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Design of A Localization-Based Collision Avoidance System For Wireless Car

Master of Science Thesis

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Göteborg, Sweden, April 2013

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Abstract

In this project, a reliable and inexpensive collision avoidance system was designed for vehicles traversing roads in high speeds. Miniature wireless cars in an indoor traffic model are used to simulate real vehicles movements. Several experiments were done to make the car movement reliable. The selected localization system keeps track of each car's movement. Each car's speed and steer is adjusted by the collision avoidance system, and it is done through sending control commands with regards to the cars location information obtained from the localization system.

Acknowledgment

I would like to thank my supervisor Elad Michael Schiller whose advice has greatly influenced this thesis. Without him this would not have been possible. I would also like to thank Mitra Pahlavan, Kouros Moabber and Amir Tohidi for their valuable feedback, support and discussions as well as my other friends and classmates who have helped me during my project.

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Chapter 1

Introduction

This Chapter first provides some backgrounds behind the topic. After that, purpose and the objectives of this thesis work is mentioned. This Chapter finishes with the outline of this thesis.

Background

Providing safety is a challenge that has been an important issue in transportation system for many decades. Providing some passive safety systems like seatbelts and airbags help to reduce the effects of the accidents. On the other hand, active safety systems have been developed so much in recent years. They refer to safety systems that help avoid accidents, such as good steering and brakes. Some examples for these systems are, Anti-lock braking system (ABS)[1], Intelligent system adoption[2], Autonomous cruise control system[3] and collision avoidance that is widely used by automotive car manufacturers like Volvo[4], Toyota[5], Volkswagen[6] and Ford[7].

Collision avoidance systems in automotive industry usually use radar(or laser)[8] and camera sensors to implement the designed algorithms. The system can notify the driver, increase the breaking pressure, or tension the seatbelt to minimize collision impact.

In some projects the localization system provides avoidance of the collisions in the highways and urban transportation. [9]

Purpose

The purpose of this thesis work is to design a reliable and cost effective collision avoidance system for vehicles in highways. In such roads, the speed is so high (about 120 km/h) and the decision needs to be taken so quick and the control system should be fast enough to reduce the risk of collisions.

In this master’s thesis, the designed system must be cost effective and with the minimum use of peripheral devices. Although, it is supposed that it can be useful for real vehicles in real transportation environment.

Objectives

The following research questions are formulated based on the purpose of this thesis.

1. How does the indoor wireless system model is designed for this project?

2. What localization system should be used that provides cost effectiveness and accuracy?
3. What safety algorithms are suitable and should be considered for this system?

Outline of the thesis

The next Chapters of this project are designed as follows. Chapter 2 describes the preparation steps of the wireless miniature car that is used as a model for the project. In Chapter 3 design of the localization system for this project has been discussed, and in Chapter 4 the safety algorithms and implementation of the controller application to be used for the designed system is discussed. Finally, the achievements, limitations and future works are mentioned in Chapter 5.

Chapter 2

Model Preparation

In this Chapter, there is an overview on Vaillante Wi-Fi, which is selected for the car model, and some test experiments over it are discussed.

Vaillante Wi-Fi

To make the designed control system in this project available to be implemented on real vehicles, it should be tested in a test environment to debug the code and minimize the potential harms. Since vehicles moving fast in highways, the car model should be able to simulate moving in highways very well.

For this purpose, Vaillante Wi-Fi produced by Controlbytel[10] was used. The followings are the specifications of Vaillante:

Length: 258 mm
Width: 177 mm
Weight: 633 g
Power supply: battery Nimh 1200
Speed(max): 30 km/h
Wireless connection: Wi-Fi

Fig. 1: Controller application used in smart phones

Vaillante is designed to work with iPhone and iPad, and a GUI which can be downloaded from Apple store, is used to adjust the speed and steer of the car. Since controlling the car using Smartphone is so hard and not useful for many test cases, the application needs to be customized to make

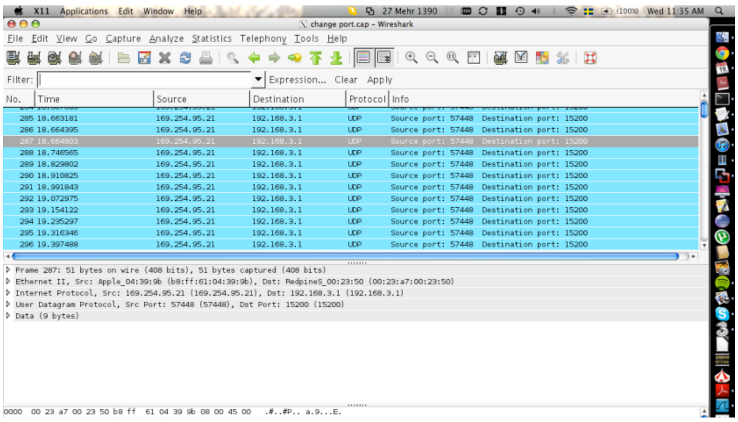


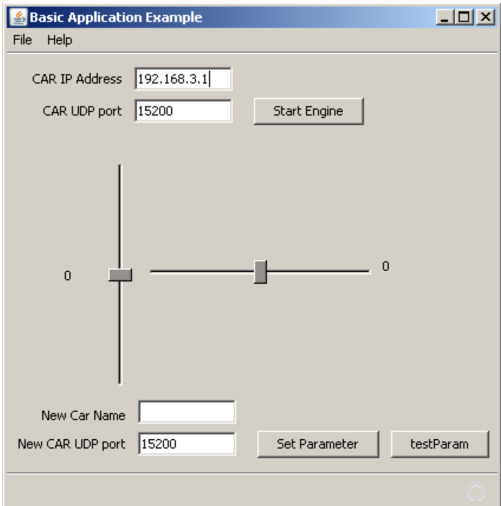
Fig. 2: A snapshot from the packet sniffing process in Wireshark

The car is like a black box for us and the network operations and the commands that are sent between the server (Vaillante) and the client (Smartphone) were unknown.

The only known parameter is the client IP address (i.e. 192.168.3.3). So another client to the network was added to monitor packets which are traversing in the system. The packet sniffing process was done using Wireshark in a laptop. Using sniffed packets, the commands related to different speed and steer values were detected. The following attributes were found as well:

Server's IP (Car):	192.168.3.1 (unchangeable)
Port:	15200 (default)
Transport protocol:	UDP

Experiments



Based on the captured data from the network, a simple application was made to send different movement commands to the car. In this project three Vaillante cars were used to assess the car's behavior in different speeds and steers.

Steer values are integers ranged from -50 (most left) to 50 (most right) and speeds are between -50 (most speed for moving back) and 50 (most speed for moving forward).

First Experiment

In the first experiment, 11 steer values in a constant minimum speed value, which was 7, 8 and 9 for each of cars, were examined.

Experiments were done in a wooden table at the same room using the measurements tools like ruler and bevel.

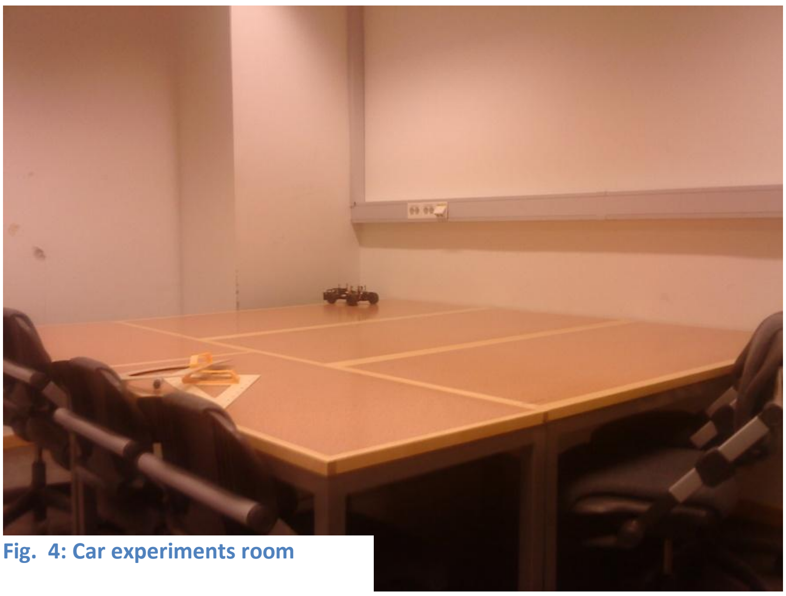


Fig. 4: Car experiments room

The following graphs achieved from the experiments, and based on the calculations the angle can be modeled as a linear function, while graphs for distances in different angles are slightly different from quadratic equations graphs.

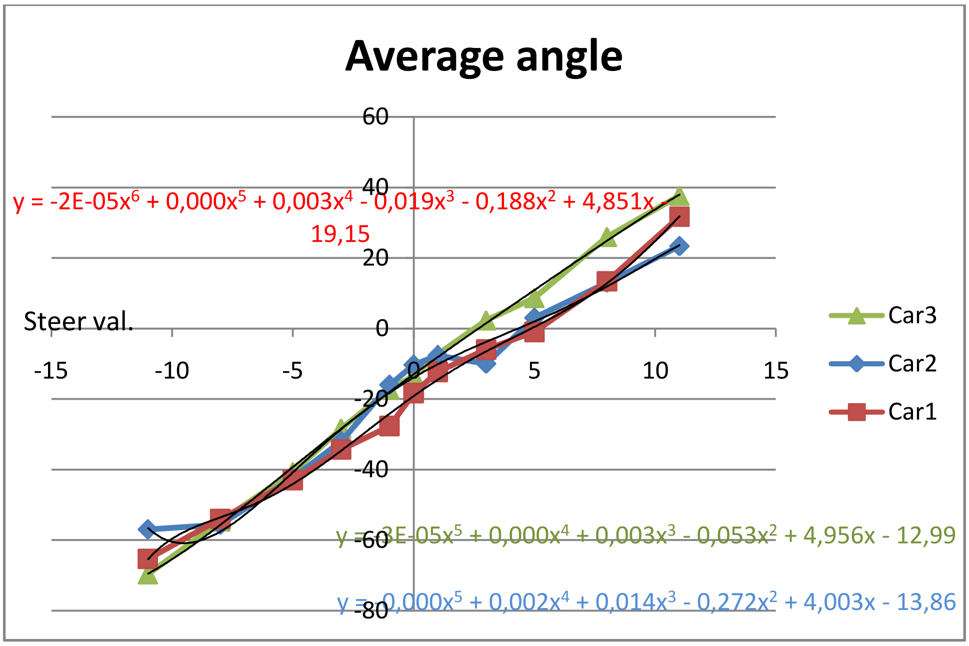


Fig. 5: Average angle graph for all cars

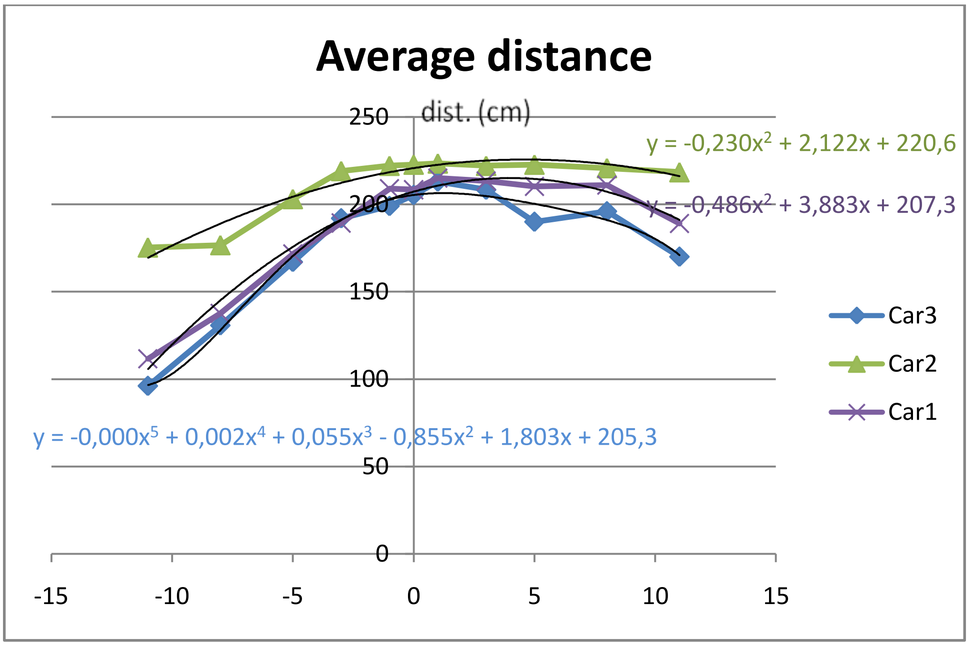


Fig. 6: Average distance graph for all cars

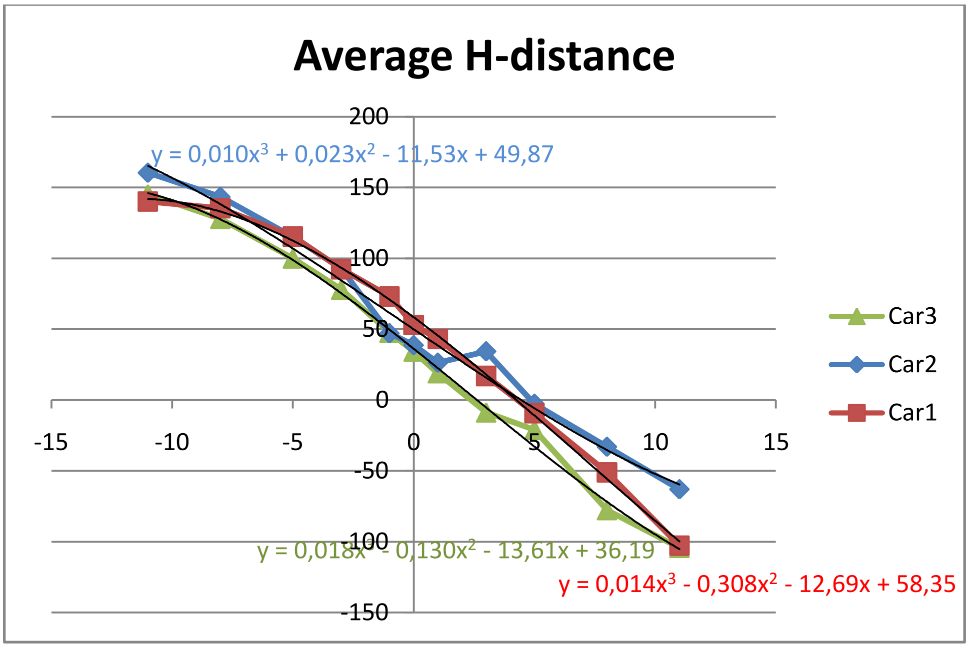


Fig. 7: Average H-distance graph for all cars

Distance and H-distance are measured with regard to the calculations shown in *Figure 8*.

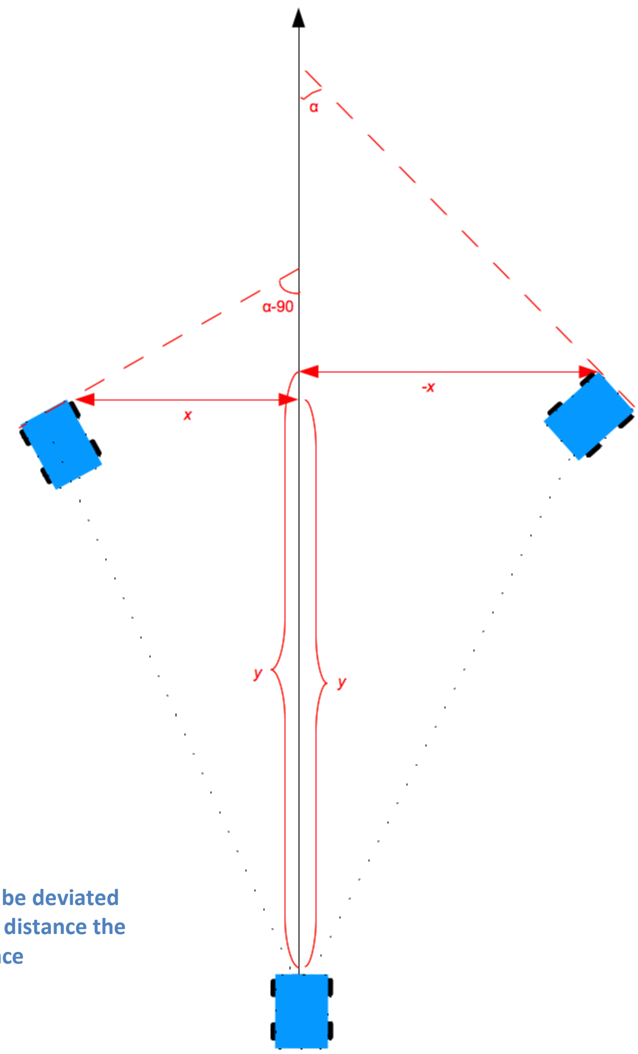


Fig. 8: Vaillante car movement model; the car can be deviated from the reference in each direction. The absolute distance the car traverses shows by y, and the horizontal distance represents by x.

Second experiment

The aim of this experiment is to simulate a circle shaped movement in speed value of 8 and steer value of -21, which is the ultimate angle, in Car ID=3.

Experiment was done in five rounds and the result is shown in *Figure 9*.

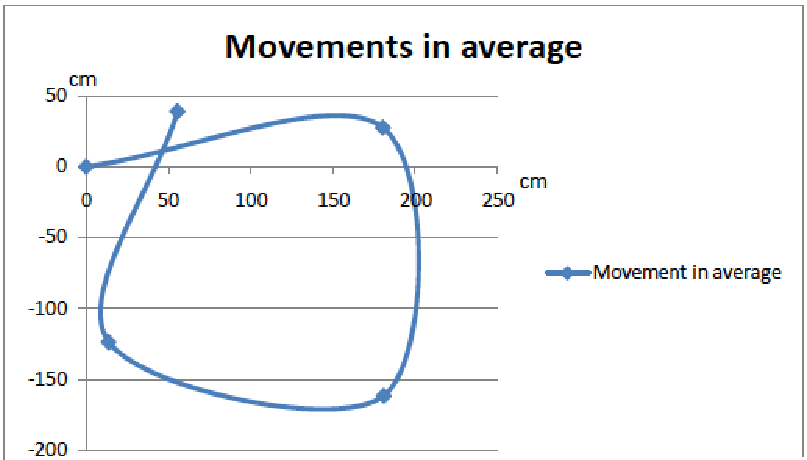


Fig. 9: Result of experiment in movement in average graph

As can be seen, it took four steps to complete a rounded movement. The diameter of the shape is about two meters. It can be seen that the diversion from the start point is 50 cm which is relatively high in this scale and such a movement should be promoted.

Finally, a nice shaped circle was achieved by taking different steers and speeds in different steps. Now, by having the knowledge of cars' behavior in different speeds and different battery consumption level, the final plan can be released expecting the most accurate results.

It should also be noted that some other minor experiments were done to get the ultimate angles.

Car3 average values			
Steer Value	Angle	Distance	Horizontal Distance
-11	-70	96	145
-8	-55	131	128
-5	-41	167	100
-3	-28	192	78
-1	-17	199	48
0	-13	205	34
1	-7	213	19
3	2	208	-9
5	9	190	-21
8	26	196	-78
11	38	170	-104

Car3 values based on equations			
Steer Value (x)	y1	y2	y3
-11	-68	104	146
-8	-53	130	127
-5	-38	171	99
-3	-28	191	75
-1	-18	203	50
0	-13	205	36
1	-8	206	22
3	2	205	-5
5	12	200	-33
8	27	190	-72
11	42	164	-105

Differences between real and formula values (f-r)			
Steer Value (x)	Angle	Distance	Horizontal Distance
-11	2	8	1
-8	2	-1	-1
-5	3	4	-1
-3	0	-1	-3
-1	-1	4	2
0	0	0	2
1	-1	-7	3
3	0	-4	3
5	3	10	-12
8	1	-6	6
11	4	-6	-1

$$y1 = + 4.9569x - 12.991$$
$$y2 = -0.0004x^5 + 0.0022x^4 + 0.0559x^3 - 0.8558x^2 + 1.8033x + 205.36$$
$$y3 = 0.0181x^3 - 0.1305x^2 - 13.615x + 36.191$$

Fig. 10: Difference between estimation equations and real implementation

Chapter 3

Design of Localization System

In this Chapter, the localization system(MoteTrack) used for this project is discussed. Plan and implementation of localization scenario are mentioned as well.

Introduction

One of the parameters that are needed for the car controller is the position coordinates of the car in different times. For this, a localization algorithm needs to be utilized. As the cars are controlled remotely, a radio frequency-based location tracking system should be used [11-18]. To obtain such parameters, MoteTrack system [19] that does not require any additional hardware to be installed over sensors was selected as location tracking system. MoteTrack designed to work in TinyOS [20] which is an operating system and Application targeting wireless sensor networks.

TinyOS

TinyOS is a BSD-licensed operating system designed for low-power wireless devices, such as those used in sensor networks. Many parts of this project, including localization, are implemented with the help of writing codes in TinyOS. In the application that has been developed in sensors, the codes are written in nesC. NesC is the language with a syntax like C primarily intended to use in embedded systems such as sensor networks. [21] [22]

MoteTrack

MoteTrack uses RADAR [23] for its localization system. It is based on small wireless sensors, and each mobile nodes' location is calculated using a signature including the strength of received signal is received from multiple beacon nodes.

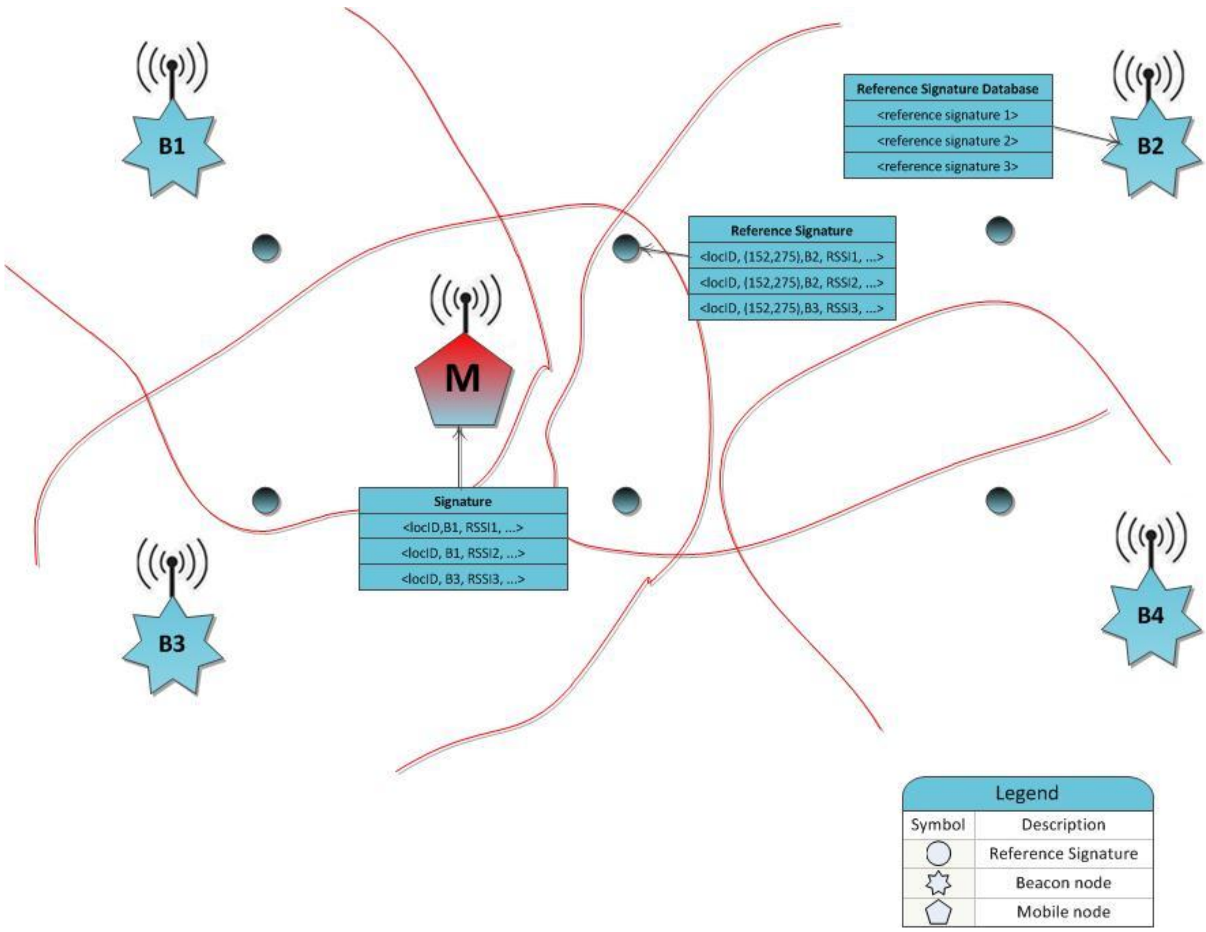


Fig. 11: MoteTrack system implementation design: red line curves determine signal coverage area for each beacon.

MoteTrack works perfectly with Berkeley Mica2, MicaZ, and TelosSky sensor “motes”[24], and MicaZ motes were used in this deployment. These motes are inexpensive, small and programmable.

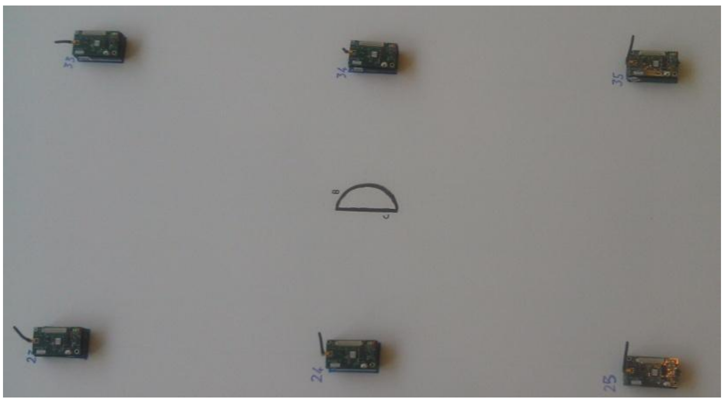
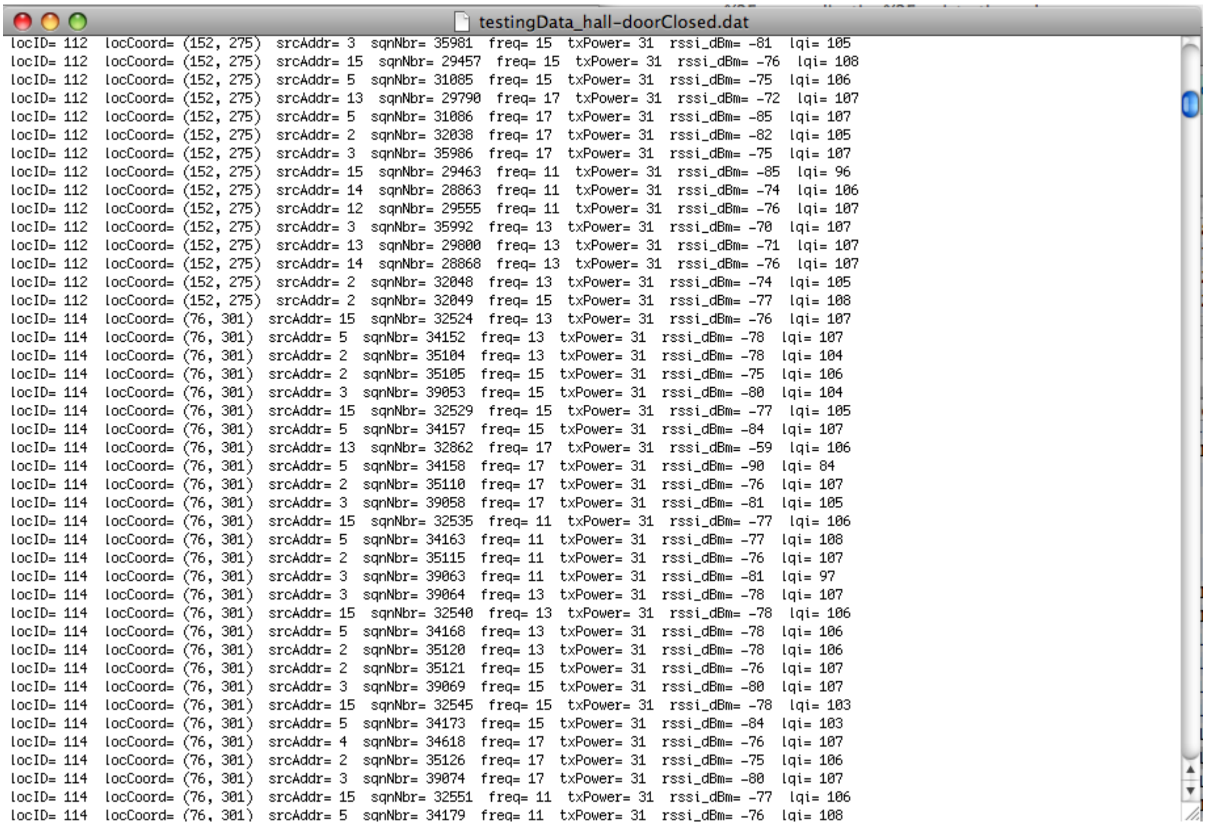


Fig. 12: MicaZ motes

The following is the format of messages that are periodically transmitted by beacons.

(sourceID, frequencyChannel, powerLevel)

sourceID is the unique identifier of the beacon node, *frequencyChannel* is the frequency channel over which the beacon was transmitted, and *powerLevel* is the transmission power level used to broadcast the message. In the system, each mobile node finds the location of itself using these beacon messages. After that, the reference signature is created, that is a combined with coordination in three dimensional (x, y, z). Since in thisdeployment all the reference location signatures are captured from the floor, z value is always equals to zero and


testingData_hall-doorClosed.dat

```
locID= 112  locCoord= (152, 275)  srcAddr= 3  sqnNbr= 35981  freq= 15  txPower= 31  rssi_dBm= -81  lqi= 105
locID= 112  locCoord= (152, 275)  srcAddr= 15  sqnNbr= 29457  freq= 15  txPower= 31  rssi_dBm= -76  lqi= 108
locID= 112  locCoord= (152, 275)  srcAddr= 5  sqnNbr= 31085  freq= 15  txPower= 31  rssi_dBm= -75  lqi= 106
locID= 112  locCoord= (152, 275)  srcAddr= 13  sqnNbr= 29790  freq= 17  txPower= 31  rssi_dBm= -72  lqi= 107
locID= 112  locCoord= (152, 275)  srcAddr= 5  sqnNbr= 31086  freq= 17  txPower= 31  rssi_dBm= -85  lqi= 107
locID= 112  locCoord= (152, 275)  srcAddr= 2  sqnNbr= 32038  freq= 17  txPower= 31  rssi_dBm= -82  lqi= 105
locID= 112  locCoord= (152, 275)  srcAddr= 3  sqnNbr= 35986  freq= 17  txPower= 31  rssi_dBm= -75  lqi= 107
locID= 112  locCoord= (152, 275)  srcAddr= 15  sqnNbr= 29463  freq= 11  txPower= 31  rssi_dBm= -85  lqi= 96
locID= 112  locCoord= (152, 275)  srcAddr= 14  sqnNbr= 28863  freq= 11  txPower= 31  rssi_dBm= -74  lqi= 106
locID= 112  locCoord= (152, 275)  srcAddr= 12  sqnNbr= 29555  freq= 11  txPower= 31  rssi_dBm= -76  lqi= 107
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locID= 114  locCoord= (76, 301)  srcAddr= 3  sqnNbr= 39053  freq= 15  txPower= 31  rssi_dBm= -80  lqi= 104
locID= 114  locCoord= (76, 301)  srcAddr= 15  sqnNbr= 32529  freq= 15  txPower= 31  rssi_dBm= -77  lqi= 105
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locID= 114  locCoord= (76, 301)  srcAddr= 3  sqnNbr= 39069  freq= 15  txPower= 31  rssi_dBm= -80  lqi= 107
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locID= 114  locCoord= (76, 301)  srcAddr= 5  sqnNbr= 34179  freq= 11  txPower= 31  rssi_dBm= -76  lqi= 108
```

Fig. 13: Collected referenced signature database in a text file generated after an experiment

it is omitted in the sniffed files.

The location estimation scenario is included two phases: an offline collection of reference signatures, and online location estimation. As in other signature-based systems, the reference signature database is achieved manually by a user with a laptop and a radio receiver, i.e. base station. Each reference signature, shown as dark dots in *Figure 11*, consists of a set of signature data in the following format;

(SID, FC, PWL, meanRSSI, meanLQI)

SID (sourceID) is the beacon node ID, FC (*frequencyChannel)* is the frequency channel over which the beacon was transmitted, PWL (*powerLevel)* is the transmit power level of the beacon message, and *meanRSSI* and *meanLQI* are the mean received signal strength indication (RSSI) and mean link quality indication (LQI) of a set of beacon messages received over some time interval. Each signature is mapped to a known location by the user acquiring the signature database.

In this deployment of MoteTrack, 10 beacon motes were used, that are distributed on the perimeter of the measuring surface, as beacon nodes. Beacons broadcast beacon messages at a range of frequency channels and the same transmission power level. Using multiple frequency channels will cause a signal to propagate at various levels in its medium and therefore exhibit different characteristics at the receiver. Varying frequency channels (four different channels in this project) delivers the set of measurements obtained by receiving nodes and in fact increases the accuracy of tracking by several meters in the experiments.

Plan

Firstly, the reference signatures collected in the area of 14x8 m^2 where the Vaillante cars suppose to move in. The surface is a quite big area and based on the decided plan 936 reference signatures are needed to be distributed in the area and each one is about 20 cm far from each other. In original MoteTrack implementation, mobile motes that transmit reference signatures for each location connect directly to the laptop using a USB cable to do the transmission process. Collecting each reference signature takes about 10 seconds. It is supposed that takes 30 seconds to prepare each new location for data collecting process. As a result, using ordinary reference signature collection, i.e. measuring reference signatures one by one, estimated to take at least 80 hours to be finished! Due to this, bulk loading method was used to collect multiple reference signatures simultaneously. Obviously, a client-server system using a MicaZ mote as a "Base station" connected to the laptop and 24 MicaZ motes transmitting reference locations to the base station was used. Base station mote is a normal mobile mote that plays the interface role between mobile motes transmitting reference locations and the packet listener program which collects transmitted information.

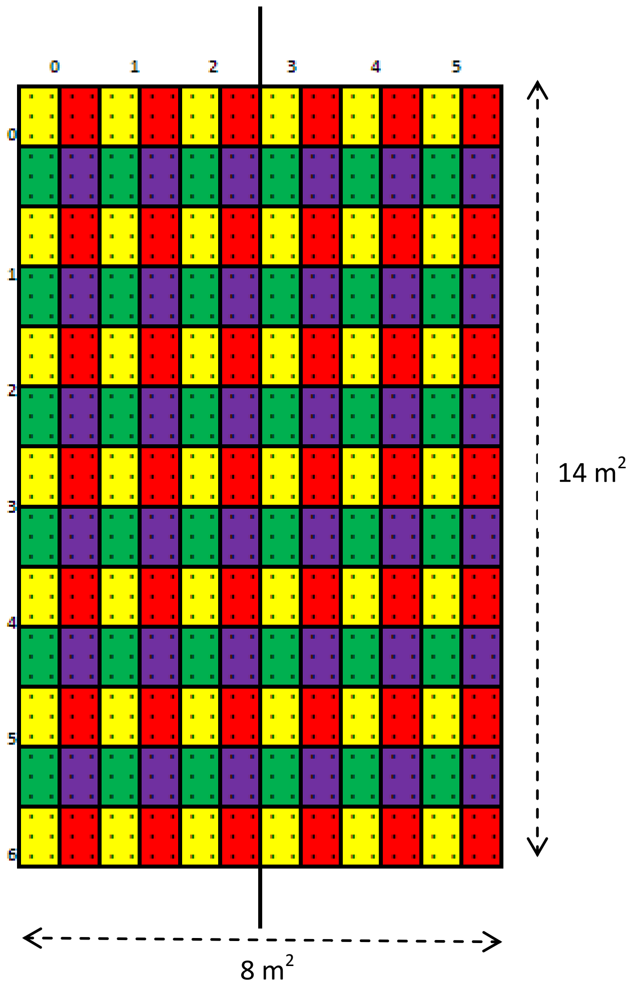


Fig. 14: Measured area and the placement of MicaZ motes on cardboards

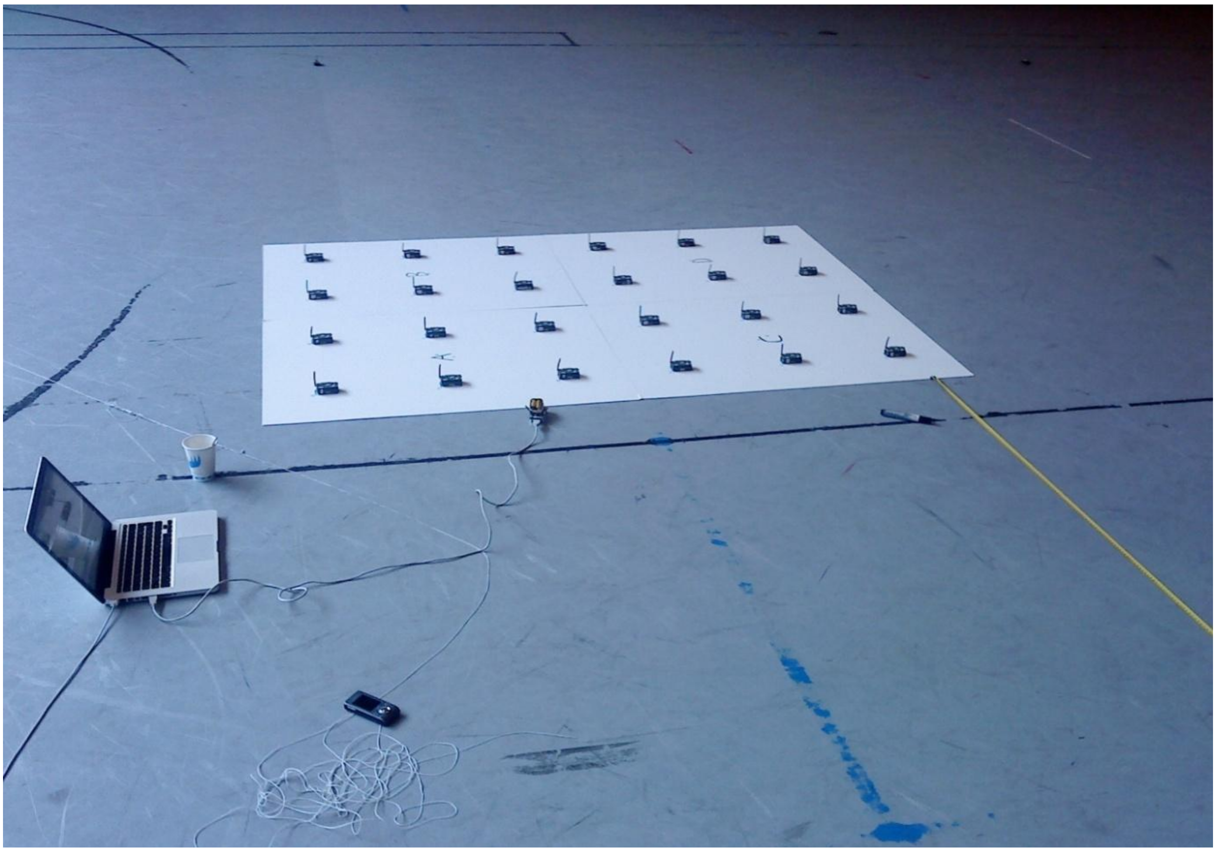


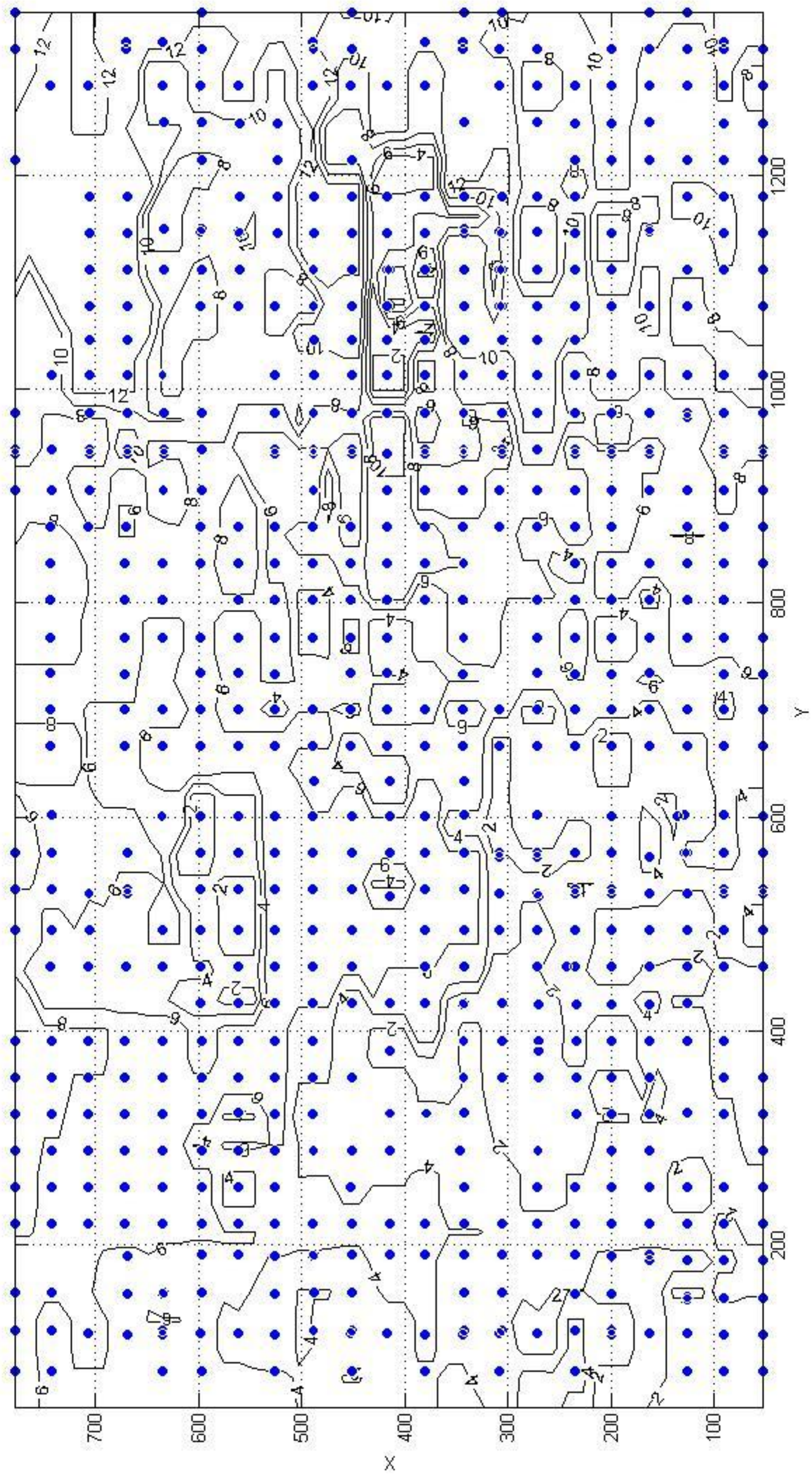
Fig. 15: A scene from bulk loading of reference signatures in the motion hall

For making the reference signatures places as accurate as possible, transmitters are placed on four thin cardboards (2 mm of thickness) which are connected together and make a 206*146 cm^2 surface. By using such plan for collecting reference signatures, 39 movements in the field for cardboard set is needed (6*6+3=39).

Results

After doing the bulk loading experiment, the reference signature database for whole surface is made. By doing some training experiments the following graph was achieved in Curve Fitting toolbox in Matlab showing the accuracy of different locations in the field.

Fig. 16: Map of the localization accuracy in different locations. Diversion rates were calculated in meters for each zone and the blue dots represent locations were the reference signatures collected.



As can be seen in *Figure 16*, when the measured location coordinates become higher than (x, 800), which indicate the places at the end of the field, the localization accuracy drops dramatically to 8 or 12 meters.

After tough inquisitions to find the reason for this drop, it was realized that MicaZ sensors seem not to have an electronic control circuit to regulate voltage to its wireless antenna. When the battery power becomes weaker, the antenna, and calculation power become weak as well. As a result, there will be no accurate localization measurements. Besides, RF signal strengths are generally unstable, especially in indoor area, and they vary over time. They also affected by other factors (building structure, people moving around, etc.). [25-30]

Chapter 4

Car Controller

Introduction

As stated in Chapter 2, one of the most important parameters that should be considered in the system is safety concepts. Since it's very dangerous and costly to implement the safety plans for highway traffic on real vehicles with real time assumptions, the application described in this thesis can be a reliable alternative for implementing safety algorithms in vehicular traffic system.

After doing experiments on car properties, i.e. speed and steer, and localization information, it's time to get the test cars ready to move in a sample field. For this, an application was written to send control commands regarding to vehicle's position and movements. The application was written in Java and can be invoked from Linux terminal or Windows command prompt.

Plan

Like an ordinary traffic plan, some safety conditions have been considered in the system. These conditions can ensure a crash free and safe traffic in vehicles transportation. In this system, a base station carefully monitors each car's movement and they are as follows:

1. ***Minimum distance:*** Euclidian distance between two cars in each step is calculated based on their current location
2. ***Preconditions checks:*** checking whether the location is stable or not. Is the communication between car and controller trustable? Is the car moving?
3. ***Post conditions check:*** is the position of the car after movement is the same as was expected before movement?

The communication among all parts of the system is also illustrated in *Figure 17*.

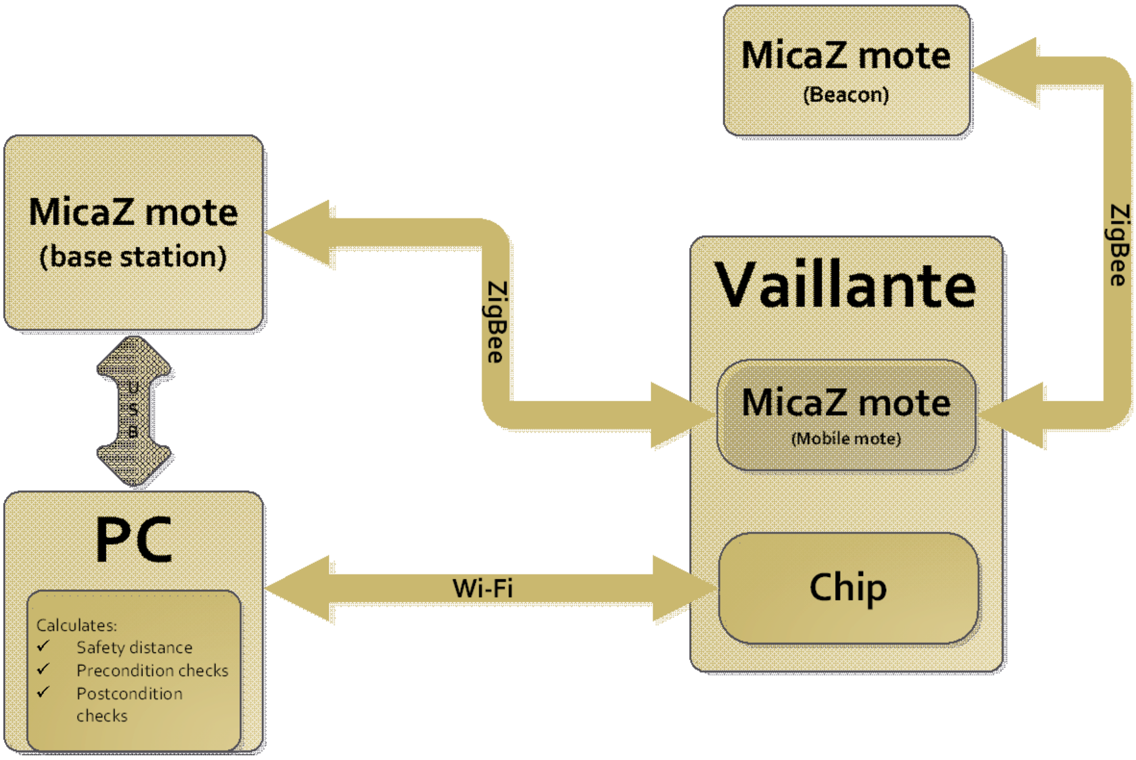


Fig. 17: Connections among different parts of controller system in online mode.

Each car has a unique UDP port and a same IP address with regard to the other cars. So, connecting to cars and making the network is done by establishing a UDP port and opening sockets in base station.

Cars start to move in a same speed and steer when they triggered by base station. As the maximum stable steps examined in experiments is 4, the system works for 4 rounds and after that automatically stops.

Algorithms

Algorithm 1: Safety distance provision between vehicles v_i

---

input : $V(v_i)$ Set of vehicles that are on v_i's line of sight;
input : $location_{v_j}$ Current geographical location of vehicle $v_j \in V_{v_i}$ in the Euclidean plain;
output: $Speed = 0$ and $Speed = "lastvalue"$ are two signals that are set to stop or resume movement respectively;
local distance(locA, locB): Returns Euclidean distance between locations $locA$ and $locB$;
constant SafeDistance: Minimum required distance between any two vehicles that are moving in the same lane;
if $\exists v_j \in V(v_i) : distance(location_{v_i}, location_{v_j}) \leq SafeDistance$ **then**
| **return** *Speed=0*
else
| **return** *Speed="last value";*

Algorithm 2: Precondition checks for vehicles v_i

---

input : $V(v_i)$ Set of vehicles that are on v_i's line of sight;
input : $Vehicletime$ Latest time signal that recieved from vehicle;
external ExperimenterControl(): Ready, Go and Terminate are three External Control commands;
local timeDiff(t_1, t_2): Returns the difference between two time variables (i.e. $t_2 - t_1$);
constant $ValidLocationPeriod$: Time period that the location is valid in;
if $ExperimenterControl() = Go \wedge chLocValid(time_{v_i}) = Go$ **then**
| **return** *Go;*
return *Stop;*
function CHLOCVALID($time_{v_i}$)
for $k = 1 \rightarrow 3$ **do**
if $timeDiff(Vehicletime_{v_i}, SystemCurrentTime) < ValidLocationPeriod$ **then**
| **return** *Go;*
return *Stop;* /* System will stop if latest packet reveived from car is three times older than $ValidLocationPeriod$. */

Algorithm 3: Postcondition check for vehicles v_i

---

input : $V(v_i)$ Set of vehicles that are on v_i's line of sight;
input : $location_{v_j}$ Current geographical location of vehicle $v_j \in V_{v_i}$ in the Euclidean plain;
input : $SimLocation$ Coordinates of estimated current location of vehicles passed by experiment results;
output: $Speed = 0$ and $Speed = "lastvalue"$ are two signals that are set to stop or resume car movement respectively;
constant *Epsilon*: minimum difference accepted between expected and real location;
if $|SimLocation_{v_i} - location_{v_i}| < Epsilon$ **then**
| **return** *Speed=0*
return *Speed="lastvalue";* /* cars move when they are in the expected with the maximum difference of *Epsilon* compared to the experiment result. */

As stated in Chapter 2, each car transmits its location continuously to the base station. The first parameter which is checked in the system is distance passed in each step. The minimum distance between two cars is defined as *SafeDistance* which is 100 cm by default.

The location parameters for each car in different times are measured continuously by base station. Each car is identified by an ID which is transmitted on each packet data. As can be seen in **Alg. 1**, PC calculates the Euclidean distance between two cars and takes a proper action.

Car location stability is the other parameter that takes in account. It assumes that transmitted data is just valid in a time called "*ValidLocationPeriod"*. If this time passes and no new data receives from car, it is probable that connection between base station and car turned off and it needs to be reconnected. In this situation, the system tests the connection for three consecutive times and if still no new data received by the base station, it will stop.

Along with stability on cars side, it is also checked weather PC and base station transmit data correctly and continuously. It is done by monitoring packet transmission (sniffing) on the system. This action is defined as *ExperimenterControl()* in **Alg. 2**. If there is a problem in USB data transmission between base station and PC, or between PC and Vaillante's micro; the system stops. All the wireless communications and movement functions, including speed and steer adjustments, in Vaillante controlled by a micro controller in the car's main circuit.

Alg. 3 is one of the last checks that are performed in the system. As the name states, this check is done after each car movement (i.e. step). All the vehicle records on movements in the system within 4 steps were sniffed and car controller application loads that information upon running the system. Here, each car's location in each step is privies and compares with the experiment result. If the difference between these two values is negligible, the system continues its operation, otherwise the system stops.

Design

All the localization information that was captured in the test experiments is loaded on a Micaz mobile mote that will be placed on the car during the experiment. After planning the system and defining algorithms it is time to implement the system in Java. The code was built and run in JRE 1.4 on a Linux system. The program flow showed on *Figure 18*.

After primary checks which are basic checks like turning each cars power on and ensure that cars and motes batteries are fully charged, SimLoc text file which contains localization information and was captured in the test experiments loaded and classified by Java StringTokenizer. So strings which are delaminated by Tab are saved in different object arrays.

The first step in the experiment is to make the connection between cars and application. Vaillante system just works in one to one client-server model. So, only one car can be connected to the system at a time and algorithms will be checked round by round for each car. Network socket for car is written in java application similar to the one in **Appx. B**. The same socket is defined and opened on Java application. Obviously the internet address and UDP port for each connection are the same in both sides.

After ensuring the car is connected to the network, a block is written to start the experiment. A "For" loop is written to control flow of the program. As the system guaranteed to work on four rounds, the loop prevents the system to run above this number. This code includes parts for sending command packets to the car. Each packet includes socket information, steer and speed values. It should also noted that SniffLoc text file is loaded and classified by StringTokenizer in this period which is consist of latest localization information sent by car in each step. As mentioned before,

Now, it is the time to implement and reference the loop to three safety algorithms. The algorithms are implemented in functions that return a Boolean value. If the car provides a violation in each algorithm the experiment ends.

The experiment finishes after the execution of the loop. Network sockets close and no other command will be sent to the system.

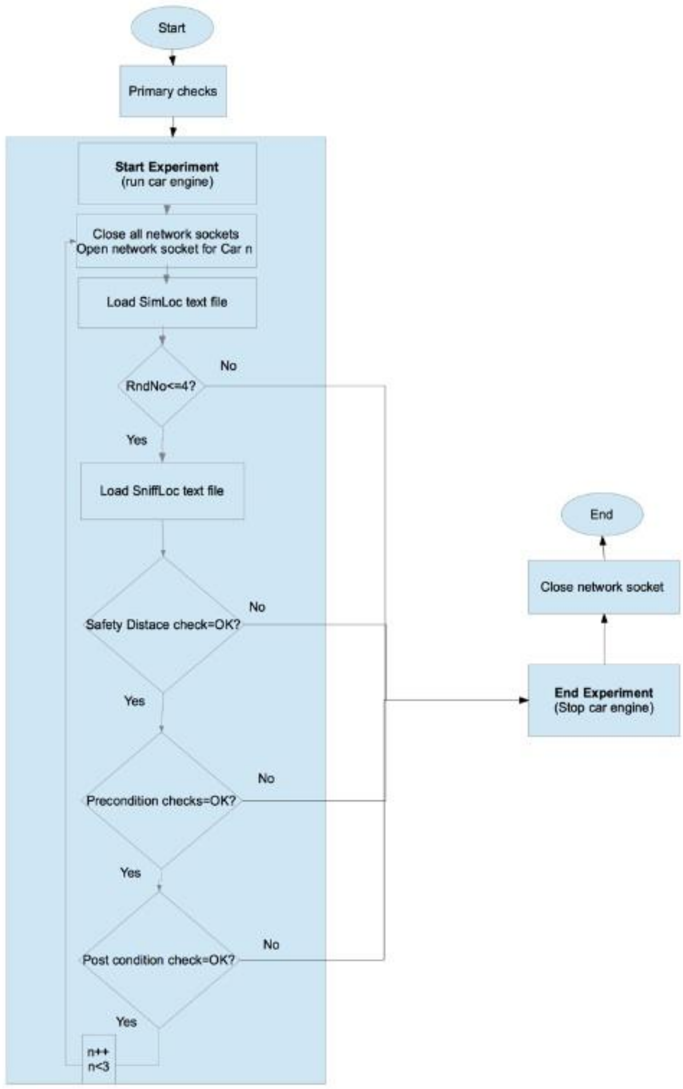


Fig. 18: Java Program flow

Implementation and results

As the accuracy of the measured area for localization in coordinates higher than (x, 800) were so weak, the implementation of the car controller system designed to be performed on lower coordination area. The localization information copied to each car to implement the MoteTrack system in normal mode. As stated earlier, mobile motes are attached to laptop trough USB for tracking location in original MoteTrack system. While in this project another mote, i.e. base station, which plays the interface role do it using Wi-Fi connection. Further, the most reliable experiments achieved in the maps where the cars are placed in a circle road. The radius of circle is 3.5m and cars were spread with equal distance on the perimeter. For this implementation two cars were used.

Although the algorithms and the system were designed very carefully, the controller application didn’t work successfully. The reasons for this case can be as follows:

1. Congestion in the network and mobile mote data process due to lots of operations and packets traversing in the network: It should be noted that as normal operation in MoteTrack localization system was used in this step, each mobile mote should compare its reference signature database with the reference signatures received from the beacons in each location. This may affect the quality of mobile mote processes.

2. Latency due to changing networks each time the new car wants to connect to the system lowers the localization accuracy dramatically.

3. Car’s mechanical parts seems to be depreciated and the estimated distance and angles for each step which were achieved from experiments in Chapter 2, are not useful.

Chapter 4

Summary

Achievements

In this thesis project, we could design and implement an application for controlling miniature cars, i.e. Vaillante Wi-Fi, by sending control commands to adjust their speed and distance with regard to the other cars. The safety algorithms seem to be trustable. We could prove the feasibility of the project by correcting and promoting results achieved in Chapter 4.

Limitations

Since Vaillante cars seem not to be so precise regarding to steer and engine regulations, the results achieved in experiments and tests are not so stable and as a result not all the experiment results are trustable.

On the other hand, transmitting localization information over ZigBee networks may not be a good solution for this project. Wi-Fi and ZigBee signal strengths are generally unstable and they vary over time. They also affected by other factors like obstacles. [11]

Limited memory capacity of MicaZ sensors [31] is another problem which limits the number of reference signatures can be taken in localization process. Obviously, the less captured reference signatures lead to less accuracy for localization process.

Future Work

The work can be developed by using a more advanced car model which probably has more abilities in controlling steer and speed of the car. It can also have some peripheral devices like cameras and the information the camera provides can be helpful for the future scenarios.

Regarding the improvement of tracking system, a more trustable system can be used. This system can deliver a more accurate location coordinates. Although ZigBee devices are very good choice for sensor networks because of the low power they consume, applying proper communication filters like Bayesian filter can be an alternative to enhance the localization results. Some of these solutions can be found at [32-33]

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Appendix A

Sniffed packets and iPhone application values mapping

Command	Steer(radix 10)	Speed(radix 10)	Status/Movement
55:96:00:c8:00:a2	-50	0	Most Left/No Speed
55:96:00:98:00:d2	-2	0	
55:96:00:97:00:d3	-1	0	
55:96:00:96:00:d4	0	0	Straight/No movement
55:96:00:95:00:d5	1	0	
55:96:00:94:00:d6	2	0	
55:96:00:93:00:d7	3	0	
55:96:00:92:00:d8	4	0	
55:96:00:91:00:d9	5	0	
55:96:00:8c:00:de	10	0	
55:96:00:64:00:06	50	0	Most Right/No Speed
55:64:00:96:00:06	0	-50	Straight/Fast Backward
55:94:00:96:00:d6	0	-2	
55:95:00:96:00:d5	0	-1	
55:96:00:96:00:d4	0	0	Straight/No movement
55:97:00:96:00:d3	0	1	
55:98:00:96:00:d2	0	2	
55:c8:00:96:00:a2	0	50	Straight/Fast Forward

Appendix B

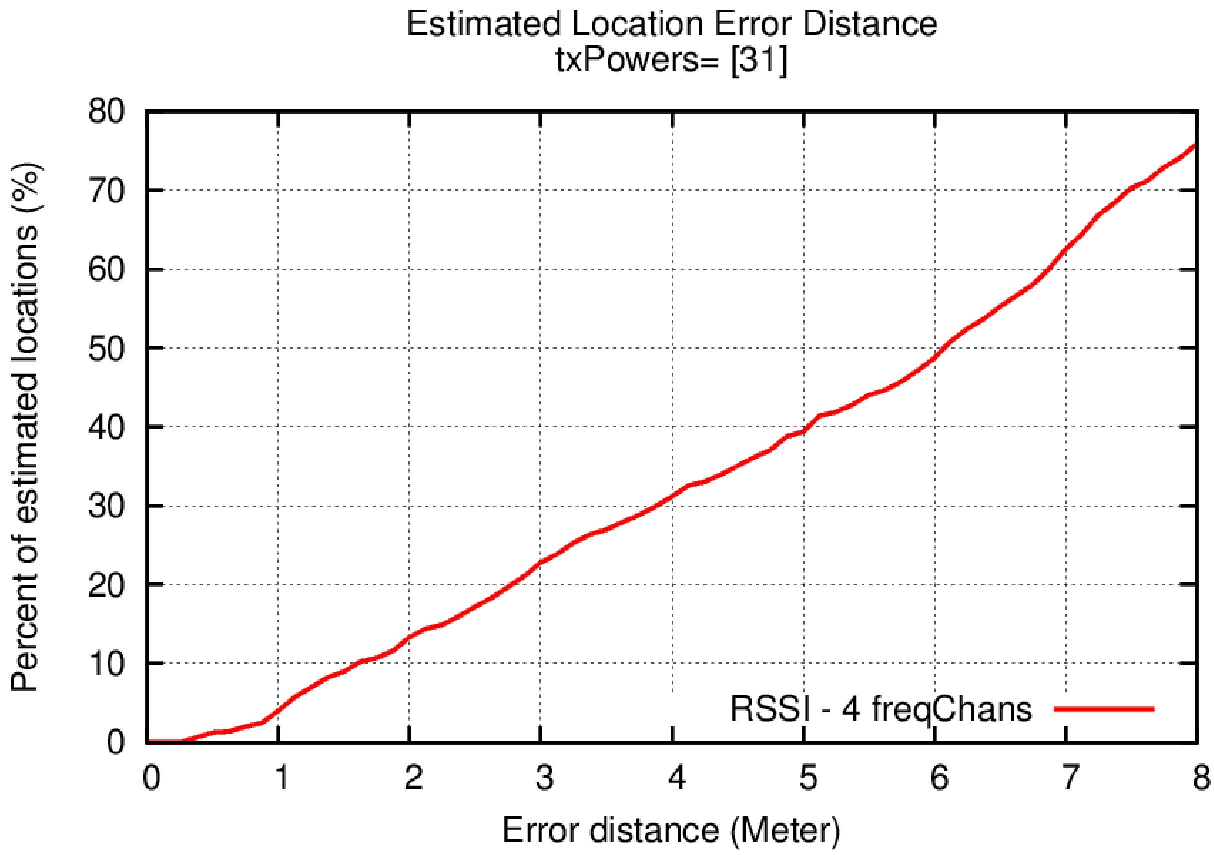
Here is a command based simple car controller code in Java. The code was written to move Car3 in a circle.

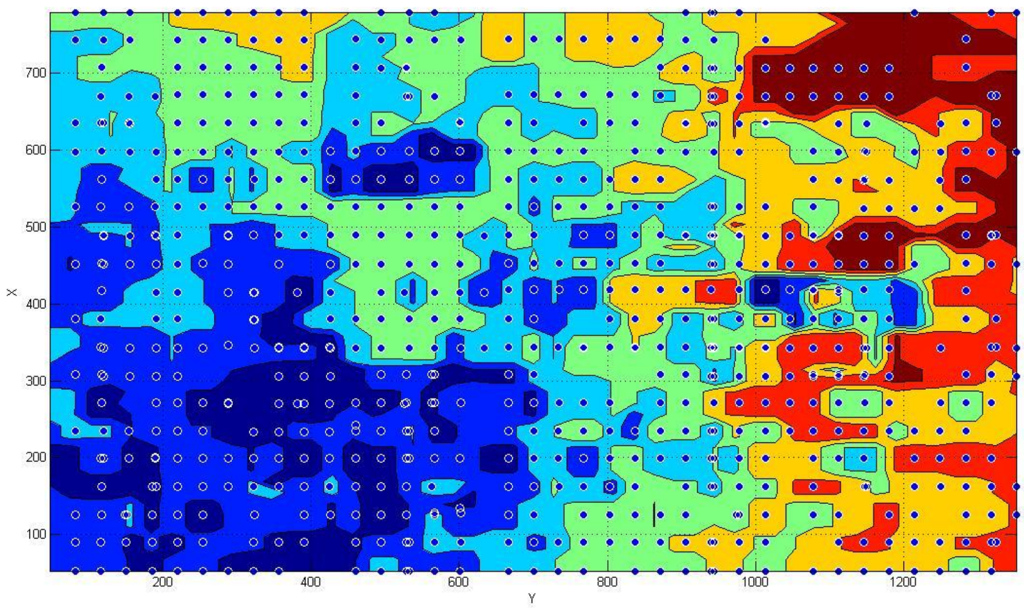
```
/////////////////////////////////////////////////////////////////////////
import java.io.*;
import java.util.*;
import java.net.* ;

public class PacketSendingtoCar3
{
  private final static int PACKETSIZE = 100 ;
  private static int speed, steer;

  public static void wait (int n){
      long t0,t1;
   System.out.println( "Wait!" ) ;
      t0=System.currentTimeMillis();
      do{
         t1=System.currentTimeMillis();
      }
      while (t1-t0<n);
  }

  public static void main( String args[] )
  {
    // Check the arguments
    if( args.length < 1 )
    {
      System.out.println( "usage: java DatagramClient Command" ) ;
      return;
    }

    DatagramSocket socket = null;
    try
    {
      InetAddress host = InetAddress.getByName( "192.168.3.1" ) ;
      int port        = Integer.parseInt( "15221" ) ;
   socket = new DatagramSocket() ;
   // retrive steer and speed values from arg[1] and arg[2]
   speed = (byte)Integer.parseInt(args[0]);
   steer = (byte)Integer.parseInt(args[1]);
   Sy
      byte[] data = new byte[6];
         data[0] = (byte)0x55; //constant
         data[2] = (byte)0x00; //constant
         data[4] = (byte)0x00; //constant
```

```
            data[1] = (byte)(0x96 + speed );
            data[3] = (byte)(0x96 - steer );
        data[5] = (byte)(0xd4 - speed + steer);
            System.out.println( "data[5]:"+ data[3] ) ;
           DatagramPacket packet = new DatagramPacket(data, data.length, host, port);
           // DatagramPacket packet = new DatagramPacket(data, data.length, remAddr);
           for(int i=0 ; i < 4 ; i++)
         {
        socket.send(packet);
        wait(5000);
            System.out.println( "i = "+i ) ;
              }
      }
      catch( Exception e )
      {
         System.out.println( e ) ;
      }
      finally
      {
         if( socket != null )
            socket.close() ;
      }
   }
}
stem.out.println( "steer: "+args[0] ) ;

/////////////////////////////////////////////////////////////////////////////
```

Appendix C

The following figure shows MoteTrack accuracy in this deployment.



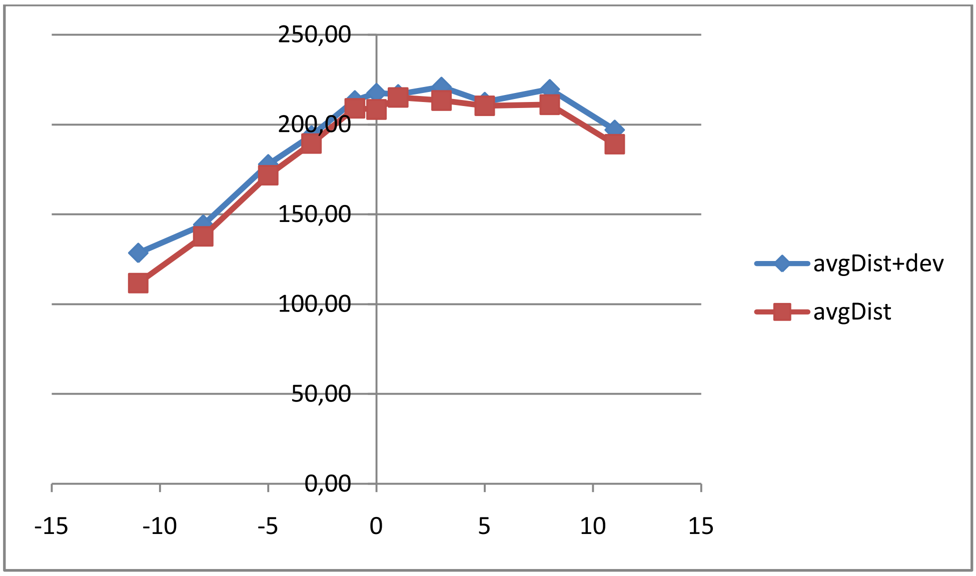


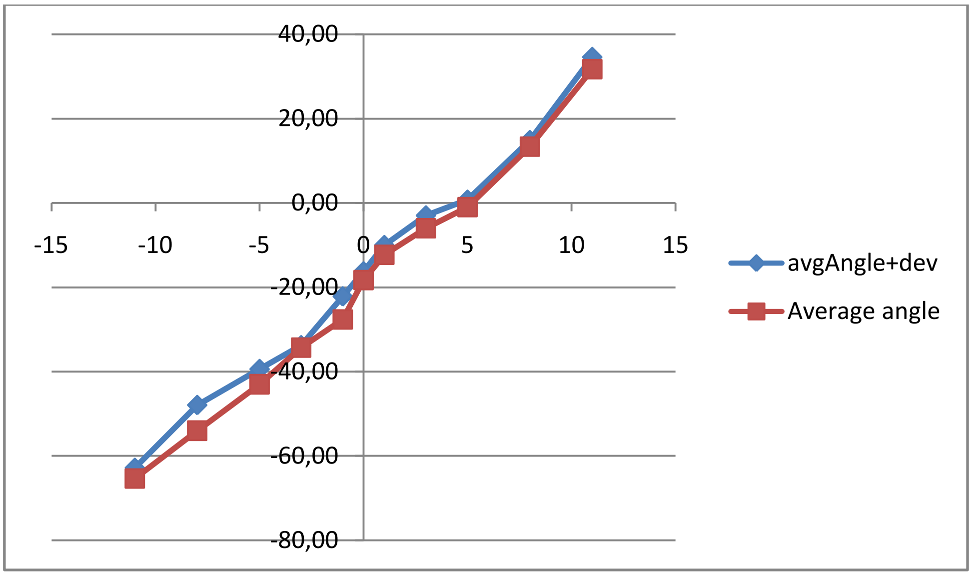
Appendix D

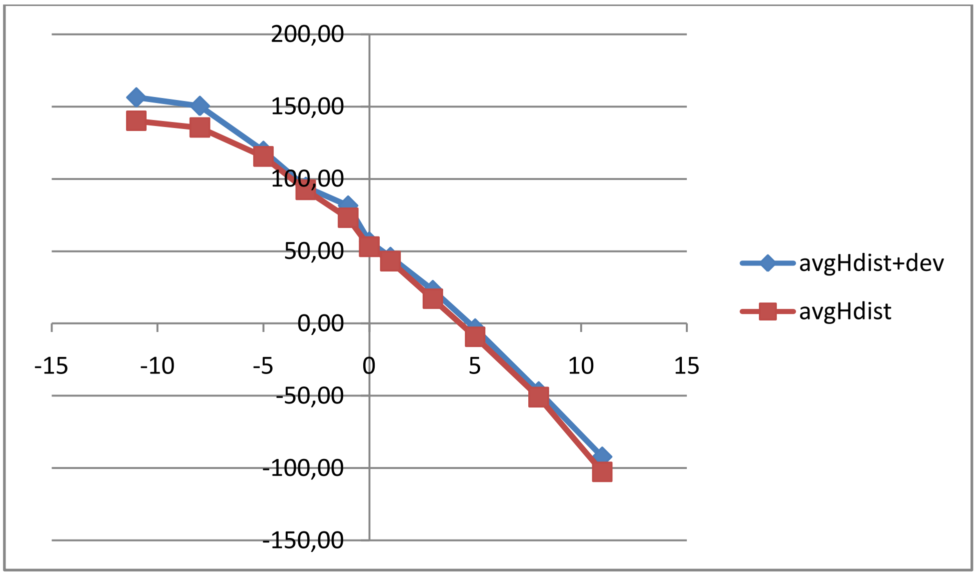
Car experiments documentations for different Vaillante cars are in the following pages.

Date:	3/14/2011
Start time:	5:20 PM
End time:	9:28 PM
Car id:	1
Place:	EDIT-6213

	Deviation Values		
Steer Value	Angle	Distance(cm)	Horizontal Distance(cm)
-11	2.52	16.77	16.37
-8	6.08	6.51	15.14
-5	3.61	6.11	4.04
-3	0.58	4.51	2.08
-1	5.51	4.36	8.54
0	2.08	9.07	3.61
1	2.31	1.73	3.00
3	3.00	7.51	6.08
5	1.73	2.08	5.86
8	1.53	8.54	4.00
11	2.89	7.94	10.50

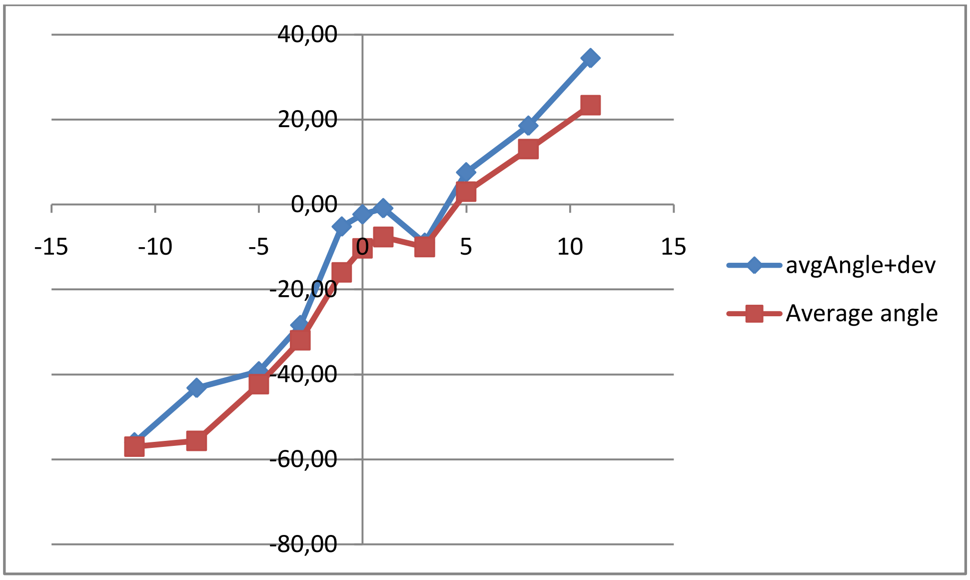


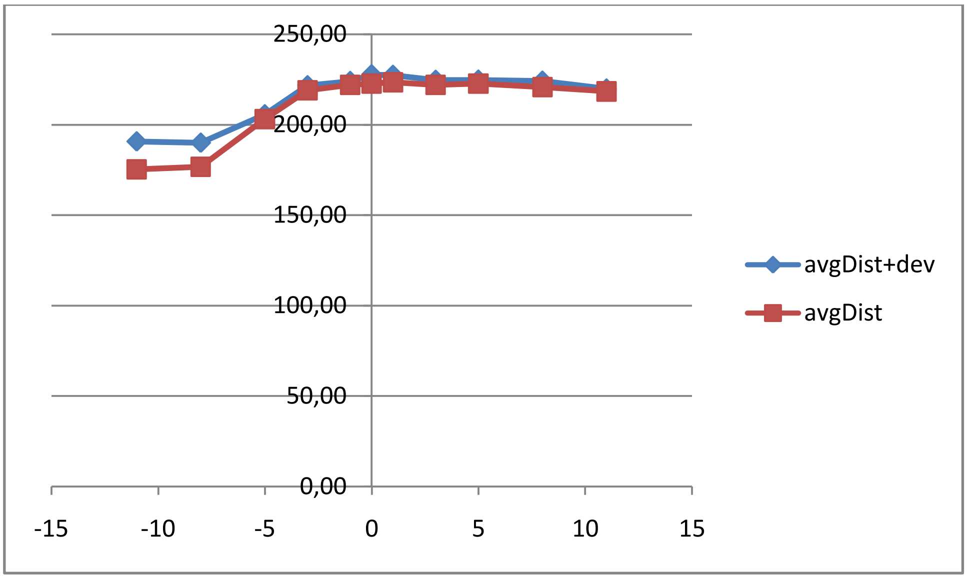

40,00
20,00
0,00
-20,00
-40,00
-60,00
-80,00
-15
-10
-5
0
5
10
15
avgAngle+dev
Average angle

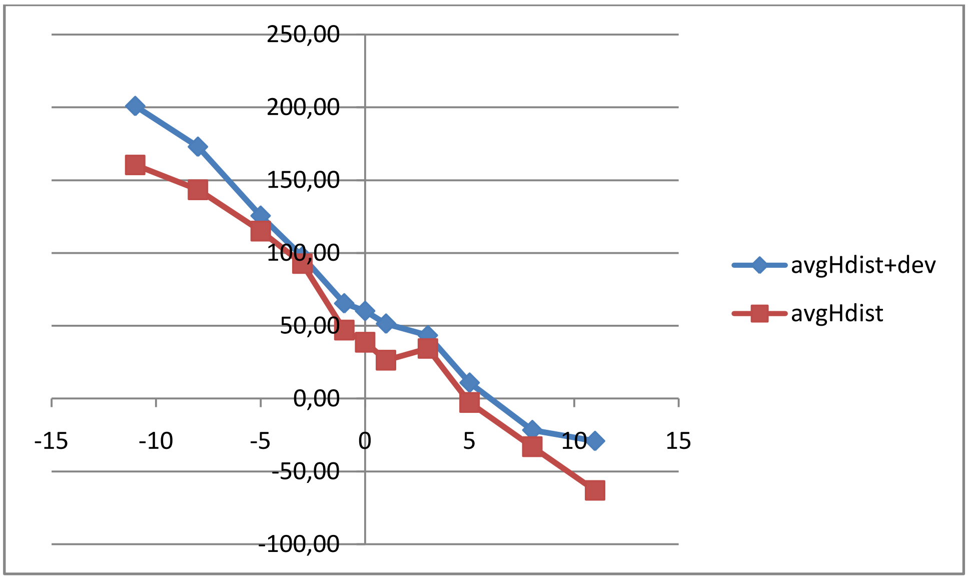

200,00
150,00
100,00
50,00
0,00
-50,00
-100,00
-150,00
-15
-10
-5
0
5
10
15
avgHdist+dev
avgHdist

Date: 3/16/2011
Start time: 5:20 PM
End time: 9:28 PM
Car id: 2
Place: EDIT-6213

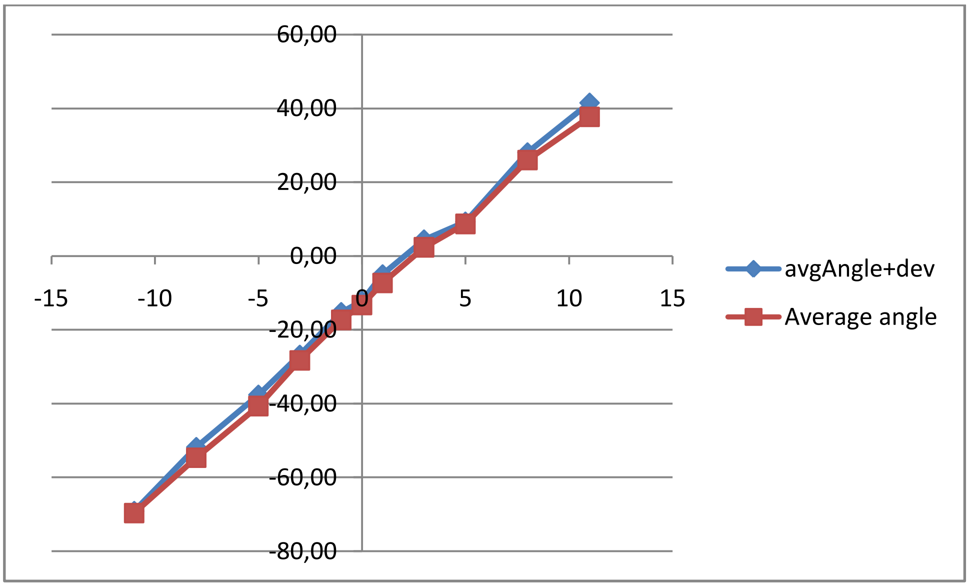
	Deviation Values		
Steer Value	Angle	Distance(cm)	Horizontal Distance(cm)
-11	1.00	15.37	40.53
-8	12.50	13.32	29.57
-5	3.06	2.65	10.54
-3	3.61	2.65	4.93
-1	10.82	2.00	18.36
0	8.02	5.03	21.50
1	6.81	4.04	25.11
3	1.00	2.65	9.07
5	4.58	2.08	13.58
8	5.57	3.51	11.36
11	11.15	1.53	33.87

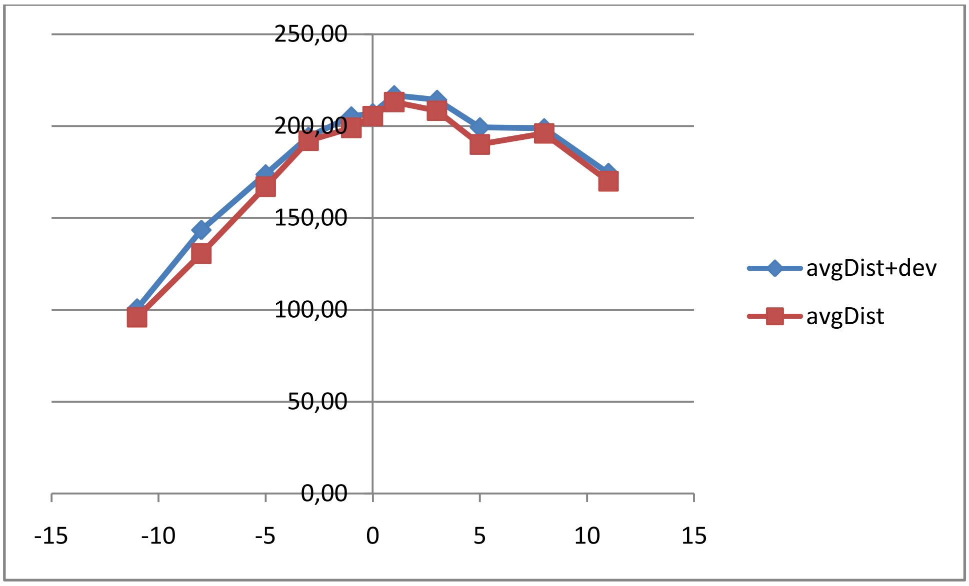


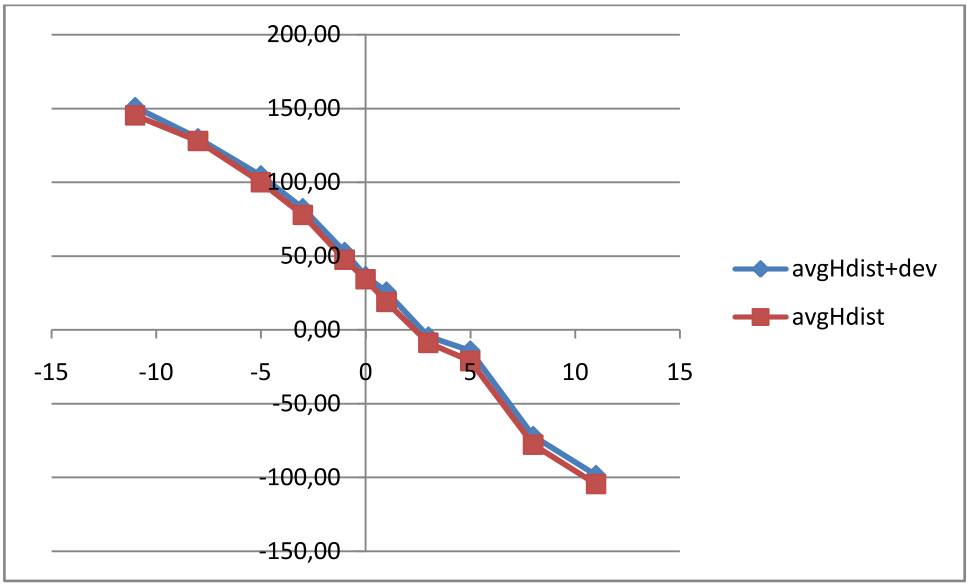

250,00
200,00
150,00
100,00
50,00
0,00
-15
-10
-5
0
5
10
15
avgDist+dev
avgDist


250,00
200,00
150,00
100,00
50,00
0,00
-50,00
-100,00
-15
-10
-5
0
5
10
15
avgHdist+dev
avgHdist

	Deviation Values		
Steer Value	Angle	Distance(cm)	Horizontal Distance(cm)
-11	0.58	4.58	5.51
-8	2.89	12.66	1.73
-5	3.06	6.56	4.58
-3	1.53	2.00	4.36
-1	2.08	6.08	5.03
0	1.15	1.53	2.08
1	2.31	3.61	6.93
3	2.08	5.77	4.16
5	0.58	9.17	7.00
8	2.00	2.65	5.77
11	3.79	4.36	6.11




250,00
200,00
150,00
100,00
50,00
0,00
-15
-10
-5
0
5
10
15
avgDist+dev
avgDist


200,00
150,00
100,00
50,00
0,00
-50,00
-100,00
-150,00
-15
-10
-5
0
5
10
15
avgHdist+dev
avgHdist