RC-glove

Controlling objects with finger movements

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Abstract

This project will research if haptic technology can be an alternative way to control remote machines. Therefore a robot formed as a car is built to see if finger movements can be used to control the robot using RF signals. The controller has a shape of a glove and mounted on the hand. When bending the middle finger, a flex sensor will also be bent. When the flex sensor is bent different analog values will be produced because of the change in resistance. An IMU is placed on the thumb and when moving the thumb up and down, the angle is measured and determinate how the robot will turn. To gain accurate results from the IMU, a Kalman filter is used.

The purpose of the project is to observe how accurate and precise a robot can be controlled by using finger movements. One factor that affects this is the time delay between the communication with the controller and the robot. Therefore this project will study the time delay and how the delay will affect the control of the robot. The user friendliness will also be judged by letting different test people drive the robot using the RC-glove.

The result gave that when the driver has gain experience, the controller works well except for reversing the robot which can be problematic. The time delay is unnoticeable by the method used in this project. Further research will be needed to get a clear answer on how the delay effects the movement of the car.
Sammanfattning

RC-handske


Syftet med projektet är att se hur noggrant och precist en robot kan styras med hjälp av fingerrörelser. En faktor som påverkar detta är tidsfördröjningen mellan kommunikationen med styrenheten och roboten. Därför kommer det här projektet att studera tidsfördröjningen och hur fördröjningen kommer att påverka styrningen av roboten. Användarvänligheten kommer också att bedömas genom att låta olika personer testa att köra roboten med hjälp av RC-handsken.

Resultatet gav att när föraren har fått erfarenhet fungerar styrningen bra förutom att backa roboten vilket kan vara problematiskt. Tidsfördröjningen är inte märkbar med den metod som används i detta projekt. En vidare undersökning kommer att behövas för att få ett tydligt svar på hur fördröjningen påverkar kontrollen av bilen.
Preface

We want to thank our supervisor Didem Gürdür for giving good discussion, ideas and feedback to our project. We also want to thank the lab assistance for providing help when we needed and the persons who tested our project.

Tobias Nilsson and Oskar Öman
Stockholm, May, 2016
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## Nomenclature

### Symbols

<table>
<thead>
<tr>
<th>Symbols</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>s</td>
<td>Seconds (s)</td>
</tr>
<tr>
<td>Hz</td>
<td>Frequency (1/s)</td>
</tr>
<tr>
<td>g</td>
<td>Gravitational force (m/s²)</td>
</tr>
<tr>
<td>dps</td>
<td>Degress per second (1/s)</td>
</tr>
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### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>RF</td>
<td>Radio frequency</td>
</tr>
<tr>
<td>IMU</td>
<td>Inertial measurement unit</td>
</tr>
<tr>
<td>RC</td>
<td>Radio control</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
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</table>
Chapter 1

Introduction

This chapter gives an introduction to the project and what the project will try to accomplish.

1.1 Background

Industries often use remote controls to navigate machines such as cranes, locomotives, material handling equipment, mining machinery, mobile equipment, shiploaders and agricultural machinery. Using remote controls makes the task safer for the operator. These controllers are usually joysticks or buttons, however this project will research if there is an alternative way to control these types of machines.

Haptic technology can most easily be described as sensing the information that is given and feeling the response. Haptic control is controlling a machine or virtual object through touch and body movements. Some applications for this technology is surgical robots in medicine or in training for tasks that requires hand-eye coordination, like space ship manoeuvres [Divya Jyothi B. and Krishnaiah R. V, 2013].

This project will use a very simple form of haptic control that through the orientation of the fingers controls the robot, but has only visual feedback. Meaning the robot drives like a normal RC-car but the information given is haptic.

There are some similar projects that have the same base idea as this project, however the approach on how to maneuver the robot is different. One example is a project named SudoGlove [Blum Jeremy, 2010]. Instead of using a IMU to steer the robot, force sensors is used instead.

The idea of this project is to make a controller that is like an extension of the body and therefore be easier and more intuitive to use than regular controllers. With a stable and straight arm, a controller could be put there to drive robotic warehouse cart or control other robotic machinery. Alternatively the RC-glove could just be a
new fun way to drive a toy car during the summer.

### 1.2 Purpose

The purpose of the project is to research how accurate and precise a unit can be controlled by finger movements. With this information, hopefully a better and with more precise control of remote object can be found. This can be used for example remote maintenance of an space ship without risking human lives.

For this project a small robot is controlled and the research question is:

- What is the time delay between the robot and the controller, and how will the time delay effect the speed regulation and steering of the robot?

- Is the RC–glove easier and more intuitive to use when speed regulating and steering?

### 1.3 Scope

This project will be mostly studied in a indoor environment. This is because indoors there are less interference with other RF signals and eliminating the environment factor to get more reliable results. For communication between the two units, RF signal is chosen because RF is believed to be the most efficient and is also often used in other applications such as RC cars.

For this project, two fingers is used to control the robot because only two degrees of freedom is studied. These are forward and backward movement and turning left and right.

### 1.4 Method

In this project, a small RC-robot and a controller with the shape of a glove is built to see if finger movements would be able to maneuver the robot like a regular joystick would do.

To make this work, an IMU is placed on the thumb that is then held perpendicular to the other finger which are straight. By moving the thumb up and down an angle between the hand and the thumb is measured by the IMU(see figure 1.1). The angle decides how the PWM should be distributed between the motors on the left and the right side of the robot. A higher angle means that the right side have a lower PWM then the left side and therefore the robot will turn right and vice versa when turning left.
1.4. METHOD

![Images of hand movements](image1)

(a) Left turn  (b) Straight forward  (c) Right turn

Figure 1.1: Picture of hand movements on how to control the robot

To regulate the speed, a flex sensor is placed along the middle finger. Depending on how much the middle finger is bent, different speed is obtained because the resistance change in the flex sensor is measured as a analog reading.

Finally to set the robot on reverse, a tilt switch is placed on top of the hand. By tilting the hand at a certain degree, a switch will trigger. When triggered, a signal will be sent to robot to reverse the pole, which is done by a H-bridge, and therefore will decide whether the robot will go backward or forward depending on current direction.
Chapter 2

Theory

This chapter summarizes the theory behind the project

2.1 Haptic technology

The word Haptic comes from the Greek word "haptesthai" and means touch. The hand, which is the primary structure associated with touch is extremely complex and therefore hard to replicate in a form of a machine. The hand has 27 bones and 40 muscles which offers a extraordinary movement capabilities. In total, the hand can move in 22 degrees of freedom because one joint is considered as a degree of freedom, and the hand has 22 of them [Divya Jyothi B. and Krishnaiah R. V, 2013][Harris William, 2008].

There is two main categories in haptic technology, force feedback and tactile feedback. Force feedback has passively existed for many years for example in gaming. For instance, vibrations in console controllers or the force feedback when turning a racing wheel controller are examples of haptic technology. Tactile feedback describes the surface properties such as roughness, smoothness and temperature [Divya Jyothi B. and Krishnaiah R. V, 2013][Harris William, 2008].

There are several ways to create a haptic system however all of them have two things in common, the software to determinate the forces that result when a user's virtual identity interacts with an object and a device through which those forces can be applied to the user. The software that preform the calculations is called haptic rendering [Harris William, 2008].

2.2 Radio frequency

Radio frequency is defined as any electromagnetic wave frequencies that lies within the range around 3 kHz to 300 GHz [Merriam-Webster, ]. Frequency used for communication and radio lies within this spectrum. Even though radio frequency
is a rate of oscillation, which is usually electric, the term radio frequency are used as a synonym for radio and is used in wireless communication [Marshall Brain, 2000].

In radio communication two components are needed, a transmitter and a receiver. The transmitter creates a wave at a specific frequency, which is amplified and transmitted through the antenna. However, because there are many waves with different frequencies constantly drifting in the air from all kind of sources, a receiver is needed to isolate a specific frequency. An example of these sources are radio stations [Marshall Brain, 2000].

For the receiver to be efficient, an antenna is needed. The antenna function is to act as a rod and interact with the waves in the air. The simplest of antennas is a metal wire pointing up in the air which increase the amount of area the waves can interact with [Marshall Brain, 2000].

To be able to specify one particular frequency, a tuner is implemented. The tuner works using a principal called resonance. The theory behind this principal is that the tuner has a component which has a natural frequency which corresponds to the frequency that is needed. The component will then start to resonate and replicate that wave that the transmitter transmitted [Marshall Brain, 2000].

The radio spectra has a huge interval and is therefore divided into bands to prevent interference which can be seen in figure 2.1. Each band is used for different purposes. For example the lowest band which range between 3-30 Hz is used for submarine communication while the highest band (30-300 Ghz) is used in radio astronomy and directed energy weapons [Marshall Brain, 2000].

![Figure 2.1](image)

Figure 2.1: Figure shows the band of the radio spectrum and potential uses for every band.
2.3 IMU

An IMU is a gyroscope and an accelerometer combined and in some cases also magnetometers. This is necessary to acquire accurate measurements of angles and forces. The reason why you need both an accelerometer and a gyro, even if both is capable to measuring angles, is that the accelerometers readings tends to be unstable for shorter timespans but accurate for longer timespans. However the gyroscope has the opposite effect that the gyroscope is accurate in shorter timespans but drifts over time. When combining them you can get very accurate readings of angles\cite{KingA.D,1998}.

IMU are ofter used in aircraft, drones or other vehicles to help them navigate and maneuver. IMU’s can also be used to enhance an GPS by making the GPS able to work without GPS-signals, or when there are lot of interference. To maximize the effects and uses of an IMU, a Kalman filter is needed to synchronise the different components in the IMU\cite{KingA.D,1998}.

2.4 Kalman filter

Kalman filter is often used in engineering and embedded systems because the Kalman filter is a good and effective way to filter out unwanted noise, for instance in radio communication. Kalman filter is a tool that estimates variables in a wide range of processes and in theory is the most effective way to minimize the variance of the estimation error of all the filters that exists today\cite{SimonDan,2001}.

In order to use the Kalman filter the system must be linear and therefore can be described by two equations,

\begin{eqnarray}
    x_{k+1} &=& Ax_k + Bu_k + w_k, \quad (2.1) \\
    y_k &=& Cx_k + z_k, \quad (2.2)
\end{eqnarray}

where $A,B$ and $C$ are matrices that represents the system, $k$ is the time index, $x$ is the state of the system, $u$ is the known input to the system, $y$ is the measured output and $w$ and $z$ are the noise. The variable $w$ is referred as the process noise and $z$ as the measurement noise. Equation $2.1$ describe the state of the system while $2.4$ is the measured output in terms of $x$\cite{SimonDan,2001}.

To acquire an accurate estimation of the true state, two condition must be met. One is that the average value of the estimated state shall be equal to the average of the true state. In other words, the expected value of the estimated state shall be equal to the expected value of the true state. The second condition is that the estimator shall have the smallest possible variance. To achieve this the assumption of that the average value of $w$ and $z$ is zero and that there are no correlation between
$w$ and $z$ [Simon Dan, 2001].

From this statement a Kalman gain can be calculated which determine if the measurement can be trusted. A high value of the Kalman gain indicates that the measurement can be trusted and vice versa [Simon Dan, 2001].
Chapter 3

Demonstrator

This chapter describes both the developed demonstrator and the work process to the final result.

3.1 Problem Formulation

The goal for the demonstrator is to be able to go through man made obstacle course as fast as possible without colliding with an obstacle. To be able to achieve this, certain problems has to be solved:

- Sending multiple signals via RF.
- How to efficiently determinate the PWM value on the right and left side using the sensor data
- Optimize the sensitivity for how the car will turn.

3.2 Software

The software consists of two parts which are programed on two different Arduino UNO’s. One of them is on the glove and controls the reading of sensor data and sending the data to the robot. To begin with the software reads the data from the IMU and the flex sensor. To extract the raw data from the IMU a special library that Sparkfun made is used. From the IMU data two angles are calculated, one based on the accelerometer and the other from the gyroscope. These angles are then implemented in the Kalman filter and a new more accurate representation of the angle is given, which is sent together with the analog reading on the flex sensor to the other Arduino UNO on the robot.

After reading the data the software checks if the tilt switch has been triggered. If so, the program sends a signal to tell the robot to reverse the poles on the motors. If the emergency brake has been activated, which is done by pressing a button on the glove, the program sends a signal to stop the robot.
Second part is on the robot’s Arduino UNO and it receives the signal from the
glove and translate them into commands for the robot. The analog value of the flex
sensor is translated into a PWM value by mapping the analog value in an interval
between the lowest acceptable value to the maximum value that can be achieved
by clenching a fist. The lowest acceptable value is set to a number that is a little
higher then when having a straight palm.

The angle determinants how much the PWM is going to the left or to the right
motors. First, a interval for when the robot goes straight is determinate which has
a range of six degrease. When the angle falls below the interval, the PWM on the
right motors is kept constant which is determinate by the flex sensor and the PWM
on the left motors decrease to the minimum PWM that the motor can drive with.
As a consequence the robot turns left. The same principle applies when the angle
is higher then the interval but vice versa.
3.2. SOFTWARE

3.2.1 Libraries

To make the code function properly, three libraries is necessary. These are Virtual Wire, a Kalman filter library and a Sparkfun library.
Virtual wire is a Arduino library that makes the Arduino able to send short messages without addressing, retransmit or acknowledgment. This make the process easier to use and is usable with low cost RF transmitter and receivers. The range of the signal is a distance of maximum 150 meter. Because this library uses timer 1 on the Arduino, digital pin 9 and 10 is not usable [McCauley Mike, 2013] [Lauszus Kristian, 2013].

The Kalman filter library contains all the necessary matrices and functions to able to filter out the correct angle from the IMU [Lauszus Kristian, 2012].

### 3.3 Electronics

This section will have a short description on what electronics parts is used and what the parts are for. There are six parts in total, split between the glove and the robot. On the glove is the RF transmitter, flex sensor, IMU and one of the Arduino UNO’s. The robot consists of the RF receiver, the H-bridge motor driver and the other Arduino UNO.

![Figure 3.3: Schematic that shows how the different components are connected on the glove](image1)

![Figure 3.4: Schematic that shows how the different components are connected on the robot excluding the motors and the H-bridge](image2)

#### 3.3.1 RF transmitter and receiver

The RF transmitter and receiver functions is to communicate between the two Arduino UNO’s. The transmitter takes the data from the IMU and sends the data
3.3. ELECTRONICS

as a digitalized byte. The frequency the data is sent through is 433 MHz because the transmitter is a RCT-433 model which is made to send at that specific frequency. The receiver picks up the byte and translates the byte into the original data sent by the transmitter.

3.3.2 Flex sensor

To determine the speed of the robot, a flex sensor is used. The theory behind this sensor is that the sensor has a base resistance of about 10 kΩ, but this value increases as the sensor is bending. Depending on the resistance of the flex sensor, a series of different analog values can be read. Therefore this is an efficient way to regulate the speed [Spectra symbol, 2009].

3.3.3 Arduino UNO

This project uses two Arduino UNO, one on the robot and one on the glove. The Arduino consists of 14 digital pins where 6 of them is PWM. There are 6 analog pins and the unit is based on the microcontroller ATmega328P which has a flash memory of 32 KB and operates with a voltage of 6-20 V. The code on the Arduino is written in C/C++ [Arduino, 2016].

3.3.4 IMU

The IMU model LSM6DS3 is able to measure 6 degrees of freedom, however in this project the IMU will only be used to measure the yaw (rotation around the z axe) and the x and y acceleration, where the x, y and z directions are defined on the IMU.

![Figure 3.5: Shows the different degrees of freedom for the IMU and the x, y and z directions](image)

This model uses I²C serial interface and can measure acceleration up to 16 g and the angular rotation up to 2000 dps. The main purpose for the IMU is to measure the angle in the xy plane because that will determine how the robot will turn [insert figure].

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3.3.5 H-bridge motor driver

The H-bridge motor driver used on the demonstrator is a model DRV8833 which operates with an voltage of 2.7-10.8 volt and able to take a peak current of 2.4 ampere. This motor driver can operate two motors, however four motors is used. To compensate this, the two motors on the left side of the robot is consider as one by serial connect the two motors on the same pin on the motor driver and the same appiles on the right motors.

Figure 3.6: Schematic over how the the H-bridge are connected to the Arduino UNO and the motors.

The function of the H-bridge motor driver is to distribute the PWM to the left and right motors and to reverse the poles of the motors.

3.4 Experimental setup

To answer the research questions, three experiment is done. These are made to test the robots ability to regulate speed and steering capabilities.

The three experiments are:

- Steering control:
  To test the steering, a short and simple obstacle course is prepared. Four obstacles (in our case, four 0.5 L plastic soda bottles) is placed in a row with a distance of one meter apart. The goal of the test is to zig-zag past the obstacles, make a U-turn around the last obstacle and zig-zag back to the start while avoiding the obstacles. The test is timed from when the robot passed the starting line and finish when the robot has returned. Meanwhile every collision is documented.
3.5. RESULTS

- Speed control:
  To test the drivers control over the robots speed via the flex-sensor, a simple test is prepared. The purpose of the test is for the robot to drive a distance of four meters as close as possible to a target time of 10 seconds. The drive is timed and the difference between the target time and the measured time is calculated.

- Time delay:
  To test the time delay following test is done. A marker made of tape is put on the floor. The driver then accelerates the robot to full speed. When the robot passed the marker the time between when the robot passes the when the robot stops is measured.

The steering control and speed control tests are performed five times for each test driver while the time delay is only performed by one driver. The time is timed by a other person who is watching the tests. At the end of these tests, the driver rates the experience of driving the robot in a scale of 1-5 in terms of how easy the controller is to use.

3.5 Results

The results for the steering and speed regulation tests is following.

Driver 1:

<table>
<thead>
<tr>
<th>Test attempt</th>
<th>Speed control $\Delta s$</th>
<th>Steering control [s]</th>
<th>Collations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-0.55</td>
<td>45</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0.35</td>
<td>36.78</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0.33</td>
<td>52.39</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>0.79</td>
<td>52.99</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>-0.03</td>
<td>49.49</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 3.1: Test result of the steering control and speed control for driver 1

Driver one is pleased with the controls. The only thing that is troubling is that the tilt switch is not working very well and sometime the controller stops working. Overall the rating is a 4 out of 5.

Driver 2:
When the robot works sufficiently enough the car is able to turn on a dime and the speed matches the bending of the finger. If there was not for the fact that you need to reset the Arduino every time the IMU stops working, everything would be great. Because of technical difficulties, diver 2 could not do the speed control test. Diver 2 gave the controller a rating of 3 out of 5.

When other persons tested the controller, problems occurred and therefore results could not be obtained. However their rate of experience is notified. Their experience is that the controller is very unstable and hard to control the robot in a proper way. Their rating is 1-2 out of 5, however these driver thought the experience is fun and exiting.

For the time delay test, which is performed by driver one, the result where:

<table>
<thead>
<tr>
<th>Test attempt</th>
<th>Time delay [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.6</td>
</tr>
<tr>
<td>2</td>
<td>0.26</td>
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<tr>
<td>3</td>
<td>0.21</td>
</tr>
<tr>
<td>4</td>
<td>0.22</td>
</tr>
<tr>
<td>5</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Table 3.3: Test result for time delay test for driver 1
Chapter 4

Discussion and conclusions

This chapter will discuss the result and answer the research questions asked in chapter 1.

4.1 Discussion

The result varies a lot between the different drives. For example diver 1’s steering is different for each attempt while diver 2 where constantly improving except for test 4 (table 3.2) where there were some troubles with the controller. This indicates that for a person to get good results, experience is necessary to use the controller properly and the learning curve is different for different people.

Driver 1 and 2 have some experience before doing the test, which made them rate higher then the other drives which is very new to the experience. This makes the the point of having experience to use the controller even clearer.

As to the answer to the second research question, the controller is not an easier and more intuitive when it comes to speed control and steering. However when learning to handle the controller better, the controller has potential of becoming a new way of remote controller because the result looks promising. With further studies and experiments, the controller could evolve to be more intuitive and easier to use.

For the time delay the result is around the same value, 0.21 seconds, which is around the reaction time for the person who times the result. Therefore the time delay for the communication via RF is smaller that can be measured with the method used in this project. To answer the first research question, the time delay has no effect on controlling the robot because the delay is not noticeable when driving a robot. However when more detailed work is done, like robotic surgery, the smallest delay can affect the outcome of the surgery. Therefore further research is necessary to answer this question properly.
4.2 Conclusions

RC-glove has a good potential of becoming a new way of controlling remote object. However for the demonstrator in this project, the driver need to have experience of driving the demonstrator to be able to handle the controller well.
Chapter 5

Recommendations and future work

This chapter will give recommendations for more optimal solutions and how the project can be improved in future works.

5.1 Recommendations

One recommendation is to try and find a different sensor to replace the tilt switch because reversing the robot is the most difficult part when controlling the robot. The problem with the tilt is that the switch is trigger multiple times which makes the pole reverse back to the original state. A simple solution to this is by using a button, however this project wanted to implement as many haptic feature as possible.

5.2 Future work

Future work for this project is to replace simple components to improve the control of the robot and make the controller easier for non-experienced driver to use. Also the time delay can be further studied by using more proper ways of measuring small time delays.
Bibliography


