at all. On these sets fuzzy IF-THEN rules can be applied.
The mapping of data to fuzzy sets is called fuzzification. Accordingly the mapping of the output of the fuzzy rules to the required output for the robot is known as defuzzification. In order to fuzzy control a robot, the sensory input has to be mapped on adequate fuzzy sets. Fuzzy rules have to be determined and to be applied to the fuzzy sets. And the actual moving commands ha ve then to be generated out of the results from the fuzzy rules.
The challenge of applying fuzzy control to a robot is the proper definition of the fuzzy rules and the control laws for the actual output of the fuzzy controller, which have to be determined in trial-error experiments. The setup of an optimal fuzzy controller can therefore be quite time consuming.

Neural Networks

The approach of using neural networks for robot navigation is used in several work with different strategies [19], [36], [10].
An adequate selection of the right neural network model for a specific application depends highly on the nature of the data that is used and the output data needed. In this case the input data are the boolean values from the infrared receivers and perhaps also the ultrasonic sensor data. The output data would be the steering angle and the speed command.
There exist a great variety of types of neural networks. A detailed analysis would be necessary to determine the most promising approach for the given task.

This chapter gave a short insight in the considerations made regarding the implementation of navigation algorithms. In order to present some ideas to be considered in the further development on the RoboSuitcase, some interesting and promising approaches where shortly introduced. The next chapter will now present the conclusion of this assignment.

8 Conclusion

This diploma thesis introduced a new approach for a person following robot with infrared sensors. The novelty of this approach lies in the use of infrared sensors instead of vision, which is widely used in the field of person identification and tracking. This allows the robot to identify a specific person also in a crowded place whereas the vision systems so far were only capable of identifying a human in general or to distinguish the cloths of different persons. But the use of personal robots in public areas requires definitely a reliable identification of the corresponding person in order to serve him/her and not a random person.

The process of implementing this approach into the existing platform of the RoboSuitcase revealed several technical shortcomings of the system. Efforts were taken to improve the system in order to be able to completely implement the person following behavior, but due to the restricted time scope of this assignment these issues have not been solved completely.
The main drawback of the system did not result from the newly integrated sensors, but from some inherited technical problems of the RoboSuitcase platform. Hence a complete implementation of the developed approach in order to test and evaluate it is still necessary. So, after six month of work the scenario of the autonomous person following RoboSuitcase, circling around passengers in the main station in Zurich, still remains fiction. But the approach is promising and once it has proved its capability for following specific persons, it can not only be used for the RoboSuitcase, but for a lot of other applications beyond the idea of robotizing daily objects e.g. for transportation issues, in health care or in the support of elderly people in everyday life.

Imagine an ordinary day at the main station in Zurich. An elderly women passes by, followed by her assistant robot, which carries her shoppings and offers itself as walking assistance when needed. The woman just tells him what she's going to cook for dinner tonight, whereupon the robot answers with "I see, Belinda". In the meantime your RoboSuitcase is waiting patiently at your side, waiting for your commands.

9 Outlook

After presenting the work done on this project, chapter 9 gives an outlook on possible future development of the actual system.
The RoboSuitcase is designed as a product that is used by real persons in real and unpredictable environments. It should for this purpose possess a stable and secure behavior. Additionally it would be nice if it would act in a comprehensible way in order to increase the acceptance among humans.

Thus we can say there are must-haves and nice-to-haves for a future version of the RoboSuitcase. The must-haves would be stability and security whereas the nice-to-haves would consist in an easy to use system, a diversity of behavior or a well thought-out robot-human interaction.

9.1 Must-haves

The system has to be strong enough to transport a fully packed suitcase, therefore it is also strong enough to cause injuries and damage when bumping into people or objects. This is not acceptable for a product on the market.
A secure behavior can only be achieved if the hardware is highly reliable, which is not the case with the actual version of the RoboSuitcase. Once having a stable hardware system the implementation of a secure controller is essential.
This section will introduce first the difficulties appearing with the individual hardware components and in the end refer shortly to the controlling mechanism and the use of additional sensory systems.

The Power Supply

The power is essentially for the RoboSuitcase. Some of the components are highly dependent on a stable power supply. If the power decreases under a certain value they may not work properly anymore. This has been observed especially with the ultrasonic sensors but might hold also for other components. It would therefore be advisable to let the system check its power supply regularly and indicate when the power falls below the minimal required threshold.
The power supply of the sensors should anyway be rearranged. They should not be powered by the PIC but directly by a battery, which would probably also be the solution for the problem with the crashing I/O board, see section 6.2.1.

The Sensors

The two sensory systems integrated in the RoboSuitcase actually are infrared and ultrasonic sensors.
The main problem with the infrared sensors, concerning the reading of the transmitted data, was already discussed in section 6.2.2 and a possible solution presented.
A second issue concerning the infrared communication is the generation of the data to be sent. Actually this is done with a laptop that is connected to the RoboBelt. For a final product the laptop has to be exchanged by a microchip, which is placed directly on the belt in order to make the system more portable and user friendly.
The ultrasonic sensors are used for obstacle detection. For a secure behavior it has to be reconsidered if a resolution of four sensors is enough. Increasing the number of sensors or using another sensory system (e.g. laser scanner) could improve the obstacle detection and avoidance.
But obstacles are not the only thing to better avoid in a train station or airport. Facing stairs or train platforms the RoboSuitcase runs the risk of falling down at some point. A sensory system should be implemented to recognize these situations. The infrared distance sensors integrated in the system, and not used at the moment, could be used for example for this task.

The Data Transmission

The system contains several components, which have to communicate with each other e.g. the ultrasonic sensor with the I/O board, the I/O board with the WLAN board or the WLAN board with the external computer. These communication channels should ideally not be the bottle neck of the system.

Especially the connection via wireless to the external computer causes a lot of problems. Additionally to the problem with the performance explained in section 6.2.1, the range of the wireless connection is limited and the RoboSuitcase can only work if the external computer is in the range of the RoboSuitcase.
But anyhow the design of the system with the external computer has been chosen in order to facilitate the development and not to be used in the final product. The sensors and the motor are situated on the same platform so it would make sense to run also the processing of the data on this platform. These calculations should be performed on the RoboSuitcase itself in order to avoid all the problems caused by the wireless connection and to make the system faster, more stable and more compact. It would then consist of no more than the RoboSuitcase and the RoboBelt.

The Motor

As stated already in section 6.2.1 there exists a problem with the actuation. In order to obtain a stable behavior this problem has to be faced.
Concerning the purpose of the RoboSuitcase to transport someone's baggage, which can

be up to 20 kg for normal flights and even more in a train, the motor has to be pretty efficient and powerful.

The Controller

Having a stable working hardware is not the only thing that is necessary to obtain a stable and secure system. An adequate controlling mechanism has to be implemented. This includes the direct control by the owner and the generation of the autonomous behavior, which should integrate the maintenance of a security distance to the target person, avoid to fall down from train platforms or stairs and call the attention of its owner, when the contact signal is gone.
A further point to consider is the possibility of thefts, eventually an alarm system should be integrated.

New Sensory Systems

In the previous sections some possibilities of integrating new sensors in the system were already mentioned. A laser scanner could be used for obstacle detection. But laser scanner have the disadvantage of not perceiving glass obstacles. Therefore laser scanners have to be used in combination with ultrasonic sensors in order to detect also glass obstacles.
Another possibility would also be to integrate RFID tags for the identification of the persons or the use of an electrical compass in order to determine the orientation of the target person and send the data over an additional communication channel to the RoboSuitcase.

9.2 Nice-to-haves

Once the system fulfills the conditions of being stable and secure, it would be nice to have a system that is useful and interesting for people, possesses an intuitive human-robot interaction and is accepted easily among humans.
This implies an user interface that is easy to handle. One could integrate “start” and “stop” buttons on the RoboBelt. By all means it should be possible to use it without any technical knowledge.
As we saw in section 7.2.1 there are differences in the acceptance of robots by humans depending on the comprehensibility of their actions. This should be kept in mind while testing the navigation algorithms.

Special Features that may be included to the RoboSuitcase may be a little remote control for the owner of the robot or the possibility of changing the following modes e.g. from “normal” to “dog following” mode, which would be follow a little behind the owner on its right side.

The outlook of this assignment made clear that there is still a long way to go from the actual version of the RoboSuitcase to one that is suitable for the use in real environments fulfilling all the requirements regarding security, stability and user friendliness. But step by step with the necessary time and knowledge it will be possible to fulfill these requirements.

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