ISSN 0280-5316
ISRN LUTFD2/TFRT--5640--SE

Precise Navigation for an Agridultural Robot

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January 2000

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Document name
MASTER THERSIS

Date of issue
January 2000

Document Number
ISRN LUTFD2/TFRT--5640--SE

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Sponsoring organization

Title and subtitle

Abstract
This report is exploring the advantages and disadvantages with some common sensors needed when positioning a mobile robot with Ackerman steering. Both absolute and relative methods are explored. Odometry based on measuring traveled distance and steering angle is tested and adjusted to obtain the best performance. A Kalman filter is constructed to improve steering angle measurements. The tests are based on an agricultural robot tended to follow a row of sugar beets while weeding it. Best position estimate was obtained with the Kalman filter filtering the steering angle information from the steering motor and the information from the difference in velocity on the rear wheels. The average error in this measurement was 6.84%/m.

Keywords

Classification system and/or index terms (if any)

Supplementary bibliographical information

ISSN and key title
0280-5316

ISBN

Language
English

Number of pages
30

Recipient's notes

Security classification

The report may be ordered from the Department of Automatic Control or borrowed through:
University Library 2, Box 3, SE-221 00 Lund, Sweden
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CONTENTS

1 Introduction

1.1 Motivation

The work in this thesis has been a part of the Mech weed Project at the Center for Computer System Architecture (CCA), Halmstad University, Sweden. The main goal of the Mech weed project is to follow a row of sugar beets while weeding it.

Often in agricultural applications the position of the vehicle is important and this is also the case for the Mech weed robot.

The Mech weed robot is equipped with two cameras. One is looking forward in the row and the other one is looking down to identify the sugar beets. When a detected sugar beet leaves the picture from the down-looking camera the robot has to drive 25 cm before the weeding tool is above the plant and should be lifted to avoid the sugar beet from being weeded. If the weeds close to the sugar beet are to be weeded this distance must be measured very accurately.

When positioning a mobile robot both relative and absolute positioning methods often are used together. The advantage of this is that the error of absolute position and the error of relative position is often complementary in nature [1]. Relative positioning smoothes out the short-term absolute error, and absolute fixes calibrate the relative position drift over long time periods. It is possible to take advantage of these complementary errors and produce a positioning performance that is better than could be obtained with either type of data alone [2].

1.2 Goal

In order to remove the weeds close to the sugar beet the 25 cm must be measured within a few millimeters. The goal of this thesis is to explore the possibilities to measure the traveled distance with this high accuracy and positioning the robot.

1.3 Previous work

There has been written some papers about positioning for mobile robots but most of them focus on robots with differential drive for example the papers by E. Abbot and D. Powell [1] and by E. Borenstein and L. Feng [3].

J. Van Bergeijk, D. Goense, K.J. Keesman and L. Speelman [2] have written a paper about dead reckoning together with GPS for a tractor. There are some basic differences between Ackerman steering, Fig. 1.1 and differential drive so I think there is a need for this paper.

1.4 Preview

This thesis focuses on the problem to get an accurate position estimate for an agricultural mobile robot with Ackerman steering.

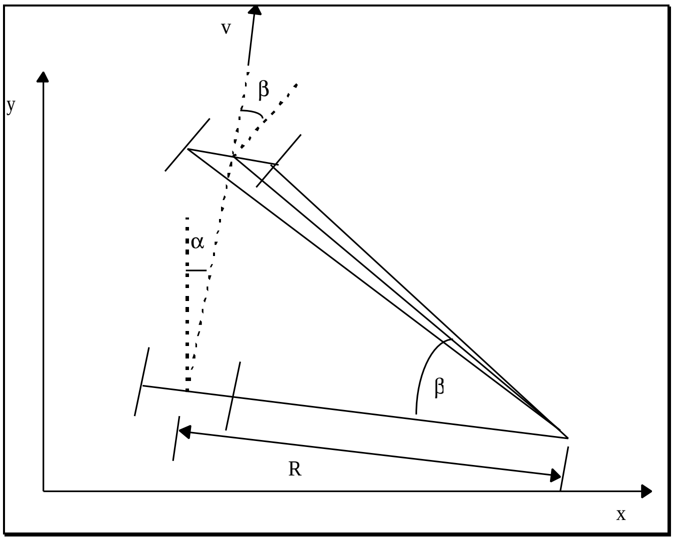

Figure 1.1: Ackerman steering

The tests has been done on the Mech weed robot, Fig. 1.2 and all simulations has been done with the parameters measured on the Mech weed robot.

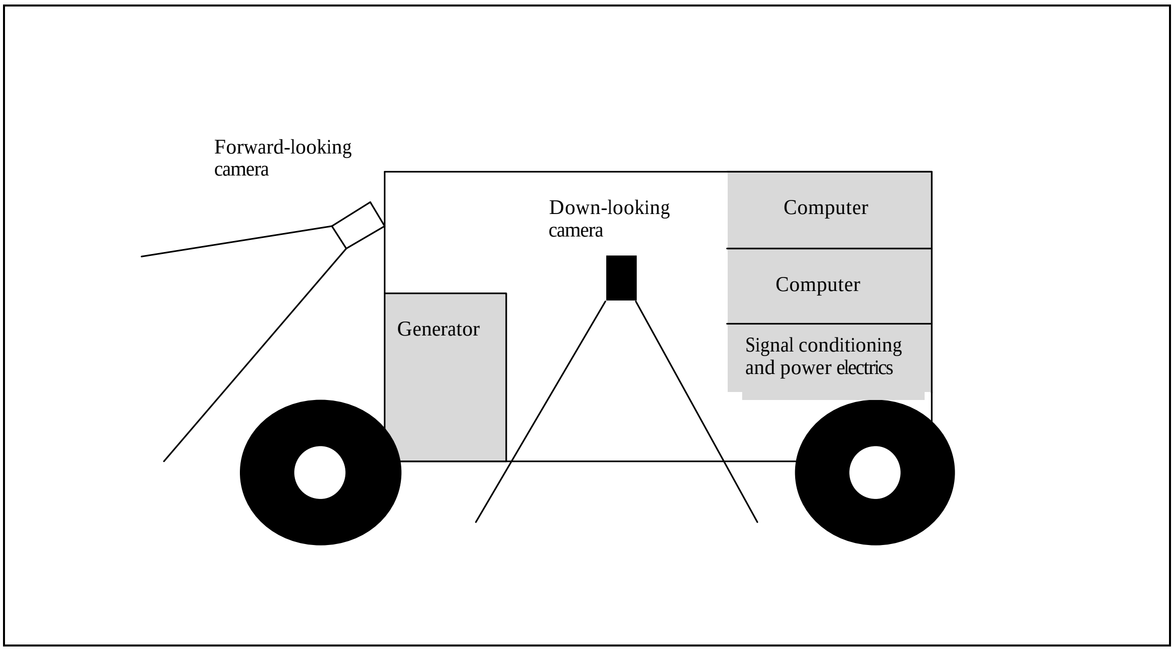

Figure 1.2 Side view of the Mech weed robot

First is an overview over some common sensors, both absolute in Section 2 and relative in Section 3. In Section 5 the errors in odometry are explored and a positioning system tested.

2 Absolute Positioning Methods

The most often used absolute positioning method is GPS but there is a variety of different techniques to improve the accuracy of standard GPS. An other way of measure an absolute position is some kind of triangulating with radio frequency. This technique will not be explored here since it often requires the user to place three transmitters nearby the area where the positioning is to be done and this is a clumsy and expensive method compared with GPS. GPS is also a kind of triangulating but with the satellites as transmitters instead of a transmitter on earth. The compass will also be mentioned here because it measures the absolute heading.

2.1 GPS

As mentioned above one solution to absolute positioning is GPS. There is however a large variety of different GPS techniques to explore.

For an introduction to GPS and how it is build see [4], [5] and [6]. I will only summarize some of the parameters that are important for positioning. All errors given here are rms errors.

2.1.1 Standard Positioning Service (SPS)

This is the standard service that is available for every one with a simple receiver. It is a rather inexpensive method but has a low accuracy, in the order of 100 meters [4] in the horizontal plane this accuracy is not enough for most mobile robot applications.

2.1.2 Differential GPS (DGPS)

DGPS is used to eliminate the effects of Selective Availability (S/A) and other uncertainties. A receiver is placed in a well known position and compares its true position with the one calculated from the satellite signals. The base station then sends the correction to the receiver in an unknown position. DGPS positioning can be carried out with some simple hand held receivers over a few 10s of kilometers, or it may be done with sophisticated multi-base station systems integrated with satellite communications, to cover a region of thousands of kilometers (wide area differential navigation). The price for these receivers varies from 10 000 - 90 000 sek [7]. The accuracy of DGPS is in the order of a few meters [4] in the horizontal plane, generally degrades with increased distance from the nearest base station.

2.1.3 Static Differential GPS

Static GPS improves the accuracy by measuring for a longer period of time at the same position. It is based on the same technique as DGPS with reference stations. This could be done with quite simple DGPS receivers but to get a centimeter precision in a reasonable amount of time the receivers will have to be more sophisticated costing about 100 000 sek [7]. These receivers use a technique where they measure on the phase of the satellite signals and compare the phase shifts. In an interview with Lars Wikmark [7] at Hushållningssällskapet in Halmstad, he demonstrated a quite inexpensive DGPS equipment that in 15 seconds could achieve a precision of 1 dm in the horizontal plane.

2.1.4 Kinematic GPS

Kinematic GPS makes it possible to get an accuracy of a few centimeters, over distances of 10 or 20 kilometers [5]. They use the technique with phase measurement but are more sophisticated then the static receivers to get the position faster. The price for this equipment is about 200 000 sek [7]. Variations on this type of technique are known by a variety of names (rapid static, fast static, stop & go kinematic, pseudo-kinematic etc.). The Swedish Company Teracom has just started a service called Ciceron. The technique is based on kinematic GPS and has centimeter precision in real time. Teracom has placed reference stations in 5 Swedish cities and sends out the correction signal on the FM band. The coverage to keep a precision on centimeter level is 20 km from nearest reference station. The price for this correction signal is 25 000 sek/year. The advantage is that you only have to buy one receiver instead of two in most other cases.

Technique	**Receivers required**	**Coverage**	**Observation Time**	**Price**	**Accuracy**
Point positioning	1	Anywhere	Seconds	Few thousand sek	50-100 m
Differential navigation (DGPS)	2	100s km	Seconds	10 000-90 000 sek	1 - 10 m
Static Differential	2	~100 km	Minutes-Hour	~100 000 sek	1 - 10 cm
Pseudo-kinematic	2	~20-40km	Seconds	~200 000 sek	1 - 5 cm

Table 2.1 Summarize of GPS techniques

2.2 Other methods

2.2.1 Compass

A magnetic compass is an electronic device that measures heading relative to magnetic north by measuring the direction of Earth’s local magnetic field. It is quite difficult to obtain an accurate heading with a magnetic compass because disturbances in the magnetic field near the compass can induce large errors in the compass’ output. Sources of magnetic disturbances in vehicle navigation is power lines, motors and residual magnetism in local metal structures such as bridges, buildings and even the vehicle’s chassis. Eric Abbot and David Powell have shown in their paper Land-Vehicle navigation using GPS [1] that a fluxgate compass can exhibit very large measurement errors. The results showed that while the gyro data indicated small changes in the vehicle’s heading, the compass data showed swings larger then 100° [1] when driving across a bridge with power lines nearby.

2.3 Conclusions

In Sweden Teracom sends out a correction signal for DGPS in the FM band which makes it available over most of Sweden. Most countries have a system similar to this so DGPS is a possible solution. In the future I think the kinematic GPS will be less expensive and there will probably be more reference stations placed over the country so this will probably be the best solution in the future for a high precision position system. If the new kinematic system is compared with DGPS when that technique was new the price will not fall in a couple of years but the accuracy will be better. However the price for the equipment used today will probably be halved in two or three years. Today I think the best solution will be a static GPS. This can be used to make corrections from time to time for instance in the beginning of every row and in the end of every row.

3 Relative Positioning Methods

A navigation system with robustness can not be based on GPS only because sometimes every GPS system loses its position fix [2]. These losses can vary from different techniques and according to Lars Wikmark [7] it is mostly the correction signal often transmitted with radio that is disturbed in some way. The loss often depends on the environment such as buildings and trees. To obtain a position when this happens there must be an other positioning system in conjunction with GPS. An agricultural robot is often tended to work in many places which makes GPS system with limited coverage not applicable. The uncertainty in GPS position fixes, in some cases no fix at all, is the reason that many land-vehicle navigation systems uses other navigation aids in conjunction with GPS position fixes to get an overall system performance. These navigation aids often give a relative positioning.

3.1 Heading

When calculating a new position from a known starting point one need to know in what direction the movement has taken place. This is the heading of the robot. Most relative methods to measure heading is done by integrating the rate of change from last position.

3.1.1 Steering angle

If the steering angle is measured this angle could be integrated to obtain the robots total rotation. The measurement could be done easy with encoders on the steering motor. This is an inexpensive and easy to accomplish method to measure heading. The drawback is its unbounded accumulation of errors. If there is only a slight offset in the steering reading this will have large consequences in a not so long period of time. But for shorter time periods this could be a good solution. The steering angle could also be measured by the difference in velocity on the rear wheels. These two measurements could be used to get a better accuracy in the steering angle.

3.1.2 Forward-Looking Camera

When controlling an agricultural robot to follow a row of plants there could be a camera mounted looking forward in the row. On the Mech weed robot this camera sends the angle between the present heading of the robot and the row of sugar beets in front of the robot to the controller. It also sends the offset between the robot and the row. This information is possible to use when calculating a heading. A drawback is that when the robot approaches the end of a row there will not be any direction reading when turning around to the next row. When calculating a heading relative to the starting heading this method will also be sensitive to offsets in the steering angle. If the steering has an offset and the controller corrects for this offset the accumulated error will grow out of bounds. But for calculating the offset for the weeding tool relative to the row it will probably be a good method.

3.1.3 Gyro

The gyroscope is a sensor that measures the rate of rotation about a particular axis. In vehicle navigation systems gyros are used to measure changes in the vehicles heading by integrating the gyroscopes output.

Examples of errors that appear in a typical gyro output include noise, a time varying bias, scale factor error, g-sensitivity and crossaxis sensitivity [1]. Borenstein and Feng measured the drift for two typical gyros in [3]. The result showed a drift of 3 to $15^0/\mathrm{min}$.

3.2 Traveled Distance

When the heading is known the traveled distance between two points in time must be known to calculate a position estimate. It is possible to measure the traveled distance direct e.g. by odometers or by measuring the speed and take the derivative.

3.2.1 Encoders

Odometry is simple, inexpensive and easy to accomplish. The disadvantage is its unbounded accumulation of errors. The sampling interval can be set rather high without decreasing the precision. The encoders on the Mech weed robot gives 500 pulses/rev. The gear box has a gear-box ratio of 56.8:1 and the counter card is set in quad scaling mode. This will give a resolution of 117200 pulses/rev. Odometry is based on the assumption that wheel revolutions can be translated to real movement relative to the ground. This assumption is only of limited validity. The wheels can slip on the ground which will make the associated encoder to register wheel revolutions even though this revolutions would not correspond to movement relative the ground. Also, if the wheels are not hard but have tyres, the air pressure might change slowly. The air pressure changing will cause the radius of the wheel to change and a change in radius will cause an error in position estimate. The ground will also effect the reading, if there are bumps or cracks the true distance will be less then the measured.

3.2.2 Fifth wheel

This solution is similar to encoders mounted on the axes. The difference is that you mount a whole wheel to measure on. The advantage of this is that it will probably not slip as much.

3.2.3 Down-Looking Camera

On the Mech weed robot it is possible to measure the traveled distance by looking how much one sugar beet has moved between two consecutive pictures or maybe several pictures. When detecting sugar beets this distance will come out as a byproduct. There are two methods to measure the traveled distance. The pictures taken by the down-looking camera are interlaced so one method to measure traveled distance is to take the correlation between two rows in one picture. An other method is to measure traveled distance between two consecutive pictures, see Fig 3.1. Both methods will measure the true speed relative to the ground. The resolution of the camera sets a limit for the accuracy. In the Mech weed robot the sampling frequency for the camera is 10 Hz which can be a bit low if the velocity is high. The Mech weed robot is tended to drive with 20 cm/s, this will give a resolution of 2 cm, which is a bit low.

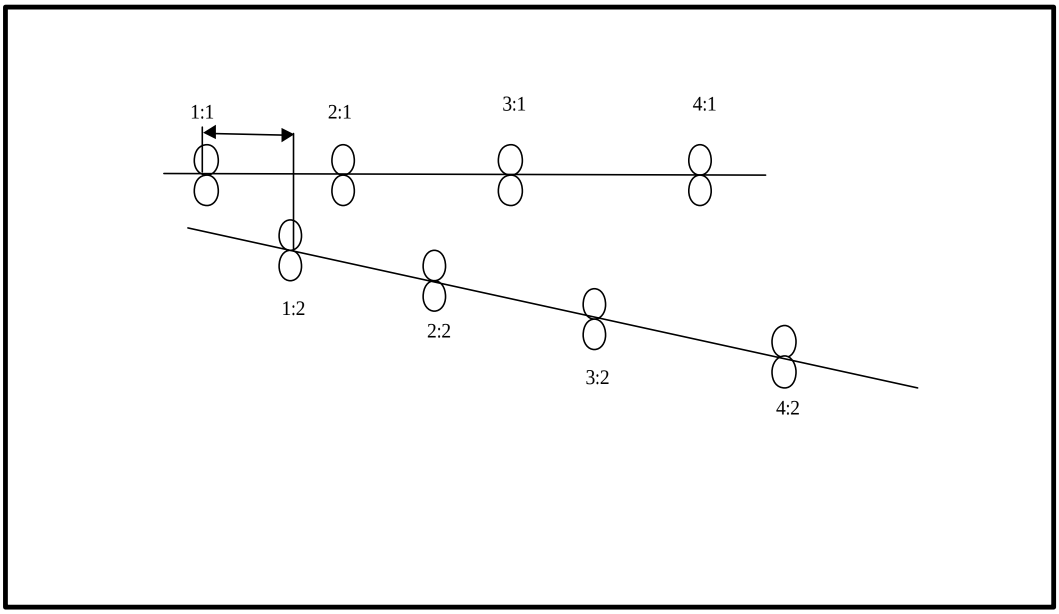

Figure 3.1 Model over two pictures from the down-looking camera laid over each other

The beets named x:1 is from the first picture and the beets named x:2 is from the following picture. Here the traveled distance in the x direction is the only interesting part. Since the picture can not rotate relative the robot the direction of the traveled distance is always in x direction. It is also possible to calculate traveled distances for every plant in the pictures and take an average between them to get a better precision

This system also depends on that there actually is a row of plants. In the end of the row when turning around to find the next it will not give any reading.

3.2.4 Radar

Radar measures speed with doppler shift technology. It is the phase shift between the transmitted frequency and the frequency of the signal reflecting on the object under measure eq. (3.3) that decides the velocity.

$$F_d = 2 \times v \times \frac{F_0}{c} \times \cos q \qquad (3.3)$$

F_d is the reflected frequency, F_0 is the transmitted frequency, v is the velocity, c is the speed of light and θ is the angle between the radar and the measured object. When measuring velocity with radar the angle of the radar relative to the target is important. It is difficult to measure this angle accurate and this is a large error source.

It makes no difference if the radar is mounted on the vehicle in motion and measures relative to an object standing still e.g. the ground. The angle should not be too large in this case. If the angle approaches $\pi/2$ rad the measured velocity will go towards infinity. On the other hand it should not be too small either because there will be less energy reflected. The radar is also sensitive to vibrations in the robot. This is a quite expensive method.

3.3 Conclusions

The most difficult parameter to measure accurate is the heading. As mentioned in section 2.2.1 a compass has a lot of errors to handle so this is not a good solution. In section 3.1.3 about the gyroscope we could se that the drift will course the error to accumulate if this method is used alone. In our applications the robot is programmed to follow a row of plants. One possibility is then to approximate the plants to be in a straight line. If the robot have a good row following system the robot can then be approximated to drive straight. This will make the heading less important but in the end of the row it can be valuable to know how much the robot has turned to be able to know when trying to find a new row.

Borenstein and Feng [3] developed a method to use gyro readings instead of encoder readings when a bump or a crack occurred. This could probably be done with a robot with Ackerman steering too. If the rotation measured by the steering angle differs too much from the gyro data the rotation measured by the gyro should be used instead. One other possibility to correct for unexpected obstacles could be to measure the effect in each driving motor. If a bump or a crack occurs the motor on the wheel driving over it should increase its effect driving up and decrease its effect driving down since the regulator is trying to keep the same velocity. When this information is known the steering action to compensate for the rotation coursed by the driving wheels could be ignored. The highest resolution is obtained with the encoders and I think it will be needed in the final solution.

4 Approach

To measure traveled distance with an accuracy of a few millimeters there has to be a rather high sampling frequency in the measurements. Even if the accuracy of measuring traveled distance with the down-looking camera is good the frequency is probably to low. The robot can move up to two centimeters between measurements.

The radar could be set to measure fast enough but the measurement is not very accurate as discussed in section 3.2.4. It is also an expensive method to measure speed.

Due to the low speed of the Mech weed robot and the low acceleration the fifth wheel solution will probably not lower the errors compared with measuring with the encoders.

The encoders mounted on the robot gives 117200 pulses/rev, this will give a possible resolution of the measurement of 10.7 μm. There are more errors to handle but this could be a possible solution to measure the traveled distance. It will also be an inexpensive method and easy to accomplish.

When measure heading there is no specific method that will be much better then the others. I will try a solution I have not read anything about in other mobile applications. I will try to measure heading with the steering angle. This will also be an inexpensive and easy to accomplish method and maybe a good complement to other methods like gyro and compass.

5 Methods

All experiments have been done on the Mech weed robot but most of the equations are applicable on any robot with Ackerman steering. For information about the Mech weed robot see [8] and [9]. A model was built in Simulink, Fig 5.1, to calculate the position of the robot with equation (5.6) and (5.7). The block steering angle generates a steering angle. It can either read it from the workspace in Matlab or generate it inside the block. It is also possible to add noise. In blocks xy pos with and without dist the next position is calculated with (5.6) and (5.7) with or without distortion. The blocks also generate the velocity in the same way as the block Steering angle. The blocks To workspace just sends the outputs to the Matlab workspace. In the tests all information from the encoders both on driving motors and steering motor was logged and the measured distance and offset was compared with the one obtained by calculating the position with the model in Simulink.

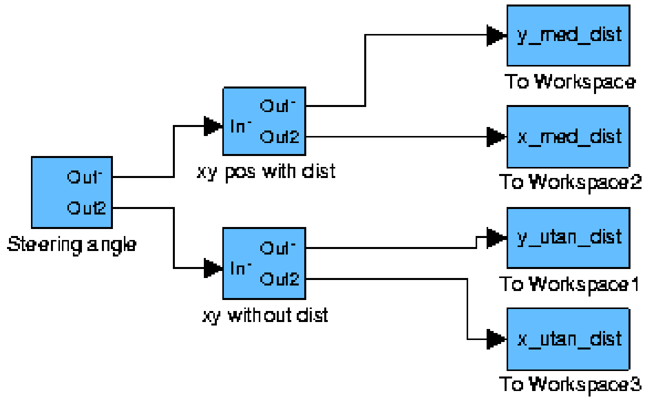

Fig 5.1 Simulink model

5.1 Radius

To be able to calculate a traveled distance from the encoder readings the radius must be well known on both driving wheels. In order to translate wheel revolutions to traveled distance Eq. (5.1) is used.

$$d = \frac{Pulses \cdot r \cdot 2p}{Pulses / rev} \qquad (5.1)$$

As can be seen here the radius is proportional to the traveled distance. If the radius has an inaccuracy of 1% the error after 10 driven meters will be ± 1 dm.

I measured the radius by driving the robot 11 meters indoors on a hard floor while counting the encoder pulses. In order to drive as straight as possible, the steering angle was set to zero so it was not possible to turn the robot with the joystick. The 11 meters was driven 10 times. The air pressures in both rear wheels were set to 1.2 kg/cm^2. The radius was then calculated with Eq. (5.2).

$$r = \frac{d}{\frac{pulses}{pulses / revolution} \cdot 2p} \qquad (5.2)$$

Where d is the traveled distance.

Experiments were also done to see how a lower air pressure affected the radius. First the pressure was lowered 33% of nominal to 0.8 kg/cm^2 and then to 50% of nominal to 0.6 kg/cm^2. The experiments were done with the row following system active to follow a tape measure. This will make the robot to drive a bit further then if driving completely straight so this measurement can not be compared with the one above. But the figures could be compared with each other.

I also did a test of the radius outdoors in a grass field with a lot of bumps to simulate a sugar beet field. The robot was set to follow a tape measure that was laid out in the field to drive straight. The distance of 25 m was first driven 3 times and then the air pressure was lowed with 33% in the right wheel to 0.8 kg/cm^2 and the distance was driven 2 times more.

5.2 Steering angle

There is redundant information in the steering and speed measurement. If there is a steering angle set to the front wheels the speed in the rear wheels should differ some. This information could be used to better the accuracy of the steering angle measurement.

In a mobile robot with Ackerman steering, it is the steering angle in the middle of the robot that is of interest, see Fig 1.1, but usually the steering motor affect one of the wheels with the steering angle read by the encoder on the motor. In the case with the Mech weed robot the steering motor affects the left wheel. The steering angle of this wheel has to be converted to the angle in the middle of the robot in, Fig. 1.1 called β. When turning left Eq. (5.3) will do this and when turning right Eq. (5.4) will do this.

$$b = \arctan\left(\frac{l \cdot \tan(a)}{l + \frac{w}{2} \cdot \tan(a)}\right) \qquad (5.3)$$

$$b = \arctan\left(\frac{l \cdot \tan(a)}{l - \frac{w}{2} \cdot \tan(a)}\right) \qquad (5.4)$$

Here l is the length of the robot between the front and the rear wheels, w is the wheelbase in the rear and α is the steering angle read by the encoder.

To calculate a rotation of the robot concern must be taken of the geometry to the robot. It is the radius of the turning circle that is effected by the geometry, Eq (5.5).

$$R = \frac{l}{\tan(b)} \qquad (5.5)$$

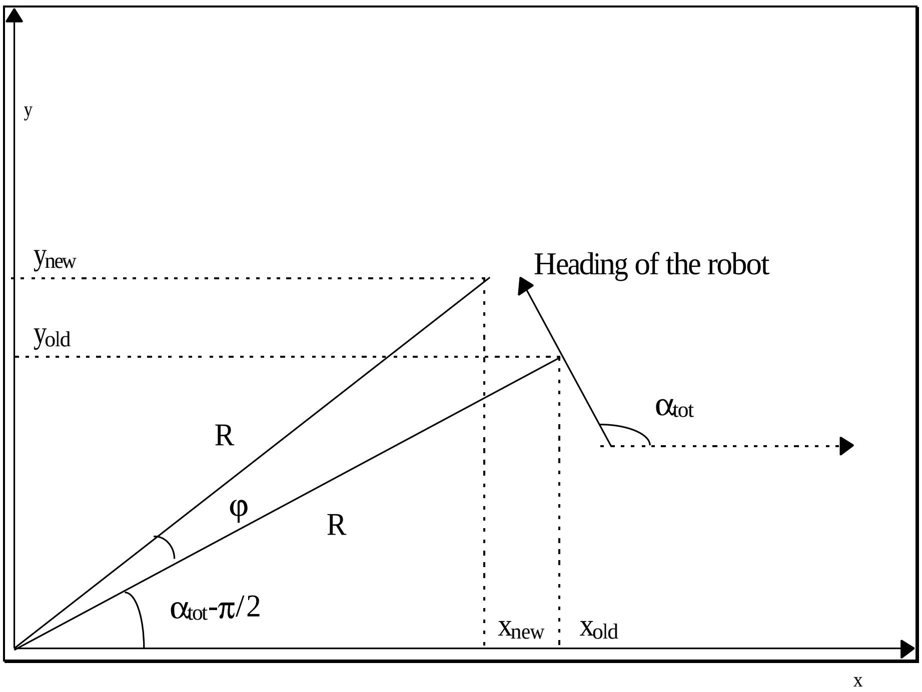

Figure 5.2 Heading update

Equation (5.6) and (5.7) will update a new position for the robot where x is forward and y is the offset, see Fig. 5.2.

$$x_{new} = x_{old} - R \cdot \sin(a_{tot}) + R \cdot \sin(a_{tot} + j) \qquad (5.6)$$

$$y_{new} = y_{old} + R \cdot \cos(a_{tot}) - R \cdot \cos(a_{tot} + j) \qquad (5.7)$$

α_{tot} is the angle of the robot relative to the starting direction. And φ is obtained by Eq. (5.8) and α_{tot} is updated by Eq (5.9)

$$j = \frac{d}{R} \qquad (5.8)$$

$$\alpha_{totNew} = \alpha_{totOld} + \varphi \qquad (5.9)$$

Here is d the traveled distance. This method is sensitive for offsets in the steering angle. If there is an offset of 1° in steering angle the Mech weed robot will be off by 1 m in just 11 m forward travel.

A lot of test runs have been done in the corridor at Halmstad University to correct for an offset in steering angle. The robot was set to follow a tape measure laid out on the floor. The wall was used as reference to measure the offset. In all measurements the true offset was zero and the traveled distance was 9 m and 14 m. Tests were also done outdoors in the same way but since the robot follows the tape measure as well the offset was not measured but set to zero. In Fig. 5.3 the traveled distance has been plotted against the offset. The measurements around 25 meters traveled distance is from outdoors the others are from indoor measurements. All figures are from table (A.1).

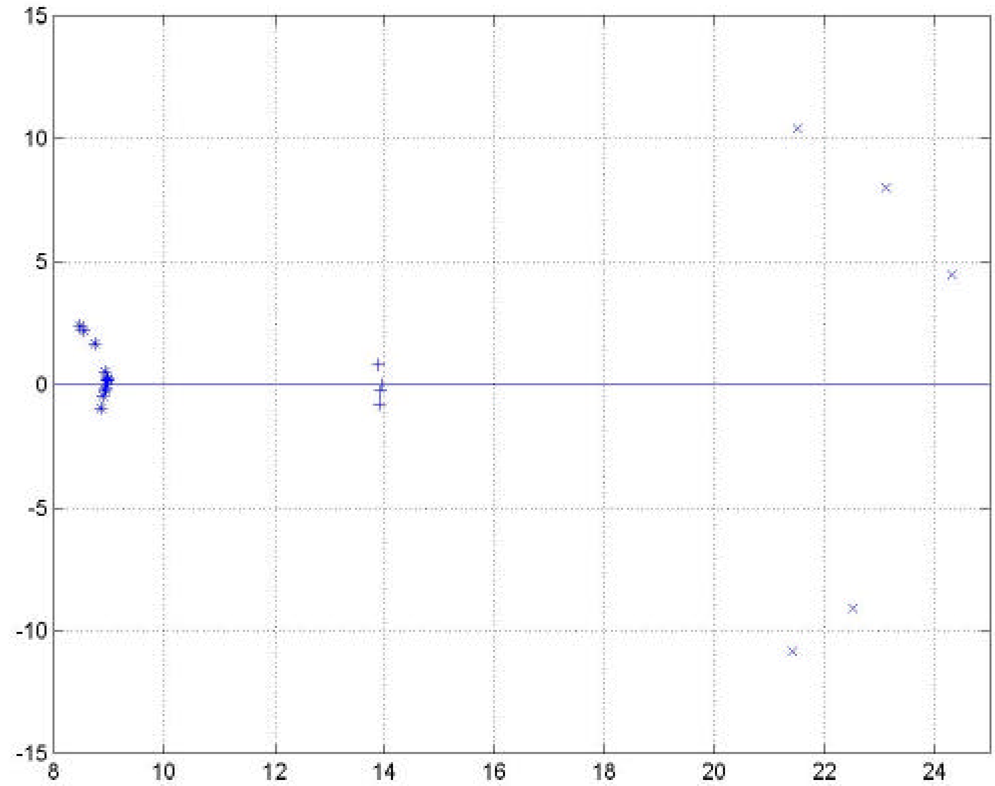

figure 5.3 Traveled distance versus Offset

In the measurements with 9 meters and 14 meters true traveled distance I tried to correct for an offset by changing the middle of the steering encoder. When the steering angle is to be measured the encoder value for angle 0 must be known to calculate an angle, Eq (5.10).

$$a = \frac{pulses - middle}{pulses / rad} \qquad (5.10)$$

One large error source in the measurements is the starting direction. If this direction is not exact the one on the tape measure there will be an offset affecting the whole test run. Before I started the measurements I settled the robot to follow the tape measure for two meters to start in a straight line relative to the tape measure.

When approximating the robot to drive straight, assuming all traveled distance is in the x-direction, the estimates showed a good accuracy when measuring indoors the error in estimated distance relative to the true distance showed a constant offset. Tests with different kinds of bumps, see Fig. 5.4, were also done in the corridor a Halmstad University.

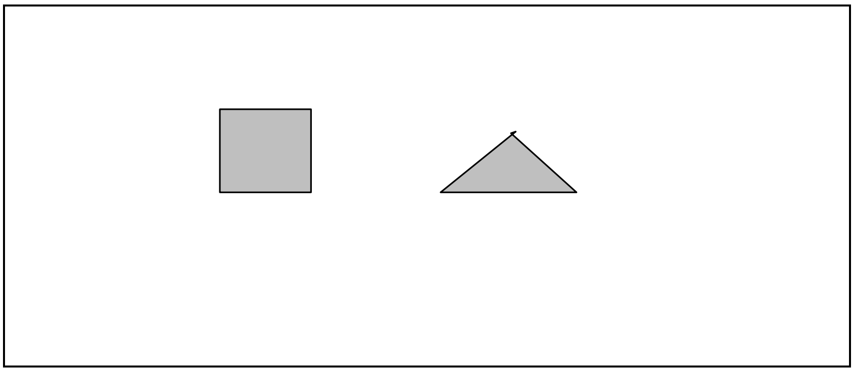

Figure 5.4 Different bumps

The theoretical change in distance affected by these bumps is for the quadrangle two times the height of the quadrangle. For the triangle the traveled distance will depend on the height and the length of the bump according to Eq. (5.11)

$$d = 2 \cdot \sqrt{h^2 + (\frac{l}{2})^2} \qquad (5.11)$$

If not both wheels are effected the estimated distance over the bumps will be half of the theoretical. When the estimate is calculated the average between the two distances is the one used. These numbers were also confirmed by the tests.

5.3 Kalman filter

In order to improve the accuracy of position estimate I constructed an ordinary Kalman filter. For details about Kalman filters see [10]. I designed a Kalman filter to approximate the steering angle from measurement of the steering angle on the motor and the steering angle calculated by Eq. (5.12) if turning left and Eq. (5.13) when turning right from the speed on right respective the left wheel.

$$\tan(a_v) = \frac{L \cdot (v_l - v_r)}{\frac{w}{2} \cdot (v_l + v_r)} \qquad (5.12)$$

$$\tan(a_v) = \frac{L \cdot (v_r - v_l)}{\frac{w}{2} \cdot (v_r + v_l)} \qquad (5.13)$$

And then use this angle when calculating a new position. Here α_v is the steering angle from the difference in velocity and α_s is the steering angle from the steering motor, L is the length of the robot, w the wheelbase and v_r velocity on the right wheel and v_l velocity on the left wheel. The equations for the steering angle looks as follows.

$$a_{k+1} = a_k + ha_k \qquad (5.14)$$
$$a_{k+1} = a_k \qquad (5.14)$$
$$a_v = a_k \qquad (5.15)$$
$$a_s = a_k \qquad (5.15)$$

α is the steering angle state and h is the time between two samples. The first equations usually are called state equations and the second are called measurement equations. Both measurements are from the steering angle and quit noisy so the purpose of the Kalman filter is to estimate a better steering angle from these two measurements. The filter equations follow the ones in [10]. To get a good result the measurement noise R_n that should be added to the state equations and the process noise Q_n that should be added to the measurement equations has to be known. The measurement noise for the steering motor is quit similar to the noise in the steering angle measurement from the difference in velocity on the rear wheels. The parameter R_n was set to 0.1 according to the mean average error from the position estimate in previous measurement. The parameter Q_n was adjusted for best performance and finally set to 0.01. The simulations were done by first estimate a new steering angle from the two measurements and then simulate the same way as the previous measurement, see fig 5.5.

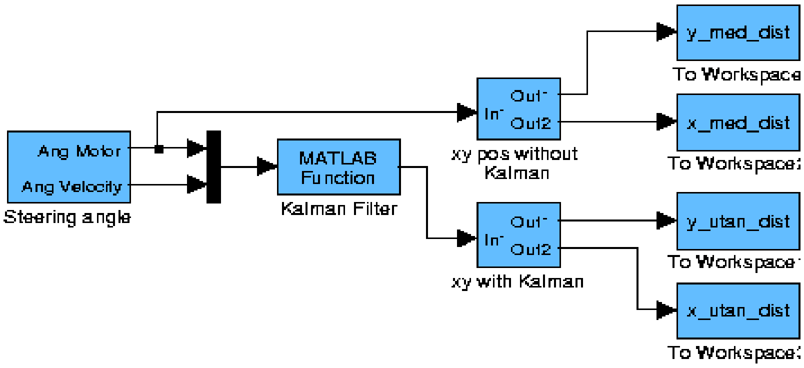

figure 5.5. Simulink modell with Kalman Filter

After adjusting the noise parameters the gain in the Kalman filter is after only a few steps: K_{11}=-1,4545, K_{12}=-0.5455, K_{21}=-0.4545 and K_{22}=0.4545. In figure 5.6 the stability of the Kalman filter was tested. In signal was a zero steering angle and both the out signal from the Kalman filter and the in signal is plotted.

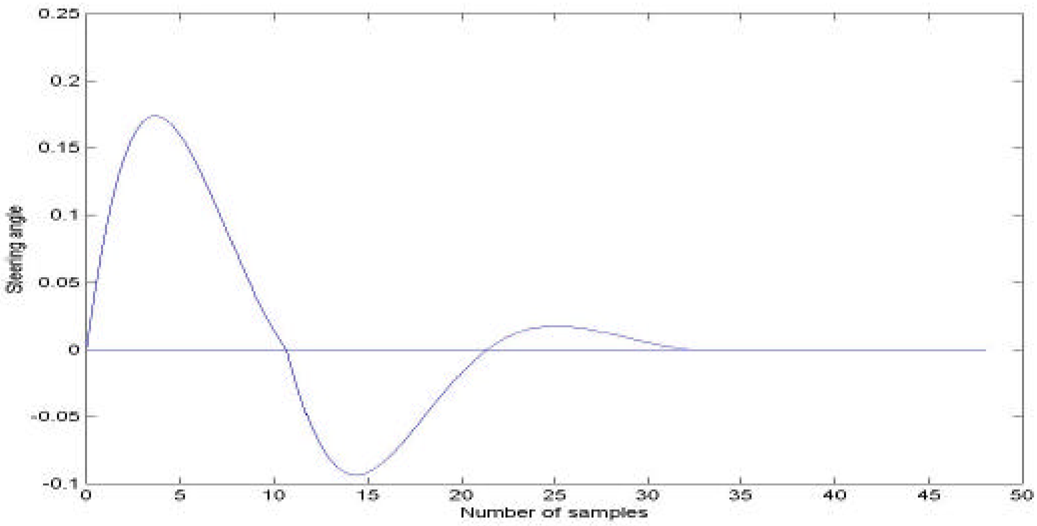

Figure 5.6 Stability of the Kalman filter

In fig 5.7 the system with a Kalman filter and the one without is compared. Plots with ‘+’ are from measurements without Kalman filter and plots with ‘.’ are from measurements with the Kalman filter described above. The figures are plotted the same way as in fig 5.3.

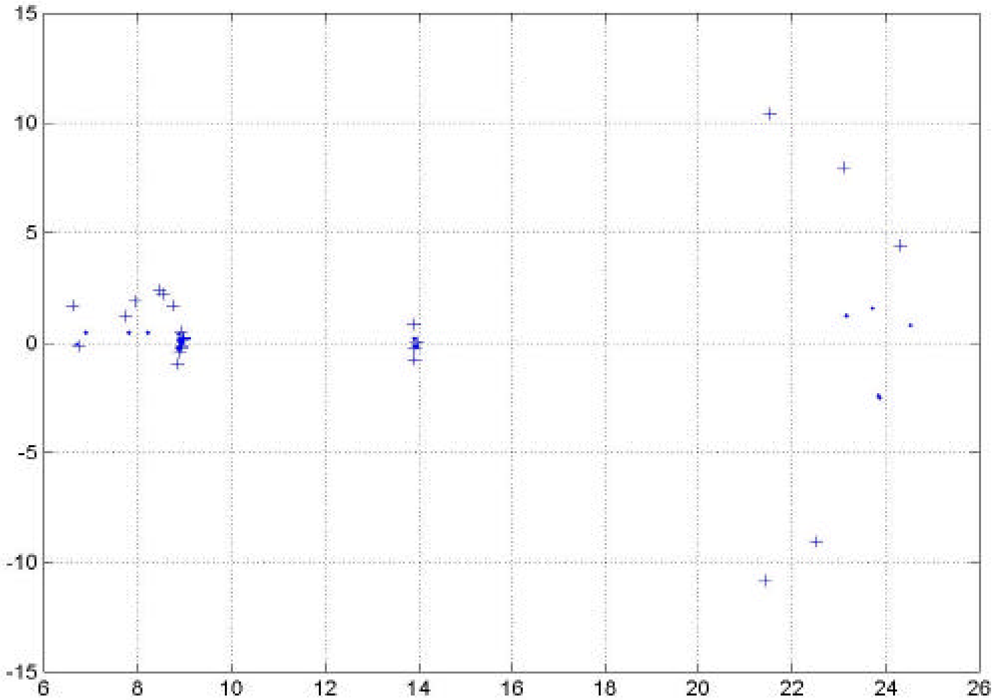

figure 5.7 Traveled distance versus offset with and without Kalman filter

6 Results

The tests on the radius showed a rather high accuracy. Mean radius on the left wheel was 0.1903 m with a standard deviation of $4.65*10^{-4}$ m and the radius on the right wheel was 0.1896 m with a standard deviation of $4.81*10^{-4}$ m. The change in air pressure did not show a significant difference in radius between 1.2 kg/cm^2 in pressure and 0.8 kg/cm^2. When the pressure was lowered to 0.6 kg/cm^2 a slight change in radius could be detected but only a few millimeters. From the outdoor measurements the following results were obtained. The air pressure change did not effect the radius in the last two measurements. The mean radius of the two measurements with 0.8 kg/cm^2 was 0.1910 m compared with 0.1909 m for the three measurements with 1.2 kg/cm^2 in the right wheel. The mean radius for all 5 measurements was for the left wheel 0.1917 m, with a standard deviation of 0.0025 m and 0.1909 m for the three measurements with 1.2 kg/cm^2 in the right wheel, and a standard deviation of 0.0022 m.

In measurements when approximating the robot to travel straight I measured 6 different distances and all showed an offset of 0.57%/m to short in average. The standard deviation was 0.0026. This means that indoors when corrected for the offset the standard deviation of the error divided by traveled distance is only ± 0.26%/m. Outdoors the offset is not surprisingly a bit lager 0.67%/m. But when corrected for the offset measured indoors the error of the outdoor measurement is quit small. In the measured 25 meters the average error is only 2.6 cm to short and the maximum error is 6.4 cm to short.

In the tests on the steering angle best results were obtained with the middle set to 496020. The mean offset of these measurements was 0.13 meters and the standard deviation was 0.28. When I tried to correct for the offset still there it became lager instead of decreasing.

When the estimated steering angle from the Kalman filter were used in the simulations they became much better. When R_n was set to 0.1 and Q_n was set to 0.01 the average offset was 2.06%/m indoors with a standard deviation of 0.0206 and 6.84%/m outdoors with a standard deviation of 0.0295.

7 Discussion

7.1 Conclusions

When estimating position it is the heading that is most difficult to measure. Small offsets will have large effects in a quit small period of time. When trying to use the steering angle in the estimate there are some errors effecting in almost the same way which makes it hard to separate them and correct for them. First there is the middle of the encoder second the starting direction and third there is a lose in the steering motor of about one degree. As discussed in section 5.2 it does not help to follow the tape measure for a while to come in straight to it. This will make it almost impossible to set the robot straight in a field also. With the Kalman filter the position error is much smaller, about 5 times smaller in the outdoor measurements. It gives an average offset error of $6.84\%/m$ and an average traveled distance error of $1.77\%/m$ This system could be used to measure an absolute position but it will probably need some kind of GPS for correction since the error tends to grow and grow. In the future when the price has fallen kinematic GPS will be the best solution but now a static GPS will be the best solution. The robot then has to stop from time to time to get a position fix from the GPS. The time between these samples will depend on the accuracy needed in absolute position.

In the Mech weed project it is most important to know the offset of the weeding tool relative to the row of sugar beets. This could easily be measured with the forward-looking camera by approximating the row of sugar beets to be straight. The camera gives the angle between the robots present heading and the row and it also gives the offset of the row. With this information it is only simple geometry to calculate the offset of the weeding tool relative to the sugar beet. It is also possible to measure the 25 cm needed to travel with an accuracy under 1 mm in most cases. As seen in section 5.2 it is possible to measure this distance outdoors with a standard deviation of 0.26%. In 25 cm this will make an error of 0.65 mm which well fulfills the goal.

The best performance for relative positioning between plants will be obtained by approximating the rows to be straight and use the odometers. The best absolute position will be obtained by using the Kalman filter suggested in section 5.3.

8 References

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1 Appendix

Table 1

This table shows the figures from measurements indoors and outdoors. Measurement 20 - 24 are from outdoors and all others are from indoors. Middle of steer is the middle value set in the robot to know which encoder value that is straight forward. Offset is the offset at the end of the test run. The offset should be close to zero. Forward is the estimated traveled distance and Approx. driving straight is the traveled distance when just looking at the traveled distance from the encoders and approximating them to be in the forward direction.

Test	Middle of steer	Offset no kalman /m	Offset with kalman /m	Forward no Kalman /m	Forward with Kalman /m	Approx. Driving straight /m	True distance /m
1	503980	1.2022	0.4586	7.7539	7.8164	7.8795	7.94
2	503980	1.9103	0.4506	7.9325	8.2112	8.2414	8.3
3	503980	1.6890	0.4651	6.6332	6.9012	6.9324	7.0
4	496020	0.1612	0.0145	8.9766	8.9223	8.9772	9.0
5	496020	0.5299	0.0918	8.9242	8.9156	8.9443	9.0
6	496020	-0.2240	-0.2229	8.9418	8.9098	8.9466	9.0
7	496020	0.2430	0.0311	8.9937	8.9674	8.9980	9.0
8	496020	-0.1525	-0.0489	8.9542	8.9211	8.9565	9.0
9	496020	0.2022	0.0608	8.9933	8.9134	8.9677	9.0
10	495730	-0.9563	-0.2898	8.8687	8.8812	8.9326	9.0
11	495730	-0.1514	-0.0633	6.7512	6.7124	6.7557	6.8
12	495730	-0.4461	0.3698	8.9027	8.8765	8.9227	9.0
13	504270	2.3810	0.0117	8.4741	8.8999	8.9124	9.0
14	504270	1.6879	0.0264	8.7476	8.9123	8.9564	9.0
15	504270	2.2268	-0.2547	8.5400	8.8649	8.9126	9.0
16	495730	-0.2574	-0.1577	13.9224	13.9230	13.9268	14.0
17	495730	0.0079	-0.1049	13.9593	13.9609	13.9614	14.0
18	496020	0.8315	0.1873	13.9008	13.9118	13.9270	14.0
19	496020	-0.7614	-0.1817	13.9165	13.9351	13.9409	14.0
20	496020	10.4269	1.2577	21.5122	23.1483	24.7943	25.0
21	496020	-10.8180	-2.5149	21.4188	23.8467	24.8276	25.0
22	496020	4.4568	0.8002	24.3004	24.5054	24.8176	25.0
23	496020	-9.0854	-2.3994	22.5167	23.8194	24.8519	25.0
24	496020	8.0210	1.5825	23.0908	23.6936	24.8689	25.0

Table A. Measurement figures

Table 2
Here the offsets in previous table are divided by the true traveled distance and the mean and standard deviations are calculated. Straight is the estimated traveled distance when approximating a straight motion divided by the true traveled distance.

	Indoors no Kalman	**Outdoors no Kalman**	**Indoor with Kalman**	**Outdoors with Kalman**
Straight mean	0.57 %/m	0.67%/m		
Straight std	0.0026 m	0.0012 m		
Std	0.0933 m	0.1020 m	0.0206 m	0.0295 m
Mean error	9.48%/m	34.25%/m	2.06%/m	6.84%/m

Table A.2 Means and standard deviation

Table 3
Table over figures from radius measurement.

	Pulses Left	**Pulses Right**	**Radius Left/m**	**Radius Right/m**
1	1079975	1084402	0.1900	0.1892
2	1079495	1083907	0.1901	0.1893
3	1083857	1088270	0.1893	0.1885
4	1075241	1079641	0.1908	0.1900
5	1075207	1079608	0.1908	0.1901
6	1076803	1081209	0.1905	0.1898
7	1075278	1079679	0.1908	0.1900
8	1077220	1081628	0.1905	0.1897
9	1078452	1082859	0.1903	0.1895
10	1078237	1082640	0.1903	0.1895

Table A.3 Radius measurement

Table 4
Average speed and standard deviation for the speed and steering angle from measurements with 9 meters true traveled distance indoors.

Test Run	**Right Speed**		**Left Speed**		**Beta**	
	Mean	Std	Mean	Std	Mean	Std
1	0.1004	0.0050	0.0989	0.0094	499950	6015.4
2	0.1008	0.0081	0.0984	0.0077	502170	7272.9
3	0.1001	0.0067	0.0991	0.0052	498690	4952.5
4	0.1005	0.0056	0.0987	0.0048	501000	7684.6
5	0.1002	0.0070	0.0989	0.0053	499170	5594.9
6	0.1004	0.0059	0.0987	0.0053	500770	6923.3
7	0.0996	0.0056	0.0997	0.0053	495920	7729.1
8	0.0998	0.0065	0.0990	0.0062	497760	5331.6
9	0.0998	0.0056	0.0993	0.0057	497760	6960.5
10	0.1009	0.0056	0.0983	0.0063	510810	7297.2
11	0.1002	0.0052	0.0990	0.0065	507210	5390.8
12	0.1007	0.0056	0.0985	0.0053	509980	6765.3

Table A.4 Mean and Std for speed and steering angle

Table 5 and 6

The radius with different air pressures in the rear tyres and in table 6 the means.

Test num.	Air Pressure	Pulses Left	Pulses Right	Radius Left	Radius Right
1	1.2	940852	995816	0.1983	0.1873
2	1.2	973897	981373	0.1915	0.1901
3	1.2	973551	978054	0.1916	0.1907
4	0.8	966913	993887	0.1929	0.1877
5	0.8	980495	983293	0.1902	0.1897
6	0.8	976278	988496	0.1911	0.1887
7	0.6	985356	993369	0.1893	0.1878
8	0.6	965061	1004695	0.1933	0.1857
9	0.6	988108	991986	0.1888	0.1880

Table A.5 Radius with different air pressure

Air Pressure	Mean Radius Left	Mean Radius Right
1.2	0.1938	0.1893
0.8	0.1914	0.1887
0.6	0.1905	0.1872

Table A.6 Mean radius with different air pressure