User-Aided Tracking Robot

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Abstract

The use of domestic robots seems strikingly sparse in comparison to other fields of modern technology. It is plausible to assume that the lack of pull within the area is due to an unbalance between necessity and cost for the average customer, which in turn could be caused by a prevailing belief that complete autonomy is a must for a domestic robot. This thesis considers a simplified take on tracking and a robot that on the contrary is completely dependent on user involvement. Three sides to such an application were studied; the prospect of using infrared light for directional sensing, the difference in performance between infrared and ultrasonic distance-measurement and the complications that are related to omni-wheel maneuvering. The bulk of the research was conducted with the help of a robotic prototype that was constructed by the authors.

The outcome of the research boils down to three conclusions. Utilizing infrared communication in a long range while maintaining an angular reception field that is narrow poses many difficulties, it can however not be dismissed as a way of determining the desired direction of travel for the kind of tracking application that is considered. The results indicate that a distance-measuring sensor using ultrasonic sound performs more consistently than one using infrared light, wherefore ultrasonic technology is deemed to be preferable within the context. Finally, although a non-regulated motor-drive has an eminently negative affect on the dynamics of an omni-wheel setup, there is reason to believe that it would not pose an issue in a functioning tracking application.

From a broader perspective the outcome of this research might point a finger in a whole new direction of domestic robotics.
Sammanfattning

Plattformen för samarbete mellan användare och robot i en spårande tillämpning


Baserat på den utförda forskningen så har tre slutsatser kunnat dras. Riktad långdistans kommunikation med infrarött ljus har ej ästaddkommits, dock diskuteras potentiella sätt som ej undersökt. Resultaten påvisar att en ultraljuds avståndssensor fungerar mer konsekvent än infrarött ljus och anses därmed vara bäst lämpad för applikationen. En icke-reglerad motordrift har i högsta grad en negativ inverkan på funktionaliteten i omni-hjulsdynamiken, det finns dock skäl till att tro att denna problematik skulle kunna undvikas om logik som tillåter roboten att följa efter sin användare implementerats.

I ett större perspektiv strävar den här forskningen efter att kunna öppna en dörr för ett nytt sätt att se på konstruktionen av hushållsrobotar.
Preface

Among the things we have learnt throughout this bachelor, there is one on which we would like to shine a light. At the opening of the course we were told that solidarity and cooperation was one of the most prominent sides to mechatronics at KTH; looking back we can only confirm this notion. One wonders at the unlikely circumstances that somehow brought such an admirable group of people together. We would like to especially thank:

Tomas Östberg, for sharing his expertise and providing order where the rest is chaos.

Staffan Qvarnström, for being so helpful and patient.

Baha Alhaj Hassan, for his support and aid as supervisor.

Per Von Wowern and Ramtin Mass, for kindly teaching us everything we know about 3D-printing.

Beata Törneman and Mikaela Karlérus, for providing helpful and continuous feedback on the report.

All of the course assistants and fellow students who have made this semester a true delight.
## Contents

Abstract i

Sammanfattning ii

Preface iii

Nomenclature vi

1 Introduction 1

1.1 Background ........................................... 1
1.2 Purpose ............................................... 1
1.3 Scope ................................................ 2
1.4 Method ................................................ 3
1.4.1 Test - Distance Precision ......................... 3
1.4.2 Test - Various Distance Performance ............... 4
1.4.3 Test - Motor Deviation ............................ 4

2 Theory 6

2.1 Omni-wheel Dynamics ............................. 6
2.2 Motor Control ..................................... 8
  2.2.1 DC-motor ...................................... 8
  2.2.2 Pulse-width Modulation ......................... 9
  2.2.3 H-Bridge ...................................... 9
2.3 Microcontroller .................................. 11
2.4 Ultrasonic Sound .................................. 11
2.5 Infrared Light ................................... 12

3 Demonstrator 13

3.1 Hardware & Electronics ....................... 13
3.2 Software .......................................... 14
3.3 Design ............................................ 15

4 Results 17

4.1 Distance Measurement Performance ............. 17
4.2 Distance Measurement During Travel .......... 18
4.3 Straight Line Deviation .......................... 18
## CONTENTS

5 Discussion & Conclusions 19
  5.1 Discussion ........................................... 19
  5.2 Conclusions .......................................... 20

6 Future Work 21

Bibliography 23

A Test Two 24

B Ping Range Finder Datasheet 25

C Sharp 34
## Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V$</td>
<td>Velocity</td>
</tr>
<tr>
<td>$c_s$</td>
<td>Speed of sound</td>
</tr>
<tr>
<td>$d$</td>
<td>distance</td>
</tr>
<tr>
<td>$\kappa$</td>
<td>Specific heat constant</td>
</tr>
<tr>
<td>$K$</td>
<td>Kelvin</td>
</tr>
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</table>

## Abbreviations

<table>
<thead>
<tr>
<th>Abbreviations</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PWM</td>
<td>Pulse-width-modulation</td>
</tr>
<tr>
<td>DC</td>
<td>Direct current</td>
</tr>
<tr>
<td>CAD</td>
<td>Computer Aided Design</td>
</tr>
<tr>
<td>MCU</td>
<td>Microcontroller Unit</td>
</tr>
<tr>
<td>RAM</td>
<td>Random Access Memory</td>
</tr>
<tr>
<td>IDE</td>
<td>Integrated Development Environment</td>
</tr>
</tbody>
</table>
Chapter 1

Introduction

1.1 Background

The field of robotics seems to become increasingly targeted at domestic use, as suggested by products like automated vacuum cleaners and lawn mowers for instance. These types of applications share a plain purpose; relieving the user from tasks that are simple enough to be carried out by a robot. Despite the obvious intention of changing everyday life the cost of these devices tend to exceed everyday prices; thus there are signs of a conflict.

There seems to be a conviction that a robot is only requested when it is ready to carry out a task single-handedly, which demands a certain level of complexity. If the responsibilities of a domestic robot were to be partly replaced by involvement of the user, a much simpler robot could take form. The thought can be exemplified by a robot carrying groceries and following the shopper around; the user would be relieved from the weight but would still be inquired to go shopping.

This thesis is an attempt to investigate this matter, mainly with the aid of a demonstrator that will be constructed. Within the boundaries of the project there are many sides to the simplified domestic robot concept that could be considered, although the main focus of the research is tracking.

1.2 Purpose

The foundation of this research rests on two cornerstones:

1. The initial motive was a curiosity for a compromise between user and robot in handling tasks on a domestic level.

2. In accordance with possible application areas for the kind of domestic robot that has been discussed, the attempted function of the demonstrator was to follow a hand held IR-transmitting device and maintain a constant distance to the person holding the transmitter.

Within that frame the aim of this thesis lies in investigating the tracking side of a simplified domestic robot, a side which in turn comes with many
Introduction

aspects. Three of those aspects where deemed to be the most relevant for achieving a desirable tracking-behavior:

1. The ability to find the appropriate traveling-direction.
2. The ability to maintain an appropriate distance.
3. The ability to operate and maneuver in a smooth manner.

These ideas boil down to the actual purpose of this thesis, namely to find answers to the following research-questions:

"What are the possibilities of exclusively utilizing infrared sensors in a tracking application for identifying a desired direction of travel?"

"With respect to distance measuring accuracy, is infrared or ultrasonic distance measurement preferable for a simplified user-aided tracking robot?"

"How does a non-regulated motor-drive affect omni-wheel dynamics? What alternatives can be deemed preferable?"

1.3 Scope

There are many boundaries to this thesis that need to be taken into consideration. Because resources are limited, the research will be confined to comparing only one model of each distance measurement technology. Both models are of the cheaper kind, which in consequence limits the functional range of the demonstrator drastically to a maximum of one or two meters. Further, the demonstrator (and therefore all testing) will be limited to indoor use.

In a future application, a user-aided tracking robot would most likely draw benefit from some kind of obstacle-avoidance along its line of traversal, however there is no room for implementing such a function within this bachelor thesis. Instead it is assumed that the robot will only be signaled when there is a clear path to the user and that he or she will handle all obstacle avoidance while the robot merely follows at a close distance. In other words the scope is a robot that only tracks the user.

One of the main objectives of this research is to measure and identify a difference in application-performance depending on type of distance sensing.
Introduction

Naturally there is a limit to the scope of those results due to the specifics of the demonstrator itself. Therefore, eventual results are most definitely not to be taken as generally valid, but rather as an indication.

Further on the subject, the research has lead to results and conclusions that unfortunately are not equally measurable to those mentioned above. Despite their lacking measurability these results are still deemed to be worth including, although in a far more speculative manner. Therefore, these will be treated mainly in chapter 5.1 rather than 4.

1.4 Method

The studying of the desired tracking-behavior was conducted with the help of a demonstrator that was constructed specifically for the research. For a more detailed description of the demonstrator and the choices regarding its construction the reader is referred to chapter 3. The demonstrator was used for a series of tests that were designed to evaluate the performance of two different distance-sensing technologies and the capability of the chosen DC-motors within the context. All three tests were conducted in the same office environment and are accounted for below.

1.4.1 Test - Distance Precision

A simple form of comparison between two distance measuring sensors was performed by placing the demonstrator on known distances from a wall and extracting the mean of the distances measured by each of the sensors, one at a time. The test was conducted according to the following steps:

1. Placing the demonstrator 20 cm from the wall.

2. Extracting the mean value of the distance measured by the first sensor and calculating the percentual error.

3. Repeating steps 1 and 2 in every 10 cm distance between 20 and 200 cm.

4. Repeating the entire procedure with the second sensor.

5. Ploting the data with Matlab.
1.4.2 Test - Various Distance Performance

Taking the evaluation of the distance-measuring performance further, a test comparing the sensors in a scenario closer to a plausible future application was conducted. Distance was measured whilst driving the demonstrator forward, approaching a wall from a 2 meter distance and having the logic of the demonstrator call for an engine stop when the read distance was within a designated range(30, 60 and 90 cm). The test was conducted according to the following steps:

1. Placing the robot 2 meters from the wall, aligning the current measuring sensor with a strip of tape that acted as a guideline.
2. Initializing a forward motion and urging the sensor to measure every distance along the way until the designated distance is deemed to be reached by the sensor.
3. Extracting the measured distances along the way.
4. Repeating steps 1-3 twice and calculate the mean of the data.
5. Repeating steps 1-4 for the two other designated distances.
6. Repeating the entire procedure with the second sensor.
7. Plotting the data with Matlab.

1.4.3 Test - Motor Deviation

A functioning omni-wheel drive comes with the benefit of instantaneous movement in every direction, however it demands accurate mounting and more importantly that the motors can be controlled in accordance with the dynamics derived in section 2.1. The possibilities of living up to those requirements with DC-motors without using feedback are what this test sought to measure. A simple course was set up to test the demonstrator's capability of driving in a straight line in each of the six directions illustrated in figure 1.1.

The test was conducted according to the following steps:

1. Placing the demonstrator concentrically in one end of a two meter long strip of tape on the floor, aligning one of the six directions with the direction of the tape.
2. Urging the demonstrator to drive in the current forward direction using an IR-transmitting remote, stopping after having reached the end of the two meter long strip of tape.

3. Measuring the offset between the center of the tape and the rear end of the demonstrator.

4. Repeating steps 1-3 twice and extracting the mean offset.

5. Repeating the entire procedure for every other direction in figure 1.1.

The test-results are accounted for in chapter 4 and appendix A.
Chapter 2

Theory

2.1 Omni-wheel Dynamics

An omni-wheel allows movement in the direction perpendicular to that of its own rotation. This is made possible by smaller rollers mounted along the periphery of the main wheel. The principle is illustrated in figure 2.1.

![Figure 2.1: CAD-model of Omni-Wheel](image)

Because of their behaviour a robot using omni-wheels can move instantaneously in any direction it desires, hence being relieved of having fixed front and rear ends. On the downside, this benefit comes at the cost of having to control every wheel individually, raising the need for a separate motor and driver per wheel. The dynamics of a three omni-wheel drive are derived below.

Assume that three omni-wheels installed on DC-motors where mounted on the corners of an equilateral triangle in perfect symmetry. The system could then be reduced to the diagram in figure 2.2 (a), where $x$ and $y$ depict the orientational coordinates of the robot and the wheels $A$, $B$ and $C$ are respectively placed on $-60^\circ$, $60^\circ$ and $180^\circ$ angles relative to the $y$-axis. Each motor supplies a velocity vector $\vec{V}_x$ with a direction that is fixed relative to the $y$-axis. As a result of symmetry that direction will be $90^\circ$ greater than the already specified angle between wheel- and $y$-axis for every wheel. In accordance, the directions of $\vec{V}_A$, $\vec{V}_B$ and $\vec{V}_C$ are derived to $30^\circ$, $150^\circ$ and $270^\circ$ relative to the $y$-axis.

A desired velocity vector $\vec{V}_{\text{tot}}$ with the direction $\alpha$ relative to the $y$-axis
and the hereby defined magnitude $V$ is introduced in figure 2.2 (b). In order to achieve the desired velocity the vector sum of the particular motor contributions $\bar{V}_A$, $\bar{V}_B$ and $\bar{V}_C$ is required to be equal with $\bar{V}_{\text{tot}}$, which yields:

$$\bar{V}_{\text{tot}} = \bar{V}_A + \bar{V}_B + \bar{V}_C$$ (2.1)

The hence required magnitude of each motor contribution can be obtained by projecting the desired velocity vector on each fix velocity direction $30^\circ$, $150^\circ$ and $270^\circ$, as illustrated in figure 2.2 (b). The projection as such can be expressed mathematically as the cosine of the angle between the desired direction $\alpha$ and the fix direction of the current motor contribution, which yields

$$\bar{V}_A = V \cdot \cos(30 - \alpha)$$ (2.2)
$$\bar{V}_B = V \cdot \cos(150 - \alpha)$$ (2.3)
$$\bar{V}_C = V \cdot \cos(270 - \alpha)$$ (2.4)

where $V$ is the linear traveling speed. This means that for every given desired direction there is an appropriate contribution from every motor that will satisfy equation (2.1). These were computed in Matlab and are presented in figure 2.3 below.
2.2 Motor Control

2.2.1 DC-motor

Any mechanical component capable of converting direct current electrical power to mechanical power is a DC-motor. The basic principle of a DC-motor is illustrated below.

The DC-motor consists of a stator that provides a static magnetic field and a rotating armature made of coil connected to a power source through a pair of commutator rings. When a current is induced in the armature a magnetic field will arise. A resulting force causes the armature to rotationally align
its own magnetic field with the static one, hence achieving a mechanical movement. When the armature starts to rotate the commutator rings will connect to an opposite polarity of the power source, reversing the magnetic field in the armature just in time to ensure that the direction of torque remains the same throughout the whole motion.[2]

### 2.2.2 Pulse-width Modulation

The rotational speed of an electric motor is directly proportional to the effective voltage. The most intuitive way to adjust the rotational speed might be to use a rheostat to drop the voltage. The downside to this approach is that when the voltage drops over the resistor there is a consequential loss of heat, meaning that valuable energy is wasted. This problem can be avoided by using a technique called pulse-width modulation. The magnitude of that voltage is determined by the relation in time between on and off. This relation is referred to as the duty cycle and it is defined as:

\[
\text{Duty Cycle} = 100 \cdot \frac{\text{Pulse Width}}{\text{Period}} \tag{2.5}
\]

For example, consider a PWM-signal applying a duty cycle of 50%. In this case the effective voltage would be 50% of the maximum voltage available, as illustrated in figure below.

![Figure 2.5: Pulse-width modulation with 50% duty cycle](image)

As well as the rotational speed, the torque of the motor is proportional to the voltage, and since the PWM uses the maximum voltage in pulses there will not be any unnecessary loss in torque or energy, as in the case of a rheostat implementation.[3]

### 2.2.3 H-Bridge

A DC-motors rotational direction depends on how the current flows through the motors poles. Therefore, by regulating the currents direction the rota-
tion can be controlled. An h-bridge allows this behavior. Illustrated below is a basic schematic of the component.

![Basic H-bridge schematic](image)

Figure 2.6: Basic H-bridge schematic, where S depicts a transistor.

The currents path is determined by which transistors are on or off. Table 2.1 below shows how the motors rotation depends on the state of the transistors.

<table>
<thead>
<tr>
<th>S₁</th>
<th>S₂</th>
<th>S₃</th>
<th>S₄</th>
<th>Motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>Motor rotates right</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>Motor rotates left</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Motor coasts</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>Motor brakes</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>Motor brakes</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>Short circuit</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>Short circuit</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>Short circuit</td>
</tr>
</tbody>
</table>

Table 2.1: Operational logic for a DC-motor controlled with an H-bridge.
2.3 Microcontroller

In every product that can interact with or be controlled by a user there is a microcontroller (also called single-chip computer) of some sort. A microcontroller consist of the most basic parts of a computer. It has a processor, memory and input/output ports etcetera. Within the MCU are something called timers, each timer operates a number of the digital ports. These timers are used to clock the operations made, for example controlling the operational frequency of the ports who functions under said timer.[5]

2.4 Ultrasonic Sound

Sound is nothing more than a vibration propagating through a medium. A sound is deemed to be ultrasonic when that vibration is at a frequency that is higher than those perceivable to the human ear. Similar to sound at normal frequencies ultrasonic sound will bounce of a surface and produce an echo, which makes it suitable as means of judging distances. The technique occurs both in nature and in man made appliances and can be briefly explained as using the elapsed time between producing a sound pulse and receiving the echo for determining a distance. The principle is expressed mathematically below and is illustrated in appendix B. The velocity of sound, $c_s$, is determined according to equation 2.6.

$$c_s = \sqrt{\kappa \cdot R \cdot T} \quad (2.6)$$

Here $\kappa$ specifies the specific heat ration, $R$ the individual gas constant and $T$ the temperature measured in kelvin. Further, distance can be expressed as:

$$d = t \cdot v \quad (2.7)$$

Where $t$ denotes the elapsed time and $v$ the velocity. Since the sound travels to the object and then back to the speaker unit, the actual travelled distance will be twice the distance to the object. Therefore the distance can be obtained according to equation 2.8.

$$d_{object} = \frac{t_{sound}}{2} \cdot c_s \quad (2.8)$$
2.5 Infrared Light

The human eye can perceive light with wavelengths between 350 and 700 nm. However, there is a lot of light beyond those wavelengths, infrared light for instance lies just beyond the human reach, in the range 700 - 1000 nm. [6]

With a transmitter and receiver pair it is possible to communicate with infrared light. The transmitter sends a specific sequence of pulses depending on what action it wants the receiver to communicate. This is how the remote control can change the channel or adjust the volume on a TV. [7]

A infrared distance measurement sensor emits light and then calculates the distance to objects by the angle of the returning light [8]. The principle is illustrated below in figure 2.7.

Figure 2.7: Infrared distance measurement
Chapter 3
Demonstrator

The demonstrator will be used as means to conduct the measurements necessary to answering the research questions. This chapter covers practicalities regarding the demonstrator and the general construction.

3.1 Hardware & Electronics

The demonstrator will be equipped with two different sensors for distance measurement. One ultra sonic sound sensor named "Ping Distance Sensor" and one infrared sensor named "Sharp GP2Y0A02YK0F". For further information about the sensors the reader is referred to appendices B and C.

In order to assess the research question regarding the motor-drives affect on omni-wheel dynamics three Maxon DC-motors of type 327305 are used to drive the demonstrator. Unfortunately, no data sheets regarding these specific motors have been acquired since they were provided by the institution and the model could not be identified. In order to control each motor separately a driver circuit based on an exercise held by the institution was soldered. For further details regarding the circuit, a link to the institutions website can be found in the bibliography. The block diagram in figure 3.1 illustrates how parts and components are mounted and connected.

Figure 3.1: Blockdiagram
To process data and control the motors an Arduino Uno is used. The choice of MCU was based on the amount of ports needed and the necessary RAM and storage. The initial PWM-frequencies of the Arduino were altered due to disturbing sounds caused by motors operating within the human hearing range. This was achieved through a few simple changes to setup-code concerning the timers mentioned earlier in section reference to 2.3. Briefly explained, a timer is partly defined by a divisor that limits the operating frequency. By changing that number, the frequency-manipulations stated in table 3.1 were made.

<table>
<thead>
<tr>
<th>Timer</th>
<th>Pins</th>
<th>Initial Frequency</th>
<th>Set Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>D5 &amp; D6</td>
<td>976.56 Hz</td>
<td>62500 Hz</td>
</tr>
<tr>
<td>1</td>
<td>D9 &amp; D10</td>
<td>490.20 Hz</td>
<td>31372.55 Hz</td>
</tr>
<tr>
<td>2</td>
<td>D3 &amp; D11</td>
<td>490.20 Hz</td>
<td>–</td>
</tr>
</tbody>
</table>

Table 3.1: Manipulated Operating Frequencies

3.2 Software

The functionality of the demonstrator is achieved with a program that runs in the Arduino IDE environment with some additional C++ libraries.

To control the two distance measuring sensors, the main program uses open source libraries found on the web. Another library was written by the authors in order to control the motors in a compact and orderly fashion.

Infrared communication is achieved with a receiver and a remote controller which sends a modulated signal that varies with its different buttons. The code interprets the received signal and then executes the appropriate case based on the button that was being pushed. The functionality of the demonstrator is illustrated in figure 3.2 and explained below.

When a distance measuring sensor has been specified the demonstrator will allow itself to perform some kind of movement. When the user holds down a directional button on the remote control the appropriate motor contributions necessary to achieve that direction of travel are calculated. Depending on the designated and measured distance the demonstrator will either move in the users said direction or stand still. It is however always allowed to reverse so that the user can order it to move away from an object. Since this logic happens repeatedly the user will not be able to drive the demonstrator into an object whilst the sensor can see it.
3.3 Design

The demonstrator chassis consists of two 4 mm plywood plates that share the same triangular geometry and are separated using six M5 screws with corresponding nut. On the bottom of the base-plate three motor mounts have been symmetrically attached on the corners of the equilateral triangle that is the plate. With the help of CAD-software and 3D-printing the mounts were modelled and manufactured specifically for the model of Maxon DC-motors that were available at the institution.

Swift movement in every direction is a desirable trait for the kind of tracking robot that is regarded in this thesis. Taking that into consideration, the demonstrator features 3D-printed omni-wheels that similarly to the motor-mounts were developed for the project. For improved traction the rollers of the wheels were subsequently coated with rubber. The wheels themselves have been attached to the motors with aluminium hubs and stop-screws.

The base-plate also carries the three motor-driver circuits, the Arduino Uno and power supplies for the motors and the MCU. It is for protection of the
wiring and aesthetic reasons the identical top-plate is attached. Installed through fitted holes at the front of the top-plate there are two different distance-measuring sensors, one using ultrasonic sound and one using infrared light.
Chapter 4

Results

This chapter reveals the results yielded by the research, more or less divided into paragraphs based on what research question is being processed.

The performed research has not yet determined a beneficial way of using infrared reception as an indication to direction. All substantiated attempts to give the robot an indication of the direction of a user have either been dismissed because of lacking angle-wise precision or operational distances being far below what is reasonable for a functioning tracking application. In other words, studies where fruitless regarding the demonstrator and measurable results.

4.1 Distance Measurement Performance

The results of the test described in section 1.4.1 are plotted below in figure 4.1, where positive or negative percentual errors indicate whether the measured distance was shorter or longer than the actual value.

![Figure 4.1: Percentual error for each distance sensor](image-url)
4.2 Distance Measurement During Travel

The results of the test described in section 1.4.2 are rather extensive, wherefore the bulk of the data can be found in appendix A. Plotted below in figure 4.2 is the data extracted from one of the screenings.

![Distance Measurement Figure](image)

Figure 4.2: Distance measuring during the experiment

4.3 Straight Line Deviation

Finally the results of the test described in section 1.4.3 are illustrated below in table 4.1

<table>
<thead>
<tr>
<th>Degrees offset relative y [°]</th>
<th>Error [cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>41,5</td>
</tr>
<tr>
<td>60</td>
<td>11,5</td>
</tr>
<tr>
<td>120</td>
<td>38,5</td>
</tr>
<tr>
<td>180</td>
<td>81,5</td>
</tr>
<tr>
<td>240</td>
<td>38,5</td>
</tr>
<tr>
<td>300</td>
<td>46,5</td>
</tr>
</tbody>
</table>

Table 4.1: Straight line error, 2 meter drive.
Chapter 5
Discussion & Conclusions

5.1 Discussion

Regarding the comparison between the sensors there is a seemingly clear tendency; both sensors perform decently within short distances, but the results would support the claim that the ultrasonic sensor is a lot more stable than the infrared in longer ranges. For example, consider figure 4.2 where the ultrasonic sensor displays a more or less linearly decreasing distance throughout the entire screening, as should be the case when approaching a wall with a constant speed. The infrared sensor on the other hand only provides this behavior in an approximate range of 1 m.

Regarding the affect of using non-regulated DC-motors on the application, table 4.1 indicates a quite severe deviation from the attempted course. Minor defects in the triangular symmetry may play a part in that deviation, but due to the precautious measurements carried out during the mounting of the motors we find it far more likely that the deviation is caused by the simple fact that the motors simply can not perform identically to one another. This could likely be avoided by applying control-theory, either as encoders controlling the rotation of the motors or simply using servo-motors. Either way it is seemingly obvious that some kind of regulation or feedback is necessary for a precisely functioning use of omni-wheels.

However, if this discussion was to be contained within the frame of the research, an important question is raised; how precise does the maneuvering of a domestic tracker actually need to be? It is our opinion that it all comes down to a trade-off between the robot’s sense of direction and the preciseness of the motors. A tracking application that continuously (and more or less truthfully) feedbacks the error between the desired direction and the current one could likely handle the problems described above. The prospects of this approach are further discussed in section 6.
5.2 Conclusions

For the kind of tracking robot that is considered, an ultrasonic distance-sensor is deemed to be preferable.

Infrared light may be used as an exclusive means of directional indication in a tracking robot.

For a diversely functioning omni-wheel robot, DC-motors are not the most suitable choice. However, if the field of application was limited to only tracking, they are a good alternative.
Chapter 6

Future Work

In order for the prototype to identify the direction of the user, it is plausible that an infrared tracking camera could be used. Assuming that the handheld IR-transmitter would constitute one of the strongest sources of infrared light within the frame of the camera, our research on the subject indicates that such a camera could not only be used to determine a direction, but also differences in the targets position. Compared to the use of infrared receivers this would yield fewer components and give a more exact feedback on the position of the transmitter. The available resources were not sufficient for testing such a setup, wherefore no conclusion regarding the matter could be drawn. Undoubtedly however, there lies a substantial potential in implementing such a device on the considered tracking application. In a future study we would recommend to seek such a device in a Nintendo Wii-remote.

To ensure a more precise movement it would be a good idea to implement a so called encoder for the DC-motors. It could feedback the actual rotation of the wheels and combined with a regulator the quality of the movement would increase considerably.

As of now the functional potential of the omni-wheel have not been utilized to its maximum. With an infrared camera both x- and y-position would be known, by knowing the y-position a servomotor could be used in combination with an distance sensor and direct in so that the robot can be certain the read distance will be the user. Then using another distance sensor for obstacle avoidance, this would enable the robot to maintain the sensor targeted at the transmitter and avoid obstacles. This have been illustrated in figure 6.1. This kind of motion would be possible since a robot using omni-wheels are able to rotate and make an sideways offset simultaneously.
Figure 6.1: Obstacle avoidance with omni-wheel
Bibliography


Appendix A

Test Two

![Graphs showing distance vs. percentage of elapsed time for 30, 60, and 90 centimeters.]
Appendix B

Ping Range Finder Datasheet

PING))) Ultrasonic Distance Sensor (#28015)

The Parallax PING)))™ ultrasonic distance sensor provides precise, non-contact distance measurements from about 2 cm (0.8 inches) to 3 meters (3.3 yards). It is very easy to connect to microcontrollers such as the BASIC Stamp®, Propeller chip, or Arduino, requiring only one I/O pin.

The PING))) sensor works by transmitting an ultrasonic (well above human hearing range) burst and providing an output pulse that corresponds to the time required for the burst echo to return to the sensor. By measuring the echo pulse width, the distance to target can easily be calculated.

Features
- Range: 2 cm to 3 m (0.8 in to 3.3 yd)
- Burst indicator LED shows sensor activity
- Bidirectional TTL pulse interface on a single I/O pin can communicate with 5 V TTL or 3.3 V CMOS microcontrollers
- Input trigger: positive TTL pulse, 2 µs min, 5 µs typ.
- Echo pulse: positive TTL pulse, 115 µs minimum to 18.5 ms maximum.
- RoHS Compliant

Key Specifications
- Supply voltage: +5 VDC
- Supply current: 30 mA typ; 35 mA max
- Communication: Positive TTL pulse
- Package: 3-pin SIP, 0.1” spacing (ground, power, signal)
- Operating temperature: 0 – 70° C.
- Size: 22 mm H x 46 mm W x 16 mm D (0.84 in x 1.8 in x 0.6 in)
- Weight: 9 g (0.32 oz)

Pin Definitions

<table>
<thead>
<tr>
<th>Pin</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GND</td>
<td>Ground (Vss)</td>
</tr>
<tr>
<td>5 V</td>
<td>5 VDC (Vdd)</td>
</tr>
<tr>
<td>SIG</td>
<td>Signal (I/O pin)</td>
</tr>
</tbody>
</table>

The PING))) sensor has a male 3-pin header used to supply ground, power (+5 VDC) and signal. The header may be plugged into a directly into solderless breadboard, or into a standard 3-wire extension cable (Parallax part #800-00120).
Communication Protocol

The PING))) sensor detects objects by emitting a short ultrasonic burst and then "listening" for the echo. Under control of a host microcontroller (trigger pulse), the sensor emits a short 40 kHz (ultrasonic) burst. This burst travels through the air, hits an object and then bounces back to the sensor. The PING))) sensor provides an output pulse to the host that will terminate when the echo is detected, hence the width of this pulse corresponds to the distance to the target.

<table>
<thead>
<tr>
<th>Host Device</th>
<th>Input Trigger Pulse</th>
<th>t&lt;sub&gt;UT&lt;/sub&gt;</th>
<th>2 µs (min), 5 µs typical</th>
</tr>
</thead>
<tbody>
<tr>
<td>PING))) Sensor</td>
<td>Echo Holdoff</td>
<td>t&lt;sub&gt;HOLD&lt;/sub&gt;</td>
<td>750 µs</td>
</tr>
<tr>
<td></td>
<td>Burst Frequency</td>
<td>t&lt;sub&gt;BURST&lt;/sub&gt;</td>
<td>200 µs @ 40 kHz</td>
</tr>
<tr>
<td></td>
<td>Echo Return Pulse Minimum</td>
<td>t&lt;sub&gt;MIN&lt;/sub&gt;</td>
<td>115 µs</td>
</tr>
<tr>
<td></td>
<td>Echo Return Pulse Maximum</td>
<td>t&lt;sub&gt;MAX&lt;/sub&gt;</td>
<td>18.5 ms</td>
</tr>
<tr>
<td></td>
<td>Delay before next measurement</td>
<td></td>
<td>200 µs</td>
</tr>
</tbody>
</table>
Practical Considerations for Use

Object Positioning
The PING))) sensor cannot accurately measure the distance to an object that: a) is more than 3 meters away, b) that has its reflective surface at a shallow angle so that sound will not be reflected back towards the sensor, or c) is too small to reflect enough sound back to the sensor. In addition, if your PING))) sensor is mounted low on your device, you may detect sound reflecting off of the floor.

Target Object Material
In addition, objects that absorb sound or have a soft or irregular surface, such as a stuffed animal, may not reflect enough sound to be detected accurately. The PING))) sensor will detect the surface of water, however it is not rated for outdoor use or continual use in a wet environment. Condensation on its transducers may affect performance and lifespan of the device.

Air Temperature
Temperature has an effect on the speed of sound in air that is measurable by the PING))) sensor. If the temperature (°C) is known, the formula is:

\[ c_{\text{air}} = 331.5 + (0.6 \times T_{\text{C}}) \text{ m/s} \]

The percent error over the sensor's operating range of 0 to 70 °C is significant, in the magnitude of 11 to 12 percent. The use of conversion constants to account for air temperature may be incorporated into your program (as is the case in the example BS2 program given in the Example Programs section below). Percent error and conversion constant calculations are introduced in Chapter 2 of Smart Sensors and Applications; a Stamps in Class text available for download from the 28029 product page at www.parallax.com.
Test Data

The test data on the following pages is based on the PING))) sensor, tested in the Parallax lab, while connected to a BASIC Stamp microcontroller module. The test surface was a linoleum floor, so the sensor was elevated to minimize floor reflections in the data. All tests were conducted at room temperature, indoors, in a protected environment. The target was always centered at the same elevation as the PING))) sensor.

Test 1

Sensor Elevation: 40 in. (101.6 cm)
Target: 3.5 in. (8.9 cm) diameter cylinder, 4 ft. (121.9 cm) tall – vertical orientation
Test 2
Sensor Elevation: 40 in. (101.6 cm)
Target: 12 in. x 12 in. (30.5 cm x 30.5 cm) cardboard, mounted on 1 in. (2.5 cm) pole
Target positioned parallel to backplane of sensor
Example Programs

BASIC Stamp 2

This circuit allows you to quickly connect your PING))) sensor to a BASIC Stamp® 2 via the Board of Education® breadboard area. The PING))) module's GND pin connects to Vss, the 5 V pin connects to Vdd, and the SIG pin connects to I/O pin P15. This circuit will work with the example BASIC Stamp program listed below.

Extension Cable and Port Cautions for the Board of Education

If you are connecting your PING))) sensor to a Board of Education platform using an extension cable, follow these steps:

1. When plugging the cable onto the PING))) sensor, connect Black to GND, Red to 5 V, and White to SIG.
2. Check to see if your Board of Education servo ports have a jumper, as shown at right.
3. If your Board of Education servo ports have a jumper, set it to Vdd as shown. Then plug the cable into the port, matching the wire color to the labels next to the port.
4. If your Board of Education servo ports do not have a jumper, do not use them with the PING))) sensor. These ports only provide Vin, not Vdd, and this may damage your PING))) sensor. Go to the next step.
5. Connect the cable directly to the breadboard with a 3-pin header as shown above. Then, use jumper wires to connect Black to Vss, Red to Vdd, and White to I/O pin P15.

Board of Education Servo Port Jumper, Set to Vdd
Example Program: PingMeasureCmAndIn.bs2

This program for the BASIC Stamp 2 displays distance measurements in both inches and centimeters in the BASIC Stamp Debug Terminal. The example program can be downloaded from the 28015 product page at www.parallax.com. The BASIC Stamp Editor software, which includes the Debug Terminal, is a free download from www.parallax.com/basicstampsoftware.

`:Smart Sensors and Applications - PingMeasureCmAndIn.bs2
:Measure distance with Ping))) sensor and display in both in & cm
:(BASIC Stamp 2)
:(SPABASIC 2.5)
:Conversion constants for room temperature measurements.
:CmConstant CON 2260
:InConstant CON 890
:cmDistance VAR Word
:inDistance VAR Word
:time VAR Word
:DO
:  PULSOUT 15, 5
:  PULSIN 15, 1, time
:  cmDistance = CmConstant ** time
:  inDistance = InConstant ** time
:  DEBUG HOME, DEC3 cmDistance, " cm"
:  DEBUG CR, DEC3 inDistance, " in"
:  PAUSE 100
:LOOP

APPENDIX B. PING RANGE FINDER DATASHEET
Interface to Ping))) sensor and measure its ultrasonic travel time. Measurements can be in units of time or distance. Each method requires one parameter, Pin, that is the I/O pin that is connected to the Ping)))'s signal line.

Connection to Propeller

Remember Ping))) Requires +5V Power Supply

---REVISION HISTORY---
v1.1 - Updated 03/10/2007 to change SIG resistor from 10K to 1K

CON
TO_IN = 73_746                                              ' Inches
TO_CM = 29_034                                              ' Centimeters

PUB Ticks(Pin) : Microseconds | cnt1, cnt2
' Return Ping)))'s one-way ultrasonic travel time in microseconds
outa[Pin]~                                                  ' Clear I/O Pin
outa[Pin]~                                                  ' Set I/O Pin
waitpne(0, |< Pin, 0)                                       ' Wait For Pin To Go HIGH
waitpeq(0, |< Pin, 0)                                       ' Wait For Pin To Go LOW
cnt1 := cnt                                                 ' Store Current Counter Value
Microseconds := (||(cnt1 - cnt2) / (clkfreq / 1_000_000)) >> 1    ' Return Time in μs

PUB Inches(Pin) : Distance
' Measure object distance in inches
Distance := Ticks(Pin) * 1_000 / TO_IN                       ' Distance In Inches

PUB Centimeters(Pin) : Distance
' Measure object distance in centimeters
Distance := Millimeters(Pin) / 10                            ' Distance In Centimeters

PUB Millimeters(Pin) : Distance
' Measure object distance in millimeters
Distance := Ticks(Pin) * 10_000 / TO_CM                      ' Distance In Millimeters
The ping.spin object is used in an example project with the Parallax 4 x 20 Serial LCD (#27979) to display distance measurements. The complete Project Archive can be downloaded from the Propeller Object Exchange at http://obex.parallax.com. The Propeller Tool software can be downloaded from www.parallax.com/propellertool.

Parallax Propeller Chip Project Archive
Project : "ping_demo"
Archived : Tuesday, December 18, 2007 at 3:29:46 PM
Tool : Propeller Tool version 1.05.8

ping_demo.spin
│
│├── Debug_Lcd.spin
││
││├── Serial_Lcd.spin
│││
│││├── Simple_Serial.spin
│││└── Simple_Numbers.spin
││└── ping.spin

Resources and Downloads
For additional example code downloads and links to videos, tutorials and robotics projects that use the Ping))) Ultrasonic Distance Sensor, visit www.parallax.com and search "28015."

Product Change Notice
Rev A: original release
Rev B: resonator added to the SX-28 co-processor circuit. No changes to functionality
Rev C: SX-28 co-processor changed to PIC16F57. No changes to functionality.

Revision History
Appendix C

Sharp

GP2Y0A02YK0F
Distance Measuring Sensor Unit
Measuring distance: 20 to 150 cm
Analog output type

Description
GP2Y0A02YK0F is a distance measuring sensor unit, composed of an integrated combination of PSD (position-sensitive detector), IRED (infrared emitting diode) and signal processing circuit. The variety of the reflectivity of the object, the environmental temperature and the operating duration are not influenced easily to the distance detection because of adopting the triangulation method. This device outputs the voltage corresponding to the detection distance. So this sensor can also be used as a proximity sensor.

Features
1. Distance measuring range : 20 to 150 cm
2. Analog output type
3. Package size: 29.5×13×21.6 mm
4. Consumption current : Typ. 33 mA
5. Supply voltage : 4.5 to 5.5 V

Agency approvals/Compliance
1. Compliant with RoHS directive (2002/95/EC)

Applications
1. Touch-less switch (Sanitary equipment, Control of illumination, etc.)
2. Sensor for energy saving (ATM, Copier, Vending machine, Laptop computer, LCD monitor)
3. Amusement equipment (Robot, Arcade game machine)

Agency approvals/Compliance
1. Compliant with RoHS directive (2002/95/EC)

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Sheet No.: E4-A00101EN
Date Dec.01.2006
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**Block diagram**

- Signal processing circuit
- Voltage regulator
- Oscillation circuit
- Output circuit
- LED drive circuit

**Outline Dimensions**

- Terminal Symbol
  - Output terminal voltage: \( V_{O} \)
  - Ground: \( GND \)
  - Supply voltage: \( V_{CC} \)

**Notes**:
1. Unspecified tolerances shall be ± 0.3 mm.
2. The connector is made by J.S.T.TRADING COMPANY,LTD. and its part number is S3B-PH.
3. The dimensions in parenthesis are shown for reference.
4. The dimension marked by "*" shows a distance from/to the center of an internal optical slit.

**Production details**

- Production month: Jan. to Sep.; 1 to 9, Oct.; X, Nov.; Y, Dec.; Z
- Production year: Last digit of year

**Terminal Symbol**

- ① Output terminal voltage: \( V_{O} \)
- ② Ground: \( GND \)
- ③ Supply voltage: \( V_{CC} \)

**Product mass**: approx. 4.8g
### Absolute Maximum Ratings

(Ta=25°C, VCC=5V)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Rating</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage</td>
<td>VCC</td>
<td>-0.3 to +7 V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output terminal voltage</td>
<td>VO</td>
<td>0.2 to VCC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating temperature</td>
<td>Topr</td>
<td>-10 to +60 C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storage temperature</td>
<td>Tstg</td>
<td>-40 to +70 C</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Electro-optical Characteristics

(Ta=25°C, VCC=5V)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Conditions</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average supply current</td>
<td>Icc</td>
<td>L=150cm (Note 1)</td>
<td>—</td>
<td>33</td>
<td>50</td>
<td>mA</td>
</tr>
<tr>
<td>Measuring distance range</td>
<td>ΔL</td>
<td>(Note 1)</td>
<td>20</td>
<td>100</td>
<td>300</td>
<td>cm</td>
</tr>
<tr>
<td>Output voltage</td>
<td>VO</td>
<td>L=150cm (Note 1)</td>
<td>0.25</td>
<td>0.4</td>
<td>0.75</td>
<td>V</td>
</tr>
<tr>
<td>Output voltage differential</td>
<td>ΔVv</td>
<td>Output voltage difference between L=20cm and L=150cm (Note 1)</td>
<td>1.8</td>
<td>2.05</td>
<td>2.3</td>
<td>V</td>
</tr>
</tbody>
</table>

* L : Distance to reflective object

Note 1 : Using reflective object : White paper (Made by Kodak Co., Ltd. gray cards R-27: white face, reflectance: 90%)

### Recommended operating conditions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Rating</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage</td>
<td>Vcc</td>
<td>4.5 to 5.5 V</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

APPENDIX C. SHARP

GP2Y0A02YK0F
Fig. 1 Timing chart
Fig. 2 Example of distance measuring characteristics (output)

- White paper (Reflectance ratio: 90%)
- Gray paper (Reflectance ratio: 18%)

Distance to reflective object L [cm]

Output voltage [V]

Inverse number of distance [1/cm]

0 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.1

White paper (Reflectance ratio: 90%)
Gray paper (Reflectance ratio: 18%)

Sheet No.: E4-A00101EN

APPENDIX C. SHARP
**Notes**

- **Advice for the optics**
  - The lens of this device needs to be kept clean. There are cases that dust, water or oil and so on deteriorate the characteristics of this device. Please consider in actual application.
  - Please don’t do washing. Washing may deteriorate the characteristics of optical system and so on.
  - Please confirm resistance to chemicals under the actual usage since this product has not been designed against washing.

- **Advice for the characteristics**
  - In case that an optical filter is set in front of the emitter and detector portion, the optical filter which has the most efficient transmittance at the emitting wavelength range of LED for this product ($\lambda = 850 \pm 70$nm), shall be recommended to use. Both faces of the filter should be mirror polishing. Also, as there are cases that the characteristics may not be satisfied according to the distance between the protection cover and this product or the thickness of the protection cover, please use this product after confirming the operation sufficiently in actual application.
  - In case that there is an object near to emitter side of the sensor between sensor and a detecting object, please use this device after confirming sufficiently that the characteristics of this sensor do not change by the object.
  - When the detector is exposed to the direct light from the sun, tungsten lamp and so on, there are cases that it can not measure the distance exactly. Please consider the design that the detector is not exposed to the direct light from such light source.
  - Distance to a mirror reflector can not be sometimes measured exactly.
  - In case of changing the mounting angle of this product, it may measure the distance exactly.
  - In case that reflective object has boundary line which material or color etc. are excessively different, in order to decrease deviation of measuring distance, it shall be recommended to set the sensor that the direction of boundary line and the line between emitter center and detector center are in parallel.
  - In order to decrease deviation of measuring distance by moving direction of the reflective object, it shall be recommended to set the sensor that the moving direction of the object and the line between emitter center and detector center are vertical.

- **Advice for the power supply**
  - In order to stabilize power supply line, we recommend to insert a by-pass capacitor of $10\mu F$ or more between Vcc and GND near this product.

- **Notes on handling**
  - There are some possibilities that the internal components in the sensor may be exposed to the excessive mechanical stress. Please be careful not to cause any excessive pressure on the sensor package and also on the PCB while assembling this product.
● Presence of ODC etc.
This product shall not contain the following materials.
Regulated substances: CFCs, Halons, Carbon tetrachloride, 1,1,1-Trichloroethane (Methylchloroform)
Specific brominated flame retardants such as the PBB and PBDE are not used in this product at all.

This product shall not contain the following materials banned in the RoHS Directive (2002/95/EC).
• Lead, Mercury, Cadmium, Hexavalent chromium, Polybrominated biphenyls (PBB),
Polybrominated diphenyl ethers (PBDE).
Package specification

MAX. 50 pieces per tray
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   - Office automation equipment
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   - Industrial control
   - Audio-visual equipment
   - Consumer electronics

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   - Traffic signals
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   - Alarm equipment
   - Various safety devices, etc.

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