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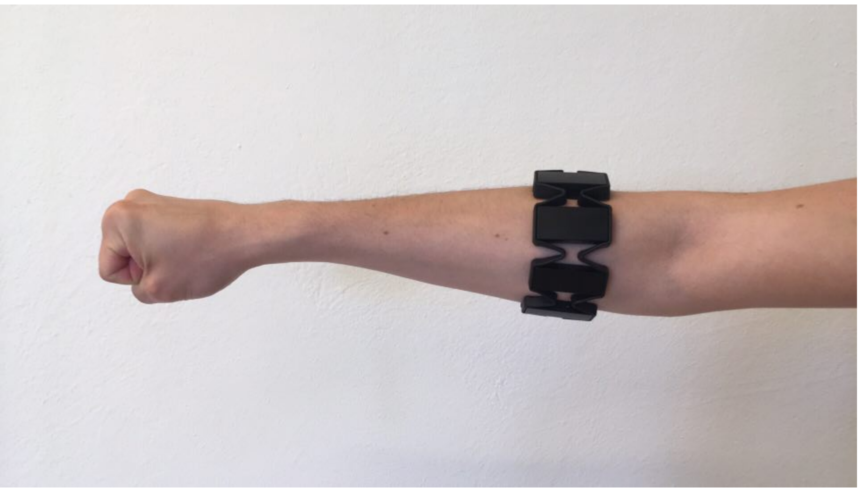

A Chalmers University of Technology Bachelor's thesis

The human in the loop robot

Bachelor's thesis
Department of Electrical Engineering
SYSCON

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Matilda Renman

Division of Systems and Control, Department of Electrical Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
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Abstract

This project is a Bachelor's thesis carried out at the department of Electrical Engineering at Chalmers University of Technology. The thesis describes the process of connecting and communicating with a robot arm and an AGV, Automated Guided Vehicle, using the Thalmic Labs Myo Gesture Control Armband, also called the Myo band. The Myo band is an armband which uses sensors to detect gestures made by the bearer. The aim of the project was to examine the potential of human robot interaction using the Myo band, and also how to make the interaction feel natural for a user when communicating with a collaborative robot set in an industrial environment.

The robots used in the project were the robot arm, Universal Robot 10 and the AGV, MiR200. ROS, Robot Operating System, was used to enable the connection between the robots and the Myo band. Using ROS, programs were developed and existing programs were modified.

Two user studies regarding the gestures for the commands were conducted. The first user study considered intuitive gestures, and lead to the choice of the final gestures to control the robots. The second user study evaluated the robustness of the final gestures, and resulted in a conclusion of which gestures that needed to be improved or remade.

Six gestures were implemented for the following commands; stop, continue, slow down, speed up, move to the left and move to the right. Those commands were chosen since they were considered suitable for an industrial environment where humans and collaborative robots work together.

Finally, the possibilities of the Myo band when used for gesture detection in an industrial environment and ethical aspects are discussed, accompanied by suggestions about future development of the project.

Keywords: Human robot interaction, Collaborative robots, Myo band, ROS

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Mattias Gerle, Daniel Jakobsson, Melina Makris,
Elmer Nordqvist, Matilda Renman

Contents

Terminology

Accelerometer - A device that measures the acceleration in its own instantaneous rest frame.

AGV - Automated Guided Vehicle, a vehicle that with the help of sensors is able to navigate through an environment autonomously. In this thesis it refers to a MiR200 robot.

API - Application program interface, software that allows communication between two applications.

EMG - Electromyography, an electrodiagnostic technique to analyse electrical activity produced by muscles.

Fiducial markers - A visual marker, much like a barcode, which is used as a reference point.

GUI - Graphical user interface.

Gyroscope - A device that conserves angular momentum. It is used for measuring or maintaining angular velocity and orientation.

IMU - Inertial measurement unit, a device that measures a body's force, angular rate, and sometimes the magnetic field surrounding the body, using a combination of accelerometers and gyroscopes, sometimes also magnetometers.

Magnetometer - A sensor measuring the strength and direction of the magnetic field surrounding it.

Myo band - The Myo band is an armband which uses sensors to detect what hand posture the wearer is making, acceleration and the orientation of the armband.

PLC - Programmable logic controller, a ruggedized computer used to automate, for example, a certain machine function.

Robot arm - Refers to the UR10, Universal Robot 10.

Robot - Refers to the Universal Robot 10 and the MiR200 mounted together.

ROS - Robot Operating System, a flexible framework for developing robot software.

Wrapper - software that allows certain programs to work together that otherwise would not.

1 Introduction

In today's industry, the usage of autonomous and collaborative robots is increasing and so are the number of companies interested in them. Within 20 years half of the current working positions in Sweden could be replaced by robots [1]. The reason for this increase can be attributed to the value that could be obtained in production from having a robot that could safely assist the operator. A robot could perform tasks that are too heavy or too dangerous for a human to perform and thus injuries can be avoided in a greater extent. The operator could then instead focus on higher value-adding tasks and thereby improve both precision and quality. Collaborative robots are also more compact and flexible than the traditional, caged industrial robots[2]. This means that an economical benefit also could be obtained since one single robot could be integrated in multiple different projects. The traditional caged robots are not only less adaptive but also often considered to be unsafe for human interaction [3].

Interaction between human and robot could also prove useful when it comes to medical application, for example as a help for people with disabilities or during surgery. Both possible uses of robotic technology for surgical uses and how tasks are carried out during surgery are inherently collaborative since they are exerted on a human [4].

However, if robots and humans are going to work alongside one another while the human still is in control, seamless communication is critical. Humans are used to, and often very good at communicating with other humans using body language, and it makes sense to use this ability for designing robots instead of making the human adapt to the robot in any special way [5]. This way, even untrained humans would be able to work with the robot and it would facilitate application in an industrial environment.

To be able to achieve this, tools such as the Myo band, which can identify small gestures made by the bearer, could be used. With the help of the Myo band the bearer could interact with the robot more freely and from a distance. Interaction could also be made to feel natural since the Myo band works through readings of the muscles and the user therefore needs no further tools than their own arm.

This way of human robot interaction could prove useful in, for example, the medical field or in an industrial setting for companies to simplify assembly. Therefore, this project aims to further investigate and develop the use of the Myo band as a tool to communicate with a robot.

1.1 Purpose

The purpose of this project is to examine the possibilities of gesture detection for making the communication between human and robot, in an industrial environment, feel robust and natural. This means that the robot should interpret a command when it is given, and respond to it without the need for it to be repeated several times. Additionally, the command should not be sent when the operator does not intend to. In short, the robot should be able to interpret the humans intention in a reliable way, while at the same time the human should be able to communicate with the robot in a way that feels natural.

In order to achieve this, the Myo band will be examined to chart its strengths and weaknesses. This will be done through evaluation of the data that can be obtained from the Myo band. A set of conditions from the evaluated data, that together build a gesture, will be defined and if all conditions are true a response from the robot will be triggered. These conditions are either one or a set of hand postures and orientations of the forearm.

A user study aiming to collect the opinions of the test users will be conducted and these opinions will be used to define gestures. Related work from literature studies regarding communication using gestures will also affect how the gestures will be defined. The robustness of the gestures will thereafter be examined through another user study where test users will give commands in order to control the robot. This study will aim to evaluate how well the Myo band registers the gestures.

The results from both of these user studies will finally lay the foundation for the discussion of the components in the system and possibilities of controlling robots by gestures.

1.2 Delimitations

This project aims to study human robot interaction with the aid of the Myo band and motion sensors, where the main focus will lie on the communication between robot and human. The robots that will be studied are exclusively the robot arm, UR10 and the Automated Guided Vehicle, MiR200. Since the project aims to study human robot interaction set in an industrial environment, the robot will only be driving indoors on flat ground. Furthermore, ROS, Robot Operating System, is the framework that will be used for developing the software for the system.

1.3 Structure of the thesis

To cover all substantial parts of the project, the report is divided in five chapters followed by discussion and conclusion. In the chapter *Related work*, previous work done in the same field are presented to give insight in what has already been done and what could prove useful for this project. Following that, in the chapter *Technical specification*, a brief introduction and explanation of the components used in the project are given. The procedure and what methods were used are described in the chapter *Method*. The chapter *System architecture* describes the resulting system architecture and results from examining the components. In *Results and evaluations of gestures* the final results of the project are presented. In the chapter *Discussion* the results, the method and ethics are discussed. In *Conclusion* conclusions are drawn about the results of the project with reference to the purpose. The reference system used is the IEEE convention. Footnotes are also included to illuminate work which does not warrant a full reference, for example open source software that was used.

2 Related work

Due to the fact that there are multiple ways in which humans can communicate with robots, there are plenty of related work regarding this that can be found. This section explores communication by different sensors to give insight into which sensors would fit this project the best as well as how humans and robots work together.

The field of motion detection sensors is one of the largest fields of sensors, probably because motion can be detected in many ways. Other sensors such as voice control can also be used and a lot of studies can be found covering this subject as well.

As stated before, another important aspect in human robot communication is to make the communication comprehensible, comfortable and natural for the human. Since this project partly focuses on achieving that, research done on human interaction with robots also needs to be examined.

2.1 Voice control

A lot of studies has been made about using voice to control systems. H. Li, X. Lv and M. Zhang [6] performed a study in 2008 about how to control a robot system with voice control. They came to the conclusion that the method proved efficient enough for real-time operations, but that background noise was something that disturbed the systems ability to perceive the correct information from the operator.

In 2011, A. Rogowski performed an analysis about how to establish the optimal method of voice command analysis for industrially oriented systems [7]. From this analysis a voice control system for robotised manufacturing systems was made. The conclusion was that an immediate reaction to operators command is required, and a solution for variety in voice command formulations based on the regular grammar is provided. The system also has to be able to handle spontaneous speech effects such as an operators hesitations and self-corrections.

Research made in 2014 by A. Buendia and L. Devillers explored the ability for a system to have dialogues and maintain a long-term social relationship with a human [8]. In order to do this there is a lot of aspects for the system to take into account, such as perceiving the humans emotions and intents. It also has to know which information that is relevant to memorise and which information is irrelevant.

Another difficult subject is to make the system able to realise when the human lies or tells a joke.

2.2 Vision

One of the ways to recognise human gestures is with the use of cameras. E. Coupeté, F. Moutarde and S. Manitsaris have used a depth camera for detecting gestures in an industrial environment where an operator and a robot worked collaboratively towards a task [9]. By the use of the depth camera and machine learning by collecting several sample gestures, they managed to recognise 93 % of the gestures given by the human operator. The gesture recognition did however not occur in real-time.

A. Chaudhary and J.L Raheja have demonstrated an image based light intensity invariant technique for hand gesture recognition [10]. By using a database of hand gesture images to match with a test gesture they managed to successfully identify about 93 % of the test gestures in extreme light intensity changing environments.

Detecting gestures can also be done using multibeam sonars, which are sometimes called acoustic cameras. F, Gustin et al. have implemented hand gesture recognition using high resolution multibeam sonars for detecting hand gestures of divers underwater for communication with robots [11]. Using a merge of two gesture recognition methods they managed to achieve 99 % classification precision on more than 1000 real sonar samples.

2.3 On-body sensors

There are numerous on-body sensors which could be used to interact with robots. With an accelerometer, a gyroscope and a magnetometer, IMU data can be obtained. This data was used by a team from Federal University of Espírito Santo to steer a robot [12]. The error in final position from that study were lower than 10%. This did however not solely indicate that the sensors were off by 10% since many factors could have caused this, for example the mechanics of the robot .

Gloves can be used to track hand movements accurately and these can be equipped with many different sensors. Some of them are pressure, temperature and humidity sensors. The glove can, for example, detect movement of the user to make a robotic hand follow the movement [13]. These sensors typically require wired connection between the computer and the sensors of the glove. This makes the communication between the user and the robot harder and less natural [14].

2.4 EMG

A study done by K. Akhmadeev et al. showed promising results from analysing EMG, electromyography, data from the Myo band [15]. The study explains how with the use of statistical classification techniques EMG data can be analysed. The data examined were mean absolute value (MAV), zero crossings (ZC), slope sign changes (SSL), waveform length (WL) and autoregressive coefficients (AR). The data was collected from seven subjects and the experiment had a total time of 35 minutes for each subject. The pattern-recognition-based control system had a total mean success rate of 99%. An important notion is that these tests were performed in very controlled settings.

2.5 Human with robots

Several works related to interaction between humans and robots can be found. D. Rempel et al. has looked into which gestures are the most comfortable for use in gesture based communication between humans and robots [16]. The result were that gestures with straight wrist or having adjacent fingers similarly shaped can be considered comfortable gestures. Uncomfortable gestures are those with wrists flexed, fingers extended or adjacent fingers being placed far from each other.

From a psychological perspective S. Van der Woerdt and P. Haselager came to the conclusion that if a robot's failure appears to be caused by its lack of effort as opposed to its lack of ability, humans seem to attribute significantly more agency and responsibility to the robot [17]. The response, in comparison, was different when it was towards another human.

V. Villani et al. has made a study on human–robot collaboration in industrial settings [18]. This study resulted in the conclusion that difficulty of using robots in an industrial setting are often related to the way the human operator is supposed to interact with the robot, since it usually requires specialised knowledge. Further, the study suggests that intuitive ways to interact with robots is one of the key points to further enable adoption of robotic technologies. Emphasis is put on achieving simplified ways of interaction which result in reduced time, user errors and increased situational awareness while interacting with the robot.

2.6 Summary

Relative to other possible sensors, motion sensors have in studies proved to be accurate and robust. Other methods such as voice control can be accurate in some settings but the accuracy depends a lot on external factors. Variance in human communication such as dialects, pitch, gestures and behaviour complicate the matter even further. For a sensor to be used in an industrial setting it must be robust enough to retain its accuracy independent of external factors as well as variance in human communication. Since this project was aimed to improve the robustness of the system in an industrial setting, motion detection seemed more promising.

Motion detection with depth cameras can be very accurate but since the data to be analysed is so vast, the accuracy can not be retained if the communication is handled in real time. A system that has a lot of delay is a major safety concern at the same time as it makes the communication with the robot much harder. There is a need in a robust system for the ability to quickly process data. Another way to detect a humans intention is on-body sensors. The amount of data for those is small and can be processed quickly. These sensors have been tested many times independently and with a high rate of success.

Previous studies on human robot interaction puts further emphasis on making the communication feel intuitive and easy. When designing gestures it should be kept in mind that the wrist should be straight and the adjacent fingers should be close to each other to make the gestures comfortable. This is important if the user shall be able to communicate with the robot comfortably for a longer period.

3 Technical specification

In this project, specific software and hardware was provided. The hardware mainly consisted of the Myo band and the two robots UR10 and MiR200. ROS was the framework used to develop the robot software. These components and their technical specifications are described in this chapter.

3.1 Myo band

Thalmic Labs Myo Gesture Control Armband was the main component used in this project to recognise gestures from the user. The Myo band comes equipped with medical grade stainless steel EMG sensors and highly sensitive nine-axis IMU, inertial measurement unit, which contains a three-axis gyroscope, a three-axis accelerometer and a three-axis magnetometer, see figure 3.1. The Myo band is also equipped with dual indicator LEDs, an ARM Cortex M4 processor, haptic feedback in the form of vibrations and Bluetooth communication[1].

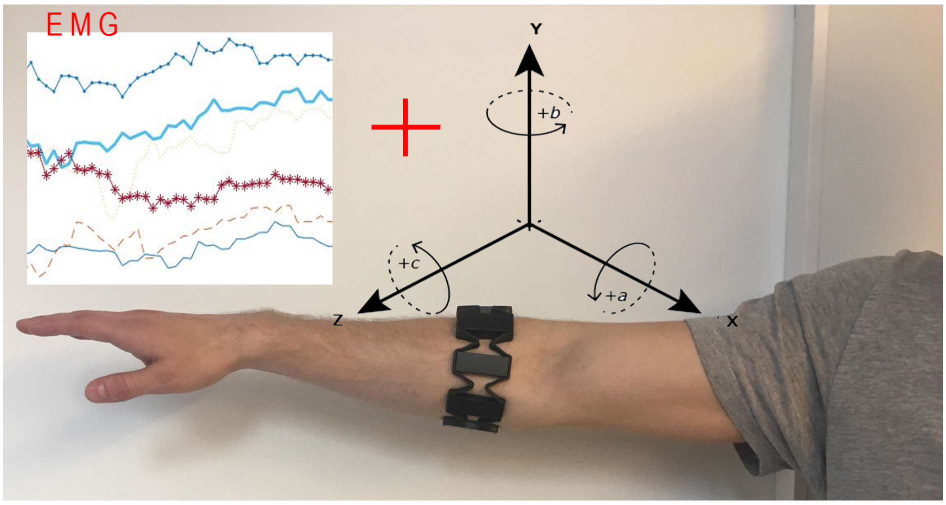

Figure 3.1: Myo band

Information can be retrieved from the Myo band via a Bluetooth connection. The Myo band sends three different types of information: IMU data, posture data and EMG data. The IMU data contains information about motion and orientation of

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[1] Retrieved from: `https://www.myo.com/techspecs`

the armband, the EMG data contains information from the EMG sensors and the posture data contains information about whether the wearer is currently doing one of the Myo band's predefined hand postures[2].

These predefined postures are recognised by the Myo bands internal software, and consists of 6 different postures; rest, fist, fingers spread, wave in, wave out and finger to pinky (see figure 3.2).

(a) Rest **(b)** Fist **(c)** Fingers spread

(d) Wave in **(e)** Wave out **(f)** Finger to pinky

Figure 3.2: The six predefined hand postures recognised by the Myo bands internal software

3.2 Universal Robot 10 - UR10

The robotic arm UR10 is designed to be used collaboratively in an industrial environment, see figure 3.3. Since it has a maximum payload of 10 kg and a range of 1300 mm it is especially useful when it comes to pick and place operations where distance is of concern[3]. The UR10 uses a programming interface called Polyscope which is made to be intuitive and easy to use. This interface can also be used as an offline simulator to visualise commands before they are applied to the real robot. Polyscope has predefined commands to perform certain actions.

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[2] Retrieved from: `http://developerblog.myo.com/myo-bluetooth-spec-released/`

[3] Retrieved from: `https://www.universal-robots.com/products/ur10-robot/`

Figure 3.3: UR10

3.3 The automated guided vehicle, MiR200

The AGV shown in figure 3.4, is designed to move around an area that has been pre-mapped by the robot. Before using it, a human has to guide the robot around the work space while the robot constructs a map of the area using its different sensors. The MiR200 is equipped with two SICK safety laser scanners S300, on the front left corner and the rear right corner of the AGV, which are used for 360° visual protection around the robot[4]. It is also equipped with a 3D camera Intel RealSense™ for detecting objects 50-500 mm above the floor ahead of the robot and four ultrasonic scanners for detection of transparent objects ahead.

The MiR200 is designed to be controlled by connecting to the local network of the MiR200 from a stand-alone device such as a mobile phone, and then accessing the URL *www.mir.com*. There, access is granted to a GUI where different functionalities can be accessed for the robot such as manual control of the AGV in a joystick mode, creating a map of the area for the robot, defining missions for the robot and adding missions to the mission queue.

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[4] Retrieved from: `http://www.mobile-industrial-robots.com/en/products/mir200/`

Figure 3.4: MiR200 with a base for the UR10 mounted on top

3.4 Robot Operating System - ROS

The Myo band, the robotic arm and the AGV is connected through the framework called ROS. ROS is, as described by the developers behind it, a flexible framework for developing robot software[5].

ROS uses *nodes* as a process to perform computation. A complete robot control system will often consist of several nodes to control different components of the system[6]. This means that the nodes can work separately, regardless of programming language. Communication between nodes can be handled through *topics*. Topics are communication channels where data is sent in the form of *messages*. Messages are a simplified description language in ROS for describing data values. A node that sends messages to a topic is a *publisher* while a node that receives messages from a topic is a *subscriber*. In the subscriber node a special type of method is implemented that runs anytime data is received from the topic. This method is then meant to handle what to do with the data that the subscriber node receives. An overview of the schematics can be seen in figure 3.5.

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[5] Retrieved from: `http://www.ros.org/about-ros/`

[6] Retrieved from: `http://wiki.ros.org/Nodes`

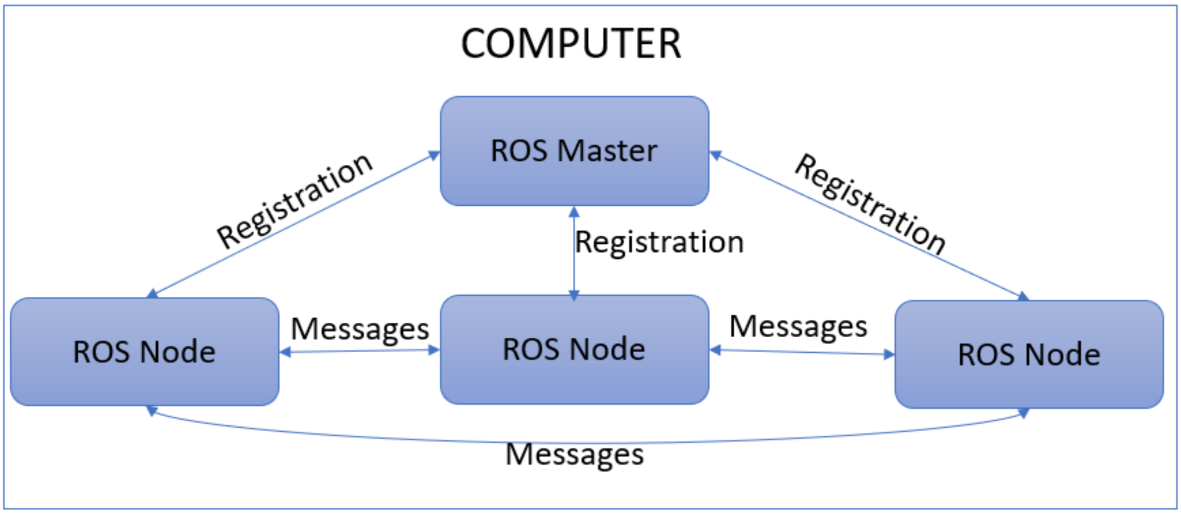
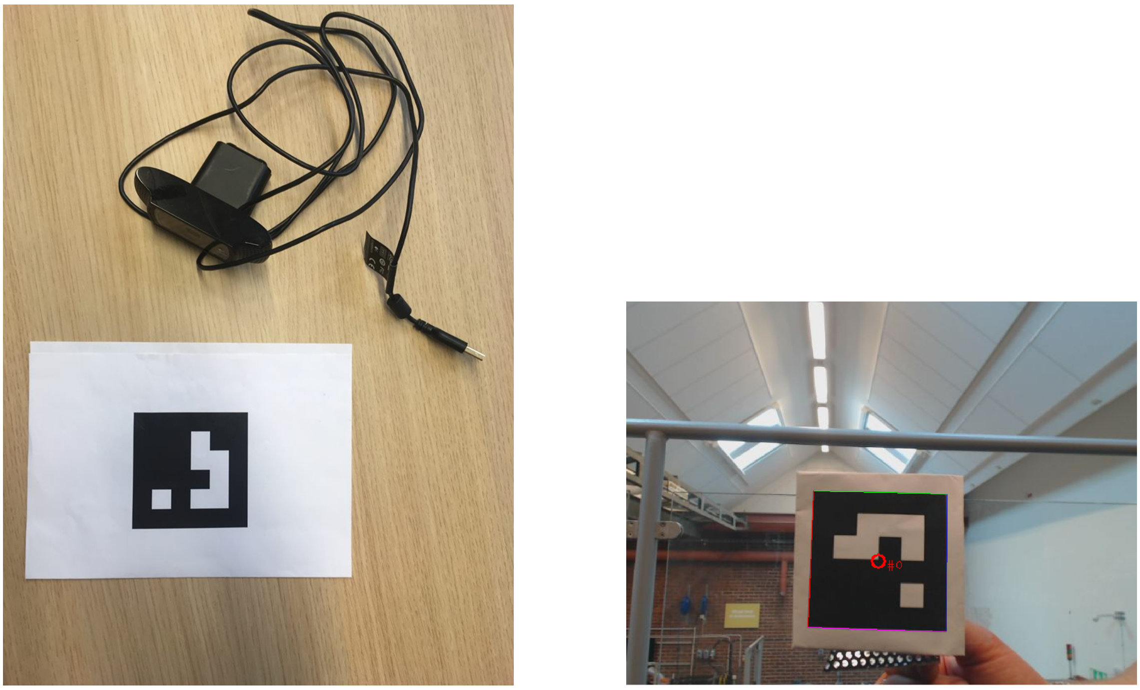


Figure 3.5: ROS schematics

3.5 AprilTag

AprilTag is a visual fiducial system where information about 3D position and orientation of a special type of tags can be retrieved with the use of any simple 2D camera. The tags are very similar to QR codes, however AprilTags are designed to carry much smaller data payloads, which allows them to be detected more robustly and from further distance. Figure 3.6 shows the graphical identification of when the camera has detected an AprilTag as well as the camera next to the same AprilTag.



(a) Web camera with AprilTag

(b) Image from the web camera that has been processed by the AprilTag software to detect a tag with ID 0

Figure 3.6: Apriltag

4 Method

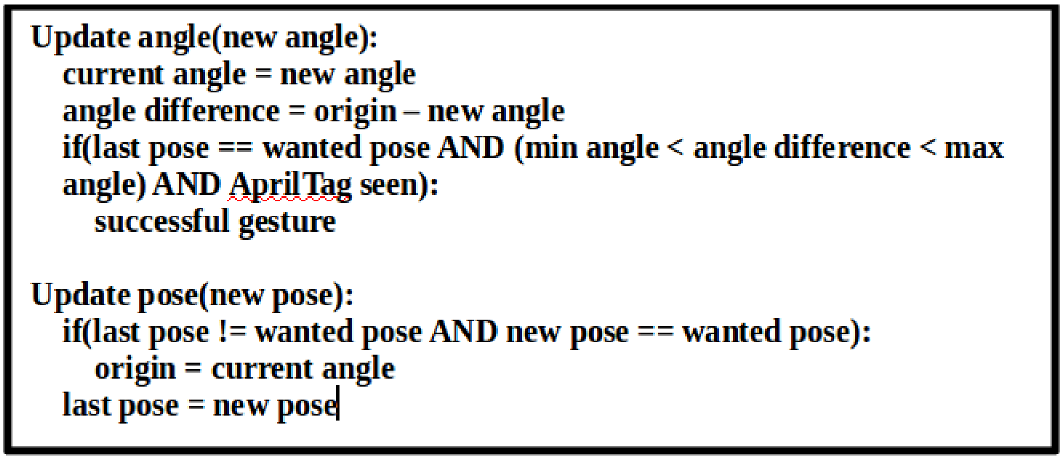
This chapter describes the process of the project. Firstly, the definition of the gestures is described. Thereafter, the goals and implementations of two different user studies are explained. The first user study explained is a user study of which gestures a user feels are natural to make, and the second is a user study which examined the robustness of the gestures chosen after the first user study.

4.1 Definition of gestures

A gesture performed with the Myo band in this context refers to a combination of movements of the arm and the hand that happens in a sequence. A gesture is defined with three basic tools; the EMG data, the hand posture data and the IMU data. A gesture is only valid if an AprilTag is visible by the system.

To define a gesture, conditions are specified that have to be true simultaneously to trigger an action, such as sending a command to to the robot. E.g. these conditions could be an interval on a particular axis of the orientation data that the arm has to be positioned into. It could also be a specific hand posture which is sent as hand posture data. A big part of this project in practice is to study how these conditions should be applied to make the gestures as natural as possible for the user.

In figure 4.1 a typical approach for how to perceive a gesture in this project is given. The program subscribes to the ROS topics that gives data about the current orientation and hand posture. Every time the data is updated in these topics, the program runs through the respective method. This gesture begins with a particular hand posture that has to be made by the user, which is "wanted pose" in the example in the figure. When the right hand posture is given, the orientation has to be within the predefined interval to make the gesture successful. The system also has to detect an AprilTag to ensure that the operator want the system to react and to prevent a reaction from happening by accident.



```
Update angle(new angle):
    current angle = new angle
    angle difference = origin – new angle
    if(last pose == wanted pose AND (min angle < angle difference < max
    angle) AND AprilTag seen):
        successful gesture

Update pose(new pose):
    if(last pose != wanted pose AND new pose == wanted pose):
        origin = current angle
    last pose = new pose
```

Figure 4.1: A general approach to recognising gestures based on rotation after a hand posture has been given.

4.2 User studies

In order to make the communication between human and robot feel natural and robust, two different user studies were conducted. The aim of the user studies was to investigate which gestures should be used, and furthermore how well the developed gestures worked with the robot respectively. The gestures examined were the command for stop, continue, speed up, slow down and move the AGV to the left and to the right. The goal and implementation of both of these user studies are described in the subsections below.

4.2.1 Goal of study of gestures

The first user study was made to examine which gestures a user would feel was the most intuitive and natural to use. Both instinctive reaction and opinions on already defined gestures was explored to obtain justification for choice of gestures. The study also investigated where a fiducial marker best could be placed.

4.2.2 Implementation of study of gestures

Six students participated in the study, one at a time. Initially, each test user was put in a scenario where the robot was driving towards them and they were asked to give a command with their right arm to stop, continue, slow down, speed up the robot and move the robot to the left and to the right. This was to test what command they would be giving instinctively in that kind of situation. After this, four different questions were asked:

- Why did you react the way you did?
- Can you think of any other gesture that would fit the command?
- Which of the these gestures do you think would be the best to use in a varying and hectic environment?

- This gesture is the defined gesture for that command right now, what do you think of it?

The first question gave insight into if there was anything in particular that made the test users react the way they did. The other questions were asked to get data on the opinions of the test users on different gestures after they had gotten the opportunity to think them through. Finally, each test user was asked to imagine a situation where they were working with something and they had to stop the robot, which was moving behind them, to prevent an accident from happening. This test was mainly performed to observe if the test users would turn around to face the robot or not, as a step to investigate where a fiducial marker should be placed. For compilation of the complete study, see appendix A.

4.2.3 Goal of study of robustness

The second study was constructed to evaluate the robustness of the system. It aimed to illustrate how often the system registers and interprets the different gestures correctly, as well as how often it fails and why. This enabled evaluation regarding which gestures needed to be improved or remade.

4.2.4 Implementation of study of robustness

Ten test users participated in the second user study and were asked to perform each gesture five times. The frequency of how often the confirmed gesture corresponded to the wanted command was noted. If the performed gesture did not correspond to the wanted command, an error was noted. Two different types of errors were defined. The first error noted was a hand posture error, which occurred when the correct gesture was performed but the hand posture was not recognised by the Myo band. The second error noted was an orientation error, which occurred when the correct gesture was performed but not performed within the orientation constraint. There were also failures where the cause was unknown. For compilation of the complete study, see appendix A.

In order to achieve the best results with the Myo band, electrogel was used. Electrogel is an electrode leading gel that consists of silicon impregnated with cobaltchloride. The gel is compiled to provide the best possible contact between skin and electrodes by lowering the impedance and thus improving the accuracy of the EMG data[7].

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[7] Retrieved from: `http://www.ne.se/uppslagsverk/encyklopedi/lång/blågel`

5 System architecture

This chapter describes how the software and hardware are combined and connected to each other. Furthermore, the chapter aims to explain how the technical components are controlled and used, and what results were obtained from examining them.

In figure 5.1 a flowchart showing the overview of the system architecture is displayed. The boxes in the figure represents the hardware and software that sends or receives data and the data moving between the boxes as well as the channels connecting them is represented by the arrows and lines. In short, the input to the system is the data sent from the Myo band and the web camera, these inputs are then processed by several different programs before it is sent as commands to the UR10 and the MiR200. For further explanation of each component, see chapter 3. In addition, each box of the flow chart is described in more detail below.

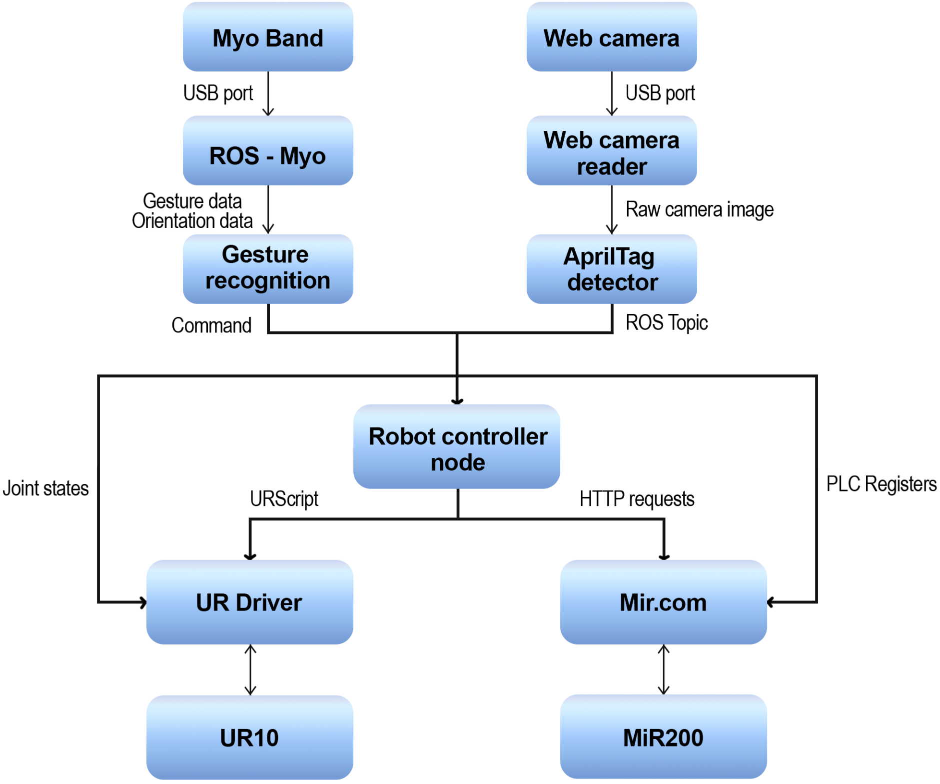

Figure 5.1: Flowchart of the system architecture

Myo band

The Myo band communicates to the computer through a Bluetooth receiver that is connected via a USB port. This enables the computer to receive the EMG- and IMU-data, as well as the Myo bands built-in hand posture recognition which is sent from the Myo band via Bluetooth.

ROS Myo

ROS Myo is a ROS wrapper for reading the Myo bands EMG- and IMU-data from the USB Bluetooth receiver[8]. The program creates several ROS topics where it publishes the following information:

- Information from the Myo bands built-in hand posture recognition.
- The data from the EMG sensors.
- Data from the IMU, inertial measurement device, excluding magnetometer data.

Gesture recognition

Gesture recognition consists of several ROS nodes which subscribes to the different ROS topics created by the ROS Myo program. These nodes use the hand posture recognition and orientation data to detect if the wearer of the Myo band is currently performing a gesture. There is one node for each gesture, except for move left and move right as well as speed up/slow down, which uses the same node respectively. This is because these gestures are essentially the same but performed in different directions.

Web camera

The web camera, connected by a cord to a USB port on the computer.

Web camera reader

The web camera reader is a ROS wrapper for reading image data from an USB camera connected to the computer[9]. The program reads the image data from the USB port and publishes it on a ROS topic.

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[8] Retrieved from: `https://github.com/uts-magic-lab/ros_myo`

[9] Retrieved from: `https://github.com/ros-drivers/video_stream_opencv`

AprilTag detector

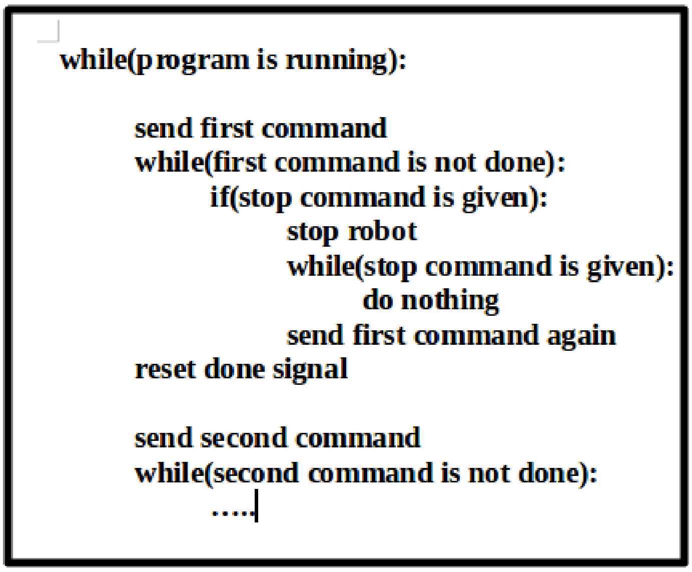
The AprilTag detector is a ROS wrapper for AprilTag[10]. The program reads the image data from the ROS topic created by the web camera reader and detects if there is a tag in the image. This information is then published to ROS topics.

Robot controller node

For simulating autonomous behaviour of the robot, a main node has been developed that makes the robot loop several commands. The node tries to simulate how the robot would work if it would pick and place different objects in a factory.

The main node receives information about whether the user is making one of the gestures from the gesture recognition nodes. It also receives information from the AprilTag detector. When a gesture is made by the user, the main node sends the corresponding command to the robot if the AprilTag is visible for the camera.

If the stop command is given by the user, the mission queue for the AGV is cleared and the robot arm is stopped. The main node then enters an inner loop where it does nothing until the continue command has been given, after which it tells the robot to finish the mission it was working with. See figure 5.2 for a pseudo code explanation.



```
while(program is running):

    send first command
    while(first command is not done):
        if(stop command is given):
            stop robot
            while(stop command is given):
                do nothing
            send first command again
    reset done signal

    send second command
    while(second command is not done):
        .....
```

Figure 5.2: The robots autonomous behaviour explained in pseudo code

UR driver

The UR10 is controlled by the use of predefined commands for the UR10, called URScript commands, which are sent to a ROS topic created by a UR driver for ROS.

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[10] Retrieved from: `https://github.com/RIVeR-Lab/apriltags_ros`

The URScript commands that is used in this project is *movej*, and *stopj*. The *movej* command takes joint position, maximum velocity and maximum acceleration as input to move the robot arm linearly through joint space to the specified position[11]. The *stopj* command stops the arm by decelerating joint speeds to zero.

The UR driver that creates the topic to send commands to the UR10 also creates other topics where messages about the state of the robot is sent. To be able to know when the UR10 has reached its goal position, the goal position is saved before the command is sent. After that, the command to move is sent and the current position of the robot arm is continually checked until it is close enough to the goal position.

UR10

The UR10 robot arm, connected through an Ethernet cable to the same router as the computer running ROS .

Mir.com

The AGV is controlled by sending HTTP-requests to the local IP-address of the MiR200 using a rest API. Through this communication pre-defined missions can be added in the mission queue and PLC registers can be read/written. The missions that can be added in the mission queue are defined trough a GUI which can be accessed through the url *www.mir.com* while connected to the AGVs local network. The missions that have been created for this project are: go to a predefined position, move left and move right. Positions are defined through the GUI in a similiar way as the missions.

MiR200

MiR200 performs the missions added to the mission queue via the ROS system one at a time, and stops as soon as the mission queue is cleared. It also sets certain PLC registers as soon as a mission is completed to make the ROS system understand when the AGV has completed a mission.

5.1 Improving Myo band robustness

When testing the predefined hand postures it was discovered that the Myo band did not recognise these accurately. Because of this it was decided to try to develop a new way of registering hand postures using the EMG sensor data from the Myo band.

Each sensor of the Myo band gives a value from 0 to 2048 depending on the strength of the electrical signal from the arm. The combination of the different values read

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[11] Retrieved from: `http://www.sysaxes.com/manuels/scriptmanual_en_3.1.pdf`

from the EMG sensors define the hand posture. A ROS node was made to record a number of EMG signals from each sensor. The data was sorted from low value to high value. A span between one of the lower values and one of the higher values, see figure 5.3, was used to define what EMG signal is an accepted value to register as a correct hand posture.

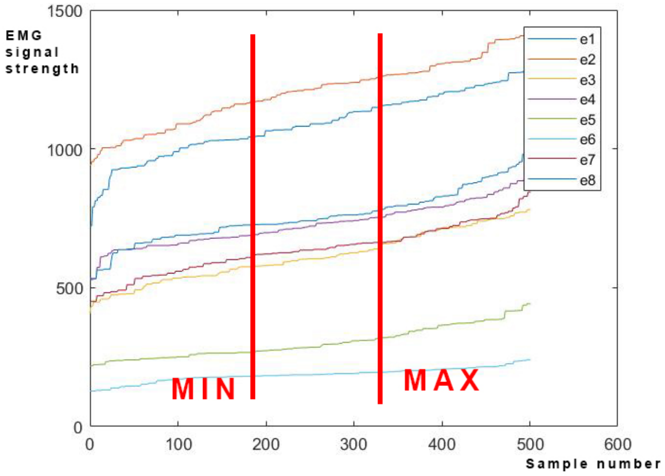

Figure 5.3: The values from the EMG sensors sorted from lowest value to highest value, the span that defines the desired EMG values for this hand posture is defined as being between a certain minimum and maximum value as shown here.

Since the values of each sensor can vary between samples the mean value of a certain amount of recorded samples was used instead of one single sample. This gave a much more stable value to be compared with the span of acceptable values.

A problem that was encountered was that certain hand postures often got mistaken for other hand postures. Because of this, another condition for successfully registering a hand posture was added. This condition was that a certain hand posture had to be successfully identified a certain number of times before the system registered it as a hand posture.

The different parameters that has been described for the hand posture recognition is summarised in a list below:

1. **Sample size:**
   Larger number makes the span of acceptable EMG values better, but it takes longer to calibrate.
2. **Amount of values the mean is calculated for:**
   This is the amount of real time recorded samples that the mean is calculated for and compared to the span of acceptable values. A higher amount makes the recognition more reliable but the user has to hold a hand posture for longer before it registers.
3. **Minimum and maximum value:**
   Which value to be selected as minimum and maximum value within the span

of accepted values. If, for example, 600 values are recorded, maybe the 180th lowest value is set as minimum and the 420th lowest value is set as maximum. A larger span makes it easier to register the hand posture but it also makes it easier to register the hand posture by mistake.

4. **Amount of correct EMG values:**
   This is the amount of times the EMG values has to be inside the span of accepted values before the system registers it as a successful hand posture. A higher number results in less hand postures being registered by mistake but the user has to hold a correct hand posture for a longer time.

By tuning these parameters the hand posture recognition might be made more robust.

6 Results and evaluation of gestures

In this chapter the results obtained from the test studies and examination of the Myo band are presented. The six final gestures for the following commands are described; stop, move to the left, move to the right, continue, and finally increase/decrease speed. There are two examined gestures for changing the speed, the Wave gesture and the Volume gesture. Both of these are explained and compared to each other, before a conclusion of which one is the most suitable is drawn. In addition, how well the Myo band can detect these gestures is explained. In addition results from examination of AprilTags are presented.

6.1 Functions of Myo

Examination of the EMG signals for different hand postures shows clearly why the six hand postures, as shown in figure 3.2, have been predefined for the Myo band. These hand postures are all distinct. Fist and spread fingers are opposites of each other, as well as wave in and wave out. One possible reason as to why these postures give the most distinct signal patterns can be explained by examining the anatomy of the arm. When the muscle that works as the prime mover contracts, the antagonist muscle that it forms a pair with relaxes and thus movement is created[12]. Since the Myo band measures the electric signal, which is a result of contraction, opposite hand postures would theoretically activate different EMG sensors on the Myo band. The EMG signal for each hand posture was recorded two times. The mean calculated from the values received from this for the wave in and wave out move are shown in figure 6.1.

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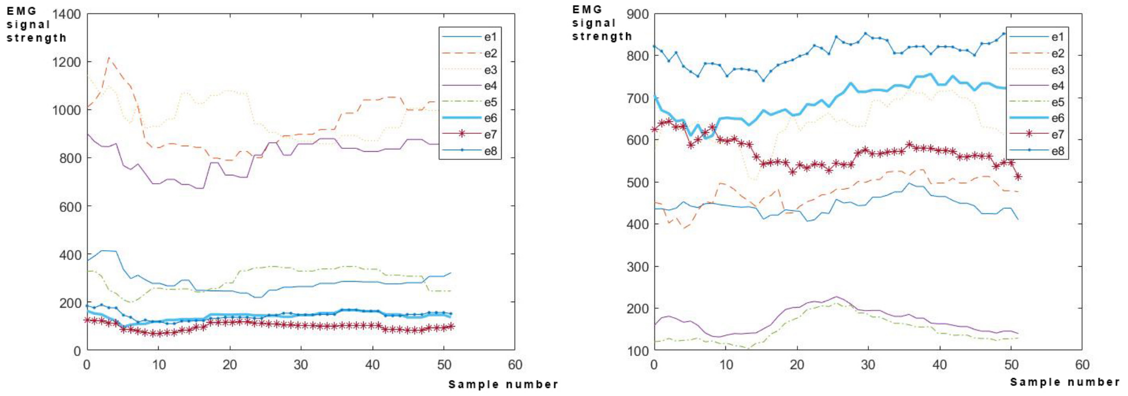
[12] Retrieved from: `http://www.bbc.co.uk/schools/gcsebitesize/pe/appliedanatomy/3_anatomy_muscles_rev4.shtml`



(a) Wave out **(b)** Wave in

Figure 6.1: EMG data

Comparing these two graphs a distinct difference between some sensors can be seen. The values for the sensors e2 and e3 are relatively high in both. This difference is not as distinct when looking at the same data for fist and spread fingers but is still present. Some distinct differences can be seen between some sensors, see appendix B.

The four hand postures that were used in this project were: fist, fingers spread, wave in and wave out. These are the same hand postures that are predefined for the Myo bands built-in hand posture recognition. These hand postures, as explained in section 5.1, are unique and therefore convenient to use together. The thumb to pinky hand posture, which is one of the predefined hand postures, was not used. However, the EMG data for this particular move is quite unique and could therefore be an appropriate complement to future projects.

The hand postures in combination with the orientation data were used to define the gestures for communication with the robot. The orientation data is both stable and precise, making it useful for defining different gestures. All gestures have some form of orientation constraint in its definition but not all gestures require hand posture. This is because the orientation data is consistent between uses as compared to the EMG data which is not. The orientation data is therefore more reliable.

The software that was developed for recognising hand postures was not used in this project. This is because the conclusion was drawn that the built-in hand posture recognition of the Myo band worked well enough and required much less calibration. The software that was developed in this project required calibration for several seconds for each hand posture while the built-in software of the Myo band only required calibration with one hand posture.

6.2 User study of gestures

The results obtained from the user study of gestures, described in subsection 4.2.1 and subsection 4.2.2, showed which gestures that felt the most natural and easy to use. The study results were used when designing gestures to make them feel intuitive, while at the same time the functionality of the Myo band was taken into consideration. This way the gestures would be made to both feel natural and be distinguishable enough for the system to detect them in a reliable way. The result from the first user study of gestures and the resulting gestures are presented in the following sections.

6.2.1 Stop

When the test users were asked to try to stop the robot, they all reacted in the same way. They raised their hand with their palm facing the robot. Additionally, they held their forearm in a way that made their outstretched fingers point towards the ceiling. They all said it was a natural and instinctive way to communicate the command for stop.

Since stopping is an important gesture for the sake of safety, the gesture does not have as many constraints as the other gestures. Only orientation of the arm and detection of the fiducial marker is set as constraints. The orientation condition is that the arm is held 50° above the horizontal axis.

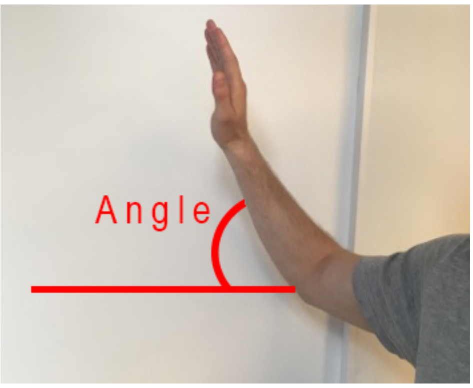


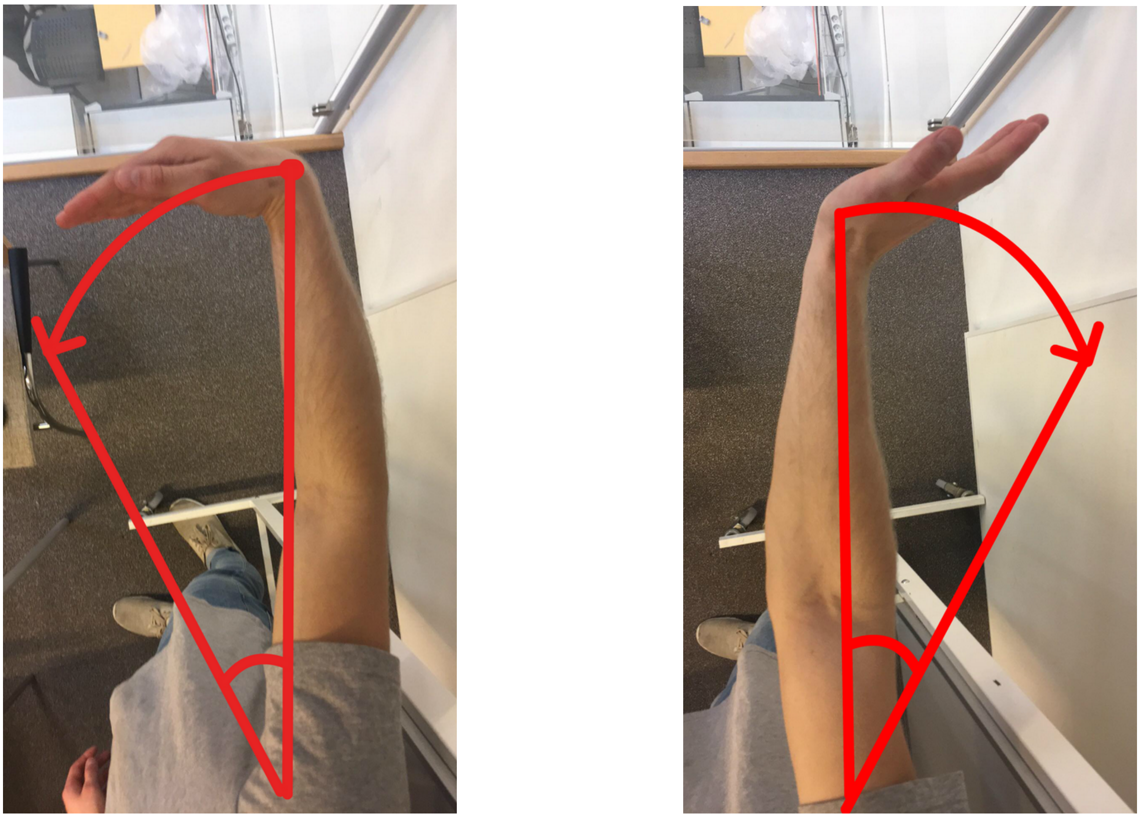
Figure 6.2: Stop gesture

One disadvantage with this command is that the gesture could be detected when not intended, since raising the hand in that way is a common gesture. Pairing it with the constraint of the robot being able to read the fiducial marker however, will decrease the risk of misinterpretation.

6.2.2 Move left/right

When the test users were asked to give a command for moving the robot to the left or right the results were different. The most common gesture that was noticed was a waving gesture to either the left or the right.

This was the basic inspiration for designing the gesture, but it still had to be designed in a way which made it possible for it to be detected by the Myo band and not easily be mixed up with other common movements. The final gesture ended up being a combination of flexing the wrist either to the right or left, and moving the arm in the same direction. This was because this gesture was both similar to the gesture from the study and it could easily be detected by the Myo band. To detect the gesture, the definition for the move left command was that the hand posture was in wave-in posture and that the arm then rotates 25°to the left. The definition for move right was the same with the exception that the hand posture had to be wave-out, and that the rotation was to the right, see figure 6.3.



(a) Move left gesture

(b) Move right gesture

Figure 6.3: Move left/right gestures

6.2.3 Change speed

The results obtained from the first user study, as described in subsection 4.2.1, produced one gesture in particular. All of the test users agreed that the most natural command for slowing down or speeding up the robot would be to move their arm downwards or upwards with palm facing either floor or ceiling. This was also the instinctive response to when the test users had to act without thinking in a hurry.

Henceforth this gesture is referred to as the ”wave gesture”, see figure 6.4.

The implementation of this gesture using the Myo band does however present some problems. There is no way to know if the palm is facing the floor or the ceiling by simply looking at the orientation data from the Myo band. To be able to determine this some form of calibration would be needed where the user tells the system that the palm is currently facing the floor. Another problem was how to determine how much the speed of the robot changes. It could change by a constant amount for each ”wave” performed or it could be based on the speed of the ”wave”. The gesture also takes time to perform meaning that the time period between when the user decides to slow down the robot to when the robot actually slows down is quite substantial. If the user wanted to slow down the robot substantially, the user would probably also have to perform several wave gestures which could be exhausting.

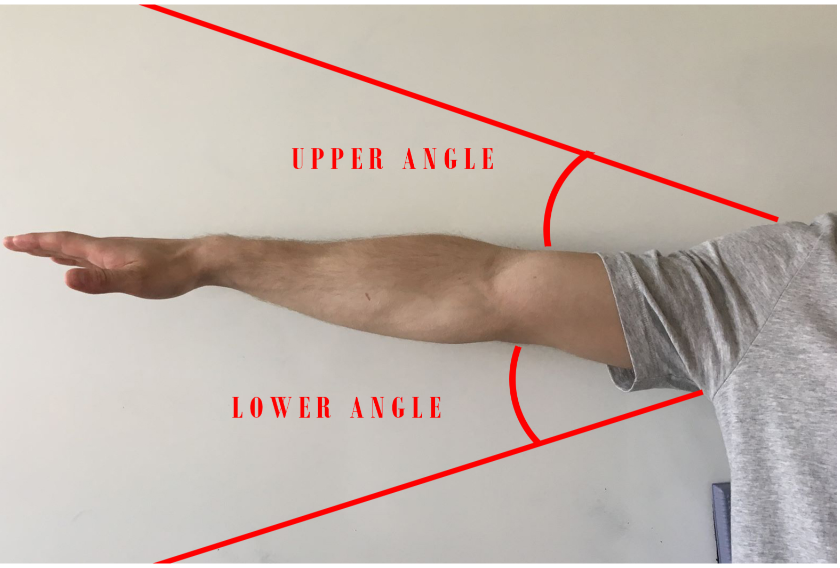


Figure 6.4: Wave gesture

Since the wave gesture had so many problems associated with it, it was instead decided to use the gesture for slowing down and speeding up which had been defined before the study. This gesture consisted of making the fist hand posture and then rotating the arm clockwise or anti-clockwise to either slow down or speed up the robot, in a similar way to how the volume is changed on an old radio. This gesture is henceforth referred to as the ”volume gesture”.

Once the user has rotated the arm at least 20° in either direction the speed of the robot will change by 0.5 % of the maximum speed every 100 ms. This has the advantage of showing the user more clearly how much the robots speed changes when performing the gesture since they can see the robot continually slowing down or speeding up as long as they hold the gesture. It is also much faster to perform and slowing down or speeding up the robot does not require repeated movements, it only requires the user to hold the gesture longer. There is also no need for calibration, something which is required for the wave gesture, since the orientation of the Myo band is simply compared to the orientation recorded when the fist hand posture first is held.

When the test users were asked about the volume gesture three out of the six test users agreed it was a good gesture for speeding up and slowing down. While the wave gesture may have been the intuitive way to tell the robot to slow down or speed up, it was difficult when it came to implementation.

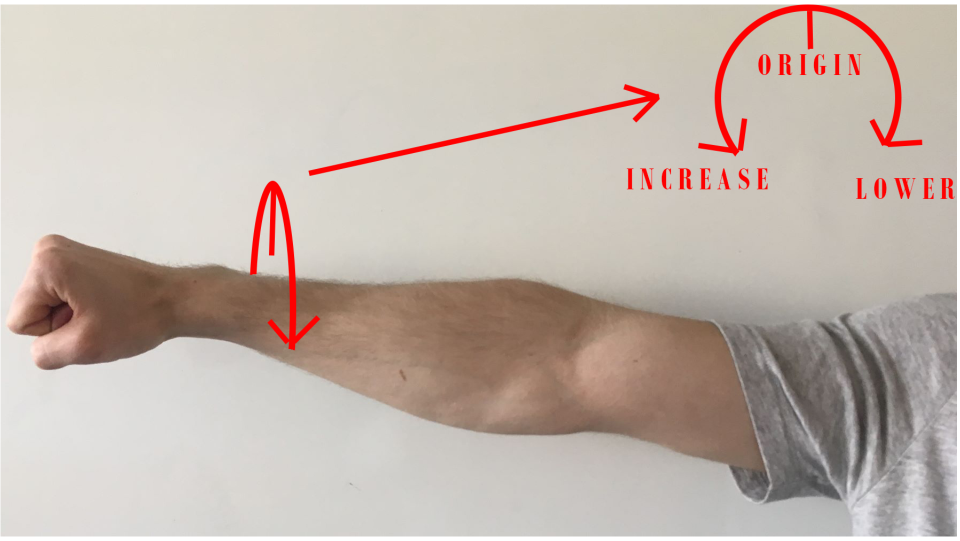


Figure 6.5: Volume gesture

Table 6.1: Comparison of the two gestures

	Wave gesture	Volume gesture
Natural gesture	+	-
Easy to implement	-	+
Comfortable	-	+
Delay in response	-	+
Requires calibration	-	+

6.2.4 Continue

The gesture made by the test users for commanding the robot to continue varied. However, the common denominator was that the commands consisted of some form of waving motion, making big circular movements.

Two new gestures were created based on this. The first one was closing the hand into a fist and then waving in a circle towards the body. The second was created in case there would be problems with the first gesture, for example if it would be too difficult for the Myo band to detect. The second gesture was holding the arm straight out, close the hand into a fist and then move the arm toward the chest and then out again.

The first gesture was chosen since it was more similar to what the test users had shown to be a natural continue gesture. The implementation consisted of continually checking the orientation of the Myo band while a fist gesture was held, similar to the "volume gesture" described in section 6.2.3. This gesture, however, instead checks the angular difference in rotation around the x- and y-axis, as compared to rotation around the z-axis, that is vertical and horizontal rotation instead of rotation around the arm. To complete the gesture two full anti-clockwise circle movements have to be made by the user. This is checked by defining four zones, where once the Myo bands orientation has passed trough all four zones it is considered one full circle move. Since the move was supposed to be similar to a wave towards oneself, it was decided that the arm starts in the right zone, meaning that the circle movement has to start by moving the arm upwards and then left.

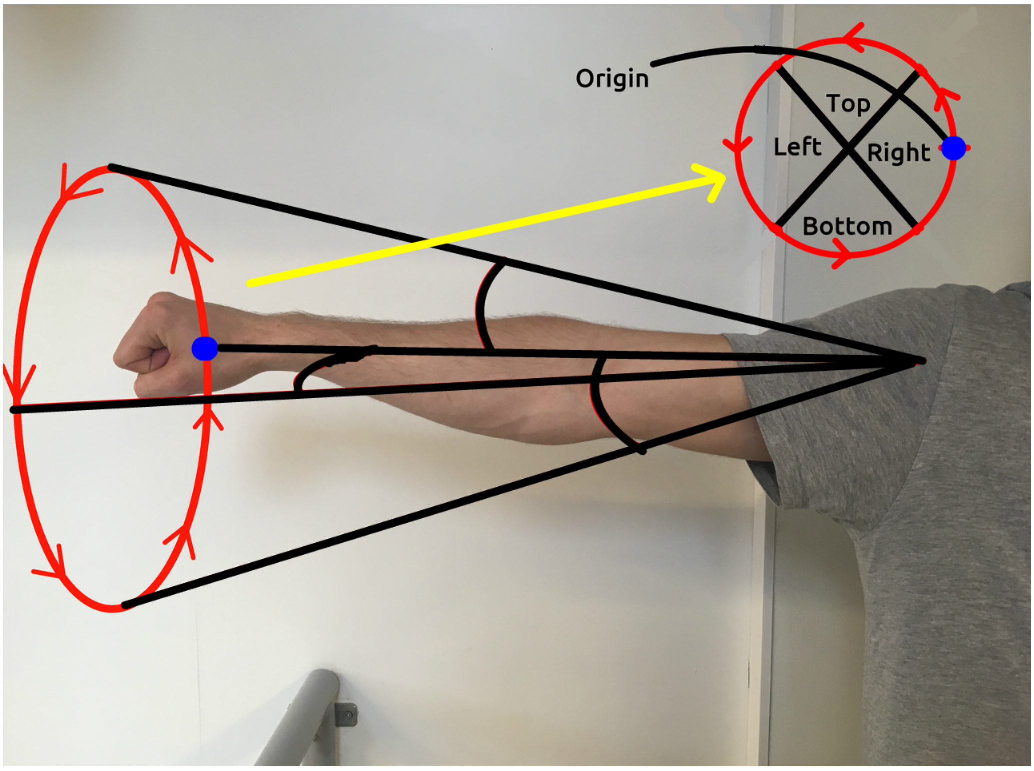


Figure 6.6: Continue gesture

6.2.5 AprilTags

Test study one showed that test users wanted to look at the robot to see what command to give and if a command is appropriate. The AprilTag could be fastened on the operators chest or helmet to make commands made by the Myo band accepted only if the operator is looking at or is facing the robot. By doing this the risk of misscommunication is reduced. The accuracy of and the distance from which the program could detect a AprilTag needed to be measured if it could be used for the intended purpose. It had to be able to detect an AprilTag from the distance the operator wish to communicate with the robot from. To test this an AprilTag of the size 10x10 was held in front of the camera and moved away until the program no longer could detect it.

AprilTags were tested separately to minimise interference that could have cause incorrect results. The distance test made with AprilTags showed that the distance from which the tags could be detected by the program was adequate enough for the needs of this project. The furthest distance possible was not noted since it depends on the size of the AprilTag and also the quality of the image of the web camera.

6.3 User study of robustness

Figure 6.7 shows the result of the study containing ten users performing every gesture five times. The users were given clear instructions on how to perform the gestures.

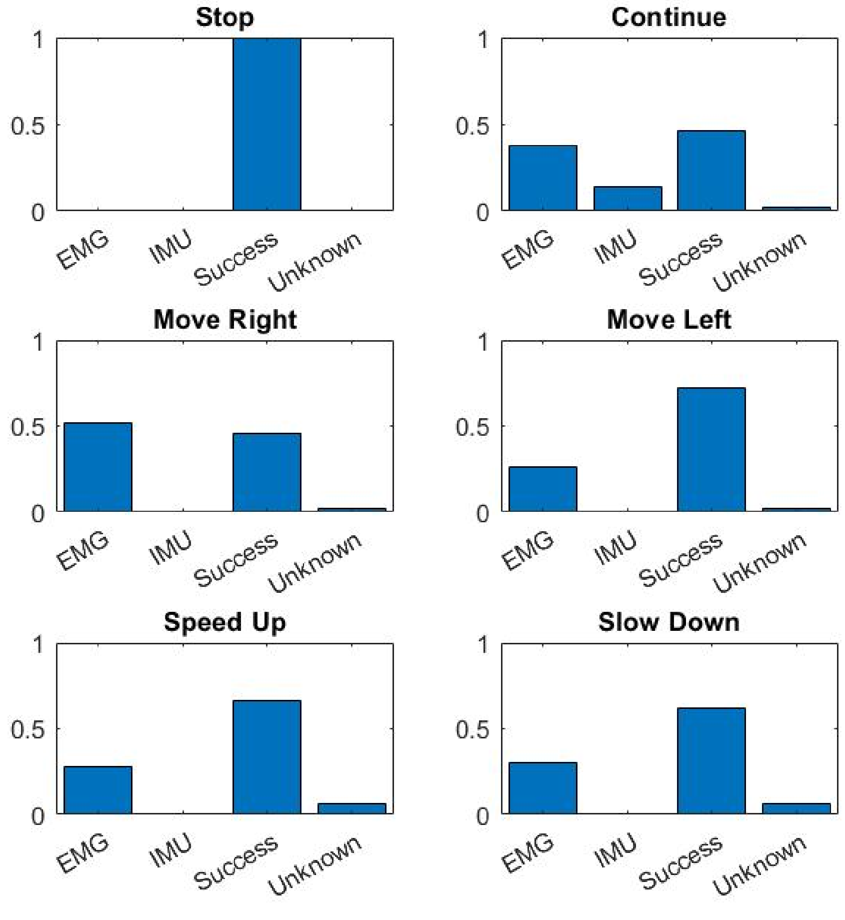


Figure 6.7: Study of robustness

In figure 6.7 EMG, IMU and unknown all refer to failure of the gesture recognition nodes for recognising the given gesture. The label refer to the reason for the failure. EMG means that the Myo band did not recognise the given hand posture either at all, too late, or stopped recognising it too early. This is henceforth called posture failure.

Table 6.2 show how many times the robot did not receive a given command. It is given in the form success/posture failure/orientation failure/unknown failure. There was also many times the robot did something as a response to a gesture when no command was supposed to be given. No statistics of this was recorded. For example, the continue command sometimes triggered change in speed instead of or at the same time as continue. The continue command also sometimes triggered the move left/right command. This was because the Myo band sent out signals telling that either the wave in or wave out gesture was being held while, in fact, the user was holding their hand in a closed fist.

Table 6.2: A table with the individual users amount of successes and failures, given in the form success/posture failure/orientation failure/unknown failure

	Stop	Continue	Move right	Move left	Speed up	Slow down
user 1	5/0/0/0	2/2/1/0	5/1/0/0	5/0/0/0	5/0/0/0	5/0/0/0
user 2	5/0/0/0	1/4/0/0	1/3/0/1	5/0/0/0	2/0/0/3	2/0/0/3
user 3	5/0/0/0	4/1/0/0	2/3/0/0	4/1/0/0	3/2/0/0	2/3/0/0
user 4	5/0/0/0	2/1/1/1	1/4/0/0	5/0/0/0	4/1/0/0	4/1/0/0
user 5	5/0/0/0	0/5/0/0	3/2/0/0	1/4/0/0	0/5/0/0	0/5/0/0
user 6	5/0/0/0	3/1/1/0	4/1/0/0	3/2/0/0	5/0/0/0	5/0/0/0
user 7	5/0/0/0	5/0/0/0	3/2/0/0	2/3/0/0	3/2/0/0	3/2/0/0
user 8	5/0/0/0	3/0/2/0	3/2/0/0	4/1/0/0	5/0/0/0	5/0/0/0
user 9	5/0/0/0	2/2/1/0	3/2/0/0	2/2/0/1	4/1/0/0	5/0/0/0
user 10	5/0/0/0	1/3/1/0	1/4/0/0	3/2/0/0	3/2/0/0	1/4/0/0

The stop command only consists of one orientation condition to register as a success and it had a success rate of 100 %. The continue command consists of many orientation conditions to register as a success and a hand posture condition. The continue gesture is also the only gesture to fail because of orientation, mostly because it is vulnerable to a switch in angle, see figure 6.8. The continue command had the lowest success rate out of all the gestures, 46 %. For one of the test users the Myo band was unable to register the fist hand posture, even though the user correctly held the hand in a fist. This made it impossible for this particular test user to successfully command the robot to continue, speed up and slow down, since all of these required the Myo band to register the fist hand posture.

The software in the Myo band succeeded at recognising the hand postures of some users while for some users certain hand postures at all were barely not recognised at all. This might have been caused by the Myo band fitting too loose on some of the test users forearms. Sizing clips should have been used on subjects with smaller forearms, these were unfortunately not available. It might also depend on the anatomy of the arm for each user.

The Myo band did in fact recognise the correct hand posture in some cases where a command failed because of a posture failure. The failure, in those cases, was caused by the Myo band either recognising the hand posture too late or stopping recognising it too early. For example, the continue gesture demands that the user makes two circles with their hand and if the fist is not closed during the entire gesture the command will not work.

All of the IMU failures refer to the program not detecting the gesture because the test user did not move his/her arm through all four zones when doing the continue gesture, as described in figure 6.6. If the gesture is performed over a certain "angle switch" the gesture will fail to be recognised. When the Myo band measures orientation the available output is between -180° and 180°, this means that if the Myo bands orientation passes 180° in orientation, it switches to -180°. This a major reason for why the continue command had such a low success rate, some test users made the command over this "angle switch". Other reasons was that the users did not perform the gesture through all four zones, which is required for it to register as a success. The cause of this could be because the user did not make large enough circle movements, which mostly made the program miss the left zone.

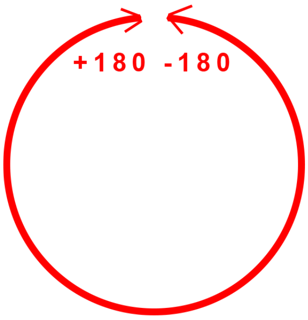


Figure 6.8: Angle switch

7 Discussion

In this chapter, the Myo band set in an industrial environment is evaluated, as well as the ergonomics of gestures along with source of errors in the user studies. Finally, the ethical aspect of introducing collaborative robots in industrial environments is discussed.

7.1 Myo band

When the Myo band is used in an industrial environment as a tool for human robot interaction, some inconveniences are to be expected. One of these inconveniences are that the operator is required to synchronise the Myo band every time it is put on. While the synchronising does not take long, it is only about 15-30 seconds, it will be a repetitive task. Furthermore, the operator will also have to re-synchronise the Myo band if it accidentally slides or rotates a few millimetres on the arm. Together these inconveniences will be time-consuming, and are therefore one of the big problems with the Myo band if it were to be used in an industrial environment.

The Myo band is accurate when detecting change in acceleration and orientation. As mentioned in section 2.3, IMU has been tested and widely used in many places where accuracy is of concern. Using the Myo band to detect EMG signals in the arm however does not meet the same standards. It is therefore questionable if the EMG readings of the Myo band could be used in situations where safety is of concern. The EMG signals that are registered are not accurate enough, which means that it is not safe to control robots this way since they can potentially cause harm to people or objects nearby. With different strategies better results can however be obtained as shown by another study which is further explained in section 2.4. This study was performed under controlled settings with a time of 35 minutes per user to obtain the results. Such settings are quite unrealistic, why the results from that study does not align with the purpose of this project where the Myo band is examined in a more realistic setting.

While the Myo band may sometimes have trouble detecting EMG signals, implementation can be made to improve the interpretation of the EMG data and regulate parameters to better fit certain situations, see section 5.1. Although, regulation is in this situation always a trade off. The trade off being between making the hand postures register with high probability when the operator intends to and reduce the risk of accidentally sending a command. More constraints complicates making the gesture but it lowers the risk of accidentally sending commands. This dilemma also applies to the gesture when including orientation constraints. When the arm is solely used to communicate this becomes a problem since many of the movements used to design the gestures are part of a regular working routine. This problem was observed in the study of robustness when gestures that were designed to be unique still caused registration of another command instead of or simultaneously as the intended command.

Moreover the Myo band can not detect whether the elbow is bent or not. As demonstrated in figure 7.1 the Myo band register these movements as being the same since the orientation of the Myo band is the same. Similarly, the Myo band detects orientation changes when the whole body changes orientation. For example if the body is turned 180° while the arm remains in a static position relatively to the body, the Myo band still detects the change in orientation from the body turning. This can further complicate the interpretation of the data from the Myo band and reduces the possibilities of making unique gestures.

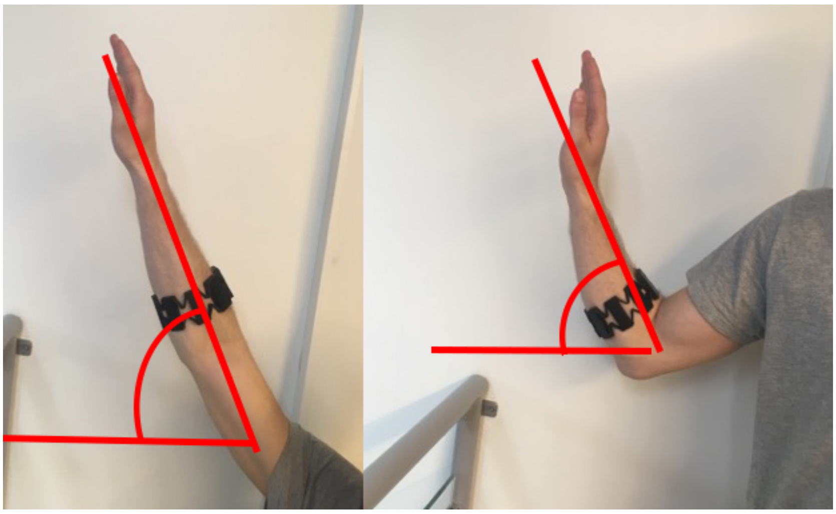


Figure 7.1: The Myo band outputs the same orientation data for both of these situations

The data from the accelerometer was not used in this project. This data can be obtained from the Myo band and could perhaps have been used to make the gestures more robust and unique.

7.2 Construction of gestures

From the study done on robustness, results was obtained which showed that defining gestures from orientation instead of hand postures is better. This is however a bit misleading since, as explained in section 5.1, the recognition of the hand postures can be greatly improved. Having just one orientation constraint, which most of the gestures had, works well. The gestures have to be unique however to avoid sending the wrong command, which requires more constraints. For the gesture for continue, a lot of orientation constraints was defined and this gesture thereby shows more orientation errors. This might be because of other reasons like the degree switch, which can be seen in figure 6.8, or because of the way the gesture is constructed. For the gesture to work, all the constraints have to meet in sequence and thus it is harder to perform.

Nonetheless, it may still be questionable if motion detection is a reliable way of sending a large number of commands to a robot. The number of constraints needed for this increases and thus the difficulty in performing the gestures increases as well. If the interpretation of the EMG data can be improved, the number of unique hand postures will also improve greatly. It is easier to know if the hand is in the right position than if the arm is angled accordingly. This means that the failure rate might be reduced if more hand postures is included. Before this can be implemented however, the errors must be fixed.

Another aspect of gesture construction is the complexity of the movement seen from a human perspective and not in how unique or how well it functions with the Myo band. Instructions are given to users on how to make the commands and the user can then interpret the move in many ways. In the robustness study it was observed that the users performed the volume gesture and the stop gesture similarly to each other. The way the move right and move left gestures were performed differed more and the way the continue command were performed varied greatly. When defining constraints, this becomes a big problem. This is because people have different perceptions on, for example, how big circle to make when given certain instructions. This is something which has to be accounted for in the program or in the instructions to make them clearer. Therefore, as mentioned earlier, it may be preferred to construct gestures from hand postures as they cannot vary and be interpreted in too many ways.

7.3 Ergonomics of gestures

When communicating with the aid of hand postures, there will be cases when the human will suffer from fatigue and pain. That will be a result from uncomfortable hand postures. One uncomfortable hand posture is the hand posture used in the gesture for moving the robot to the right, since this command requires the bearer to flex the wrist more than 45°. Another uncomfortable hand posture is when the fingers form a tight fist, which is required for the gestures that increase and decrease the speed, as well as for the gesture that commands the robot to continue.

The reason why some hand postures put more distress on the muscles than others is because of the biomechanics and physics of the hand. The postures that tend to lead to fatigue and discomfort have in common that they require high levels of muscle activity and coordination. In addition to that, the range in which people can move their wrists and fingers varies due to age, genetics and medical conditions

[16].

This is one disadvantage with gesture control, since it means that the robustness will vary depending on the physics of the operator. Furthermore, fatigue is an unwanted consequence, considering that the gesture control is supposed to be a resource rather than an impediment. A deeper study regarding comfortable gestures is recommended to develop gestures that are applicable to use, and which do not cause fatigue to the operator.

7.4 Source of errors

The user study of gestures was well thought out considering the aim of the study, which was to examine which gestures that felt the most intuitive and natural. For instance, the questions were asked in a specific order to ensure no ideas of possible gestures were given to the test users beforehand. The test users got to act instinctively when making gestures, as well as they were given time to think about which gestures they found appropriate for different commands. The study was conducted with the robot driving. This was to simulate a realistic environment. But since the users were continuously interviewed it was hard to know if the communication was in fact pure human to robot communication and not communication human to human. Some of the users made the commands whilst looking at the interviewer and some looked at the interviewer afterwards for approval.

The user study of gestures was conducted on students only. The best users for the study would have been the intended users which is factory workers. They have a better understanding on what is needed in a industrial environment and probably have a different movement pattern.

In the study of robustness similar instructions were given before each set of gestures were performed to all users. Instructions are a big part of how the users interpret the gesture and perform it, which in turn effect the result. Since the users of the study performed some gestures differently it is evident that the instructions could be made clearer which might result in better communication and better results.

The Myo band needs to sit tight around the forearm in order work properly. Some of the users in the study of robustness had smaller forearms which decreased the probability of registration of a correct hand posture.

One weakness in both of the studies is the amount of test users. Only six test users participated in the first study and ten in the second, which reduces the reliability of the studies and their results. For continued studies additional test users are recommended to receive more convincing results.

7.5 Ethics

The usage of autonomous and collaborative robots is an increasing occurrence. Since it is such a new area it is still quite unexplored, and thus the consequences of the usage of autonomous robots are yet not well known. Therefore there are difficulties predicting how the robots will influence the future.

One of the big ethical aspects are that collaborative robots probably will change how humans work. Collaborative robots are not supposed to replace the human, but they will definitely still at least change the way humans work as a result of the collaboration between human and robot. The human will have to take the robot into consideration and communicate in a different way, compared to earlier when the human worked alone or with other humans.

The attitudes of factory workers towards industrial and collaborative robots has been studied by S.A Elprama et al. [19]. All factory workers interviewed in the study expressed concerns over the fact that robots could take their jobs. However, as the study concluded, designing collaborative robot applications in a way that meet the needs of the workers might mitigate their concerns for loss of jobs and instead encourage the use of collaborative robots amongst factory workers.

Despite the intention of not replacing humans with collaborative robots, it still is a possible outcome. This will result in both positive and negative effects. On one hand, it would lead to operators focusing on higher value-adding tasks. However, on the other hand, it would lead a decrease in job opportunities, which will affect the community and possibly make partitions within society bigger since it will reduce the amount of work that requires no further education.

Another ethical difficulty is deciding who is in charge of the robot's actions. If something goes wrong and the robot accidentally injures, or even kills someone, the question of who to hold responsible may arise. To hold a machine responsible for its actions may seem questionable, but then it can be discussed if the responsibility lies with the designer of the robot or perhaps, as in this case, the bearer of the Myo band. This is not easy to give a clear answer to, and the answer will probably vary from one person to another, and depending on the situation. Thus, the usage of autonomous robots might require laws for these situations, which presumably will be complicated to make due to the ethical aspects of the questions.

8 Conclusion

In this chapter conclusions are made regarding how the human robot interaction, set in an industrial environment, works in collaboration with the provided equipment. Additionally, conclusions regarding conceivable future improvements are made.

The gestures which were defined after the first user study are designed to feel natural. Most are based on the natural response of users when spontaneously asked to command the robot to do something with a gesture.

The possibilities of human robot interaction using the Myo band are limited, but useful. The gesture recognition that was developed in this project did not achieve the level of robustness that was desired. Most gestures were however recognised almost every time for some individual users, while some gestures completely failed to be recognised for other users. The reason for this huge difference between individual users are that the built-in hand posture recognition of the Myo band seems to work poorly on some individuals. To solve this problem, the software for recognising hand postures using the raw EMG sensor data would have to be used. This software, however, requires long time periods for calibration for every single hand posture used. The time needed for calibration would have to be drastically reduced if that software were to be used. Moreover the software was not fully developed and as shown in section 2.4, statistical classification techniques could have been used to further improve the hand posture recognition software. Another possible improvement is if a more simple way to calibrate the hand posture recognition would have been developed. For instance, similar to the way the Myo band calibrates the built-in hand posture recognition software, which is simply holding the wave out hand posture for a few seconds. The hand posture recognition software is the area most in need of improvement in this project.

The orientation data from the Myo band is precise, which makes it useful when defining gestures. It is probably possible to compensate for the switch in degree from -180° to 180° in the gesture recognition program. If it would have been compensated for, most of the orientation errors in the robustness user study would have been solved.

Additionally, the robustness of the system might also have been improved by adding more sensors to track more parts of the body with better accuracy. This could possibly be achieved with for example a depth camera. The problem with that approach, however, is that real time gesture recognition using depth cameras have not been achieved yet, meaning that there is a substantial delay between a user making a gesture and the system recognising the gesture. Meanwhile the gesture recognition using the Myo band is in real time.

Bibliography

[1] S. Fölster, ”Vartannat jobb automatiseras inom 20 år - utmaningar för Sverige,” Stiftelsen för strategisk forskning, Stockholm, Sweden, 1 st edition, 2014. [Online]. Available at: `https://strategiska.se/wp-content/uploads/folder.pdf`, Accessed on: 2018-01-17.

[2] V. Mazzari, ”Collaborative robots and traditional robots: 5 key differences”, Jan 2015. [Online]. Available at: `https://www.generationrobots.com/blog/en/2015/01/collaborative-robots-traditional-robots-5-key-differences/`, Accessed on: 2018-04-08.

[3] Financial times, ”Meet the cobots: humans and robots together on the factory floor” "Financial times, Florida, May 2016. [Online]. Available at: `https://www.ft.com/content/6d5d609e-02e2-11e6-af1d-c47326021344`, Accessed on: 2018-01-24.

[4] Á. Bertelsen, D. Scorza, C. Cortés, J. Oñativia, Á. Escudero, E. Sánchez, J. Presa, ”Collaborative Robots for Surgical Applications”. In: Ollero A., Sanfeliu A., Montano L., Lau N., Cardeira C. (eds) ROBOT 2017: Third Iberian Robotics Conference. ROBOT 2017. Advances in Intelligent Systems and Computing, vol 694, pp 524-535. [Online]. doi: `https://doi.org/10.1007/978-3-319-70836-2_43` Accessed on: 2018-03-07

[5] N. Mavridis, ”A review of verbal and non-verbal human–robot interactive communication”, *Robotics and Autonomous Systems*, vol. 63, part 1, pp. 22-35, January 2015. doi: `10.1016/j.robot.2014.09.031` [Online]. Accessed on: 2018-04-10

[6] X. Lv, M. Zhang and H. Li, ”Robot Control Based on Voice Command,” in *IEEE International Conference on Automation and Logistics*, 2008. [Online]. doi: `https://www.doi.org/10.1109/ICAL.2008.4636587`, Accessed on 2018-04-17

[7] A. Rogowski, ”Robotics and Computer-Integrated Manufacturing,” *Robotics and Computer-Integrated Manufacturing*, vol. 28, Issue 3, pp. 303-315, June 2012. doi: `https://doi.org/10.1016/j.rcim.2011.09.010`, [Online]. Accessed 2018-04-19

[8] A. Buendia and L. Devillers, ”From Informative Cooperative Dialogues to Long-Term Social Relation with a Robot” in *Natural Interaction with Robots, Knowbots and Smartphones*, pp. 135-151, 2014, [Online]. doi: `https://doi.org/10.1007/978-1-4614-8280-2_13`, Accessed 2018-04-19

[9] E. Coupeté, F. Moutarde, S. Manitsaris, ıGesture recognition using a depth camera for human robot collaboration on assembly lineȷ, *Procedia Manufacturing*, vol. 3, pp. 518-525, 2015. doi: `https://doi.org/10.1016/j.promfg.2015.07.216`, [Online]. Accessed on: 2018-04-20

[10] A. Chaudhary, J.L Raheja, ıLight invariant real-time robust hand gesture recognitionȷ, *Optik*, vol. 159, pp. 283-294, April 2018. doi: `https://doi.org/10.1016/j.ijleo.2017.11.158`, [Online]. Accessed on: 2018-04-20

[11] F. Gustin, I. Rendulic, N. Miskovic and Z. Vukic, ıHand gesture recognition from multibeam sonar imagery ȷ, *IFAC-PapersOnLine*, vol. 49, Issue 23, pp. 470-475, 2016. doi: `https://doi.org/10.1016/j.ifacol.2016.10.450`, [Online]. Accessed on: 2018-04-20

[12] C. A. Cifuentes, A. Frizera, R. Carelli and T. Bastos, ”Human–robot interaction based on wearable IMU sensor and laser range finder”, *Robotics and Autonomous Systems*, vol. 62, Issue 10, pp. 1425-1439, Oct 2014. doi: `https://doi.org/10.1016/j.robot.2014.06.001`, [Online]. Accessed on: 2018-04-20

[13] A. Polishchuk, W.T. Navaraj, H. Heidari and R. Dahiya, ”Multisensory Smart Glove for Tactile Feedback in Prosthetic Hand,” *Procedia Engineering*, vol. 168, pp. 1605-1608, 2016. doi: `https://doi.org/10.1016/j.proeng.2016.11.471`, [Online]. Accessed on: 2018-04-20

[14] S. Mitra and T. Acharya, ”Gesture Recognition: A Survey,” *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)*, vol 37, Issue 3, pp. 311 - 324, April 2007. doi: `https://doi.org/10.1109/TSMCC.2007.893280`, [Online]. Accessed on: 2018-04-20

[15] K.Akhmadeev, E. Rampone, T. Yu, Y. Aoustin and E. Le Carpentier, ”A testing system for a real-time gesture classification using surface EMG,” in *IFAC PapersOnLine*, 2017, pp. 11498-11503. [Online]. doi: `https://doi.org/10.1016/j.ifacol.2017.08.1602`, Accessed on: 2018-04-17

[16] D. Rempel, M.J. Camilleri, D.L. Lee, ”The design of hand gestures for human–computer interaction: Lessons from sign language interpreters”,

International Journal of Human-Computer Studies, vol. 72, issues 10-11, pp. 728-735, Nov 2014. doi: `https://doi.org/10.1016/j.ijhcs.2014.05.003`, [Online]. Accessed on 2018-04-19

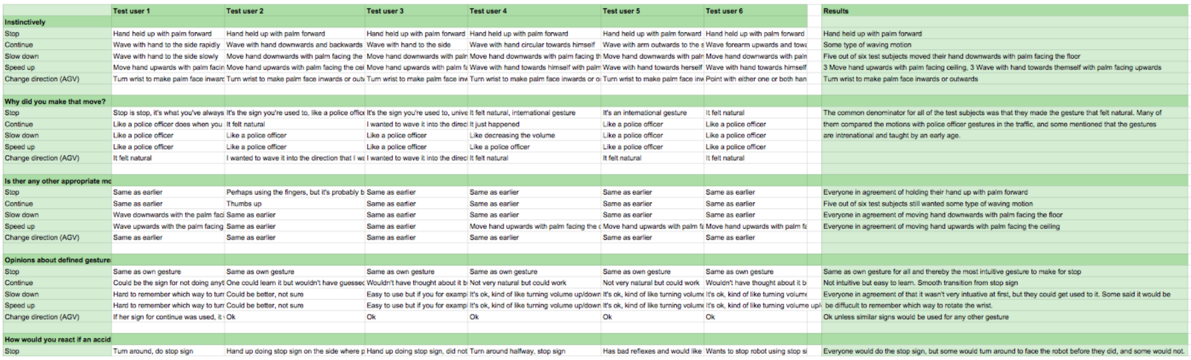
[17] S. Van der Woerdt, P. Haselager, ”When robots appear to have a mind: The human perception of machine agency and responsibility”, *New Ideas in Psychology*, Nov 2017. doi: `https://doi.org/10.1016/j.newideapsych.2017.11.001`, [Online]. Accessed on 2018-04-19,

[18] V. Villani, F. Pini, F. Leali, C. Secchi, ”Survey on human–robot collaboration in industrial settings: Safety, intuitive interfaces and applications”, *Mechatronics*, March 2018. doi: `https://doi.org/10.1016/j.mechatronics.2018.02.009`, [Online]. Accessed on: 2018-04-19

[19] S.A Elprama, C.I.C. Jewell, A. Jacobs, I.E. Makrini, B. Vanderborght, ”Attitudes of Factory Workers towards Industrial and Collaborative Robots”, in *Proceedings of the Companion of the 2017 ACM/IEEE International Conference on Human-Robot Interaction*, 2017, pp. 113-114. [Online]. doi: `https://doi.org/10.1145/3029798.3038309`, Accessed on: 2018-04-19

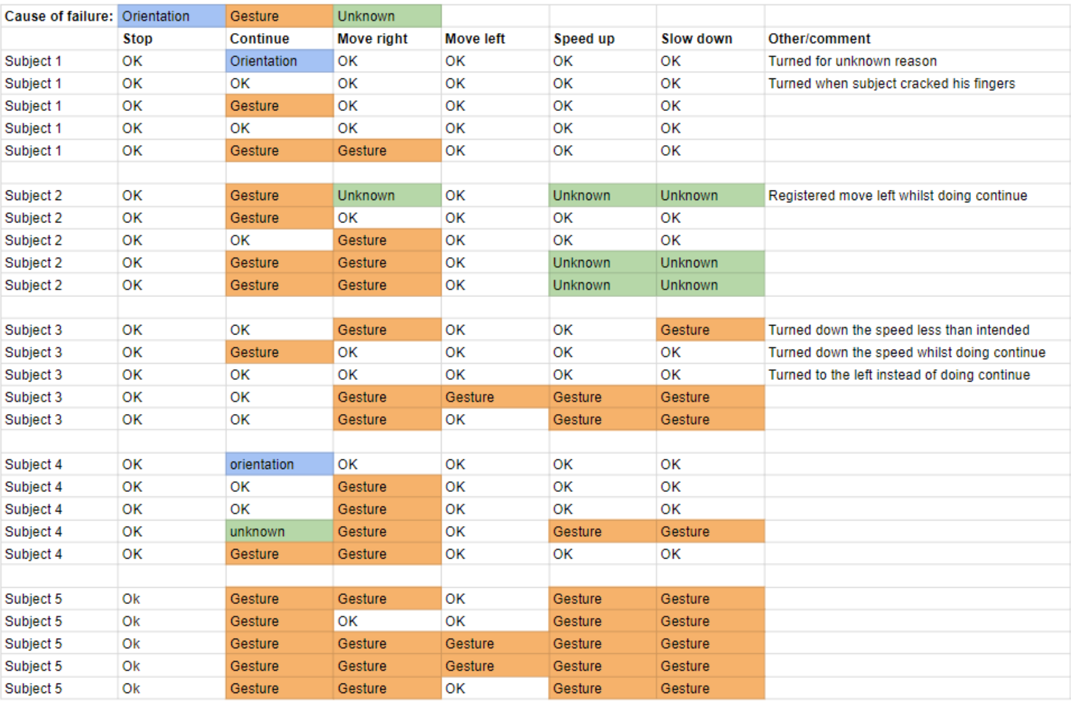
[20] K. Dautenhahn, ”Human-Robot Interaction,” in *The Encyclopedia of Human-Computer Interaction*, 2nd Ed. [Online]. Available: `https://www.interaction-design.org/literature/book/the-encyclopedia-of-human-computer-interaction-2nd-ed/human-robot-interaction`, Accessed on: 2018-04-13

A

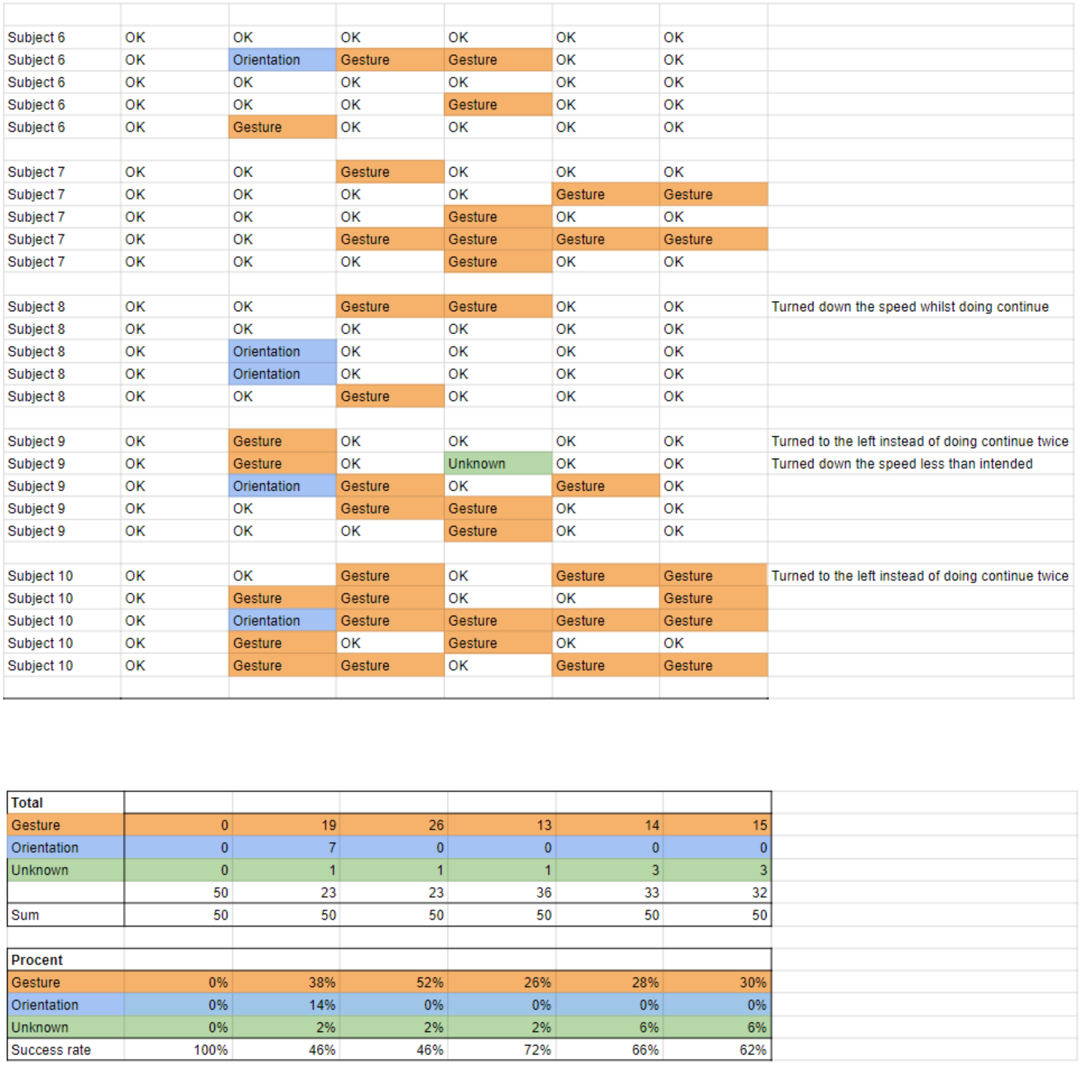


	Test user 1	Test user 2	Test user 3	Test user 4	Test user 5	Test user 6	Results
Instinctively							
Stop	Hand held up with palm forward	Hand held up with palm forward	Hand held up with palm forward	Hand held up with palm forward	Hand held up with palm forward	Hand held up with palm forward	Hand held up with palm forward
Continue	Wave with hand to the side rapidly	Wave with hand downwards and backwards	Wave with hand to the side	Wave with hand circular towards himself	Wave with arm outwards to the s	Wave forearm upwards and towa	Some type of waving motion
Slow down	Wave with hand to the side slowly	Move hand downwards with palm facing the	Move hand downwards with paln	Move hand downwards with palm facing th	Move hand downwards with paln	Move hand downwards with paln	Five out of six test subjects moved their hand downwards with palm facing the floor
Speed up	Move hand upwards with palm facin	Move hand upwards with palm facing the cei	Move hand upwards with palm fa	Wave with hand towards himself with palm	Wave with hand towards herself	Wave with hand towards himself	3 Move hand upwards with palm facing ceiling, 3 Wave with hand towards themself with palm facing upwards
Change direction (AGV)	Turn wrist to make palm face inwarc	Turn wrist to make palm face inwards or outv	Turn wrist to make palm face inw	Turn wrist to make palm face inwards or o	Turn wrist to make palm face inw	Point with either one or both han	Turn wrist to make palm face inwards or outwards
Why did you make that move?							
Stop	Stop is stop, it's what you've always	It's the sign you're used to, like a police offic	It's the sign you're used to, unive	It felt natural, international gesture	It's an international gesture	It felt natural	The common denominator for all of the test subjects was that they made the gesture that felt natural. Many of
Continue	Like a police officer does when you	It felt natural	I wanted to wave it into the direc	It just happened	Like a police officer	Like a police officer	them compared the motions with police officer gestures in the traffic, and some mentioned that the gestures
Slow down	Like a police officer	Like a police officer	Like a police officer	Like decreasing the volume	Like a police officer	Like a police officer	are intrenational and taught by an early age.
Speed up	Like a police officer	Like a police officer	Like a police officer	Like a police officer	Like a police officer	Like a police officer	
Change direction (AGV)	It felt natural	I wanted to wave it into the direction that I wa	I wanted to wave it into the direc	It felt natural	It felt natural	It felt natural	
Is ther any other appropriate mc							
Stop	Same as earlier	Perhaps using the fingers, but it's probably b	Same as earlier	Same as earlier	Same as earlier	Same as earlier	Everyone in agreement of holding their hand up with palm forward
Continue	Same as earlier	Thumbs up	Same as earlier	Same as earlier	Same as earlier	Same as earlier	Five out of six test subjects still wanted some type of waving motion
Slow down	Wave downwards with the palm faci	Same as earlier	Same as earlier	Same as earlier	Same as earlier	Same as earlier	Everyone in agreement of moving hand downwards with palm facing the floor
Speed up	Wave upwards with the palm facing	Same as earlier	Same as earlier	Move hand upwards with palm facing the c	Move hand upwards with palm fa	Move hand upwards with palm fa	Everyone in agreement of moving hand upwards with palm facing the ceiling
Change direction (AGV)	Same as earlier	Same as earlier	Same as earlier	Same as earlier	Same as earlier	Same as earlier	
Opinions about defined gesture:							
Stop	Same as own gesture	Same as own gesture	Same as own gesture	Same as own gesture	Same as own gesture	Same as own gesture	Same as own gesture for all and thereby the most intuitive gesture to make for stop
Continue	Could be the sign for not doing anyt	One could learn it but wouldn't have guessec	Wouldn't have thought about it b	Not very natural but could work	Not very natural but could work	Wouldn't have thought about it b	Not intuitive but easy to learn. Smooth transition from stop sign
Slow down	Hard to remember which way to turr	Could be better, not sure	Easy to use but if you for exampl	It's ok, kind of like turning volume up/down	It's ok, kind of like turning volum	It's ok, kind of like turning volume	Everyone in agreement of that it wasn't very intuative at first, but they could get used to it. Some said it would be
Speed up	Hard to remember which way to turr	Could be better, not sure	Easy to use but if you for exampl	It's ok, kind of like turning volume up/down	It's ok, kind of like turning volum	It's ok, kind of like turning volume up/	be diffucult to remember which way to rotate the wrist.
Change direction (AGV)	If her sign for continue was used, it	Ok	Ok	Ok	Ok	Ok	Ok unless similar signs would be used for any other gesture
How would you react if an accid							
Stop	Turn around, do stop sign	Hand up doing stop sign on the side where p	Hand up doing stop sign, did not	Turn around halfway, stop sign	Has bad reflexes and would like	Wants to stop robot using stop si	Everyone would do the stop sign, but some would turn around to face the robot before they did, and some would not.

Figure A.1: User study of gestures



Cause of failure:	Orientation	Gesture	Unknown				
	Stop	**Continue**	**Move right**	**Move left**	**Speed up**	**Slow down**	**Other/comment**
Subject 1	OK	Orientation	OK	OK	OK	OK	Turned for unknown reason
Subject 1	OK	OK	OK	OK	OK	OK	Turned when subject cracked his fingers
Subject 1	OK	Gesture	OK	OK	OK	OK	
Subject 1	OK	OK	OK	OK	OK	OK	
Subject 1	OK	Gesture	Gesture	OK	OK	OK	
Subject 2	OK	Gesture	Unknown	OK	Unknown	Unknown	Registered move left whilst doing continue
Subject 2	OK	Gesture	OK	OK	OK	OK	
Subject 2	OK	OK	Gesture	OK	OK	OK	
Subject 2	OK	Gesture	Gesture	OK	Unknown	Unknown	
Subject 2	OK	Gesture	Gesture	OK	Unknown	Unknown	
Subject 3	OK	OK	Gesture	OK	OK	Gesture	Turned down the speed less than intended
Subject 3	OK	Gesture	OK	OK	OK	OK	Turned down the speed whilst doing continue
Subject 3	OK	OK	OK	OK	OK	OK	Turned to the left instead of doing continue
Subject 3	OK	OK	Gesture	Gesture	Gesture	Gesture	
Subject 3	OK	OK	Gesture	OK	Gesture	Gesture	
Subject 4	OK	orientation	OK	OK	OK	OK	
Subject 4	OK	OK	Gesture	OK	OK	OK	
Subject 4	OK	OK	Gesture	OK	OK	OK	
Subject 4	OK	unknown	Gesture	OK	Gesture	Gesture	
Subject 4	OK	Gesture	Gesture	OK	OK	OK	
Subject 5	Ok	Gesture	Gesture	OK	Gesture	Gesture	
Subject 5	Ok	Gesture	OK	OK	Gesture	Gesture	
Subject 5	Ok	Gesture	Gesture	Gesture	Gesture	Gesture	
Subject 5	Ok	Gesture	Gesture	Gesture	Gesture	Gesture	
Subject 5	Ok	Gesture	Gesture	OK	Gesture	Gesture	



Subject 6	OK	OK	OK	OK	OK	OK	
Subject 6	OK	Orientation	Gesture	Gesture	OK	OK	
Subject 6	OK	OK	OK	OK	OK	OK	
Subject 6	OK	OK	OK	Gesture	OK	OK	
Subject 6	OK	Gesture	OK	OK	OK	OK	
Subject 7	OK	OK	Gesture	OK	OK	OK	
Subject 7	OK	OK	OK	OK	Gesture	Gesture	
Subject 7	OK	OK	OK	Gesture	OK	OK	
Subject 7	OK	OK	Gesture	Gesture	Gesture	Gesture	
Subject 7	OK	OK	OK	Gesture	OK	OK	
Subject 8	OK	OK	Gesture	Gesture	OK	OK	Turned down the speed whilst doing continue
Subject 8	OK	OK	OK	OK	OK	OK	
Subject 8	OK	Orientation	OK	OK	OK	OK	
Subject 8	OK	Orientation	OK	OK	OK	OK	
Subject 8	OK	OK	Gesture	OK	OK	OK	
Subject 9	OK	Gesture	OK	OK	OK	OK	Turned to the left instead of doing continue twice
Subject 9	OK	Gesture	OK	Unknown	OK	OK	Turned down the speed less than intended
Subject 9	OK	Orientation	Gesture	OK	Gesture	OK	
Subject 9	OK	OK	Gesture	Gesture	OK	OK	
Subject 9	OK	OK	OK	Gesture	OK	OK	
Subject 10	OK	OK	Gesture	OK	Gesture	Gesture	Turned to the left instead of doing continue twice
Subject 10	OK	Gesture	Gesture	OK	OK	Gesture	
Subject 10	OK	Orientation	Gesture	Gesture	Gesture	Gesture	
Subject 10	OK	Gesture	OK	Gesture	OK	OK	
Subject 10	OK	Gesture	Gesture	OK	Gesture	Gesture	

Total						
Gesture	0	19	26	13	14	15
Orientation	0	7	0	0	0	0
Unknown	0	1	1	1	3	3
	50	23	23	36	33	32
Sum	50	50	50	50	50	50

Procent						
Gesture	0%	38%	52%	26%	28%	30%
Orientation	0%	14%	0%	0%	0%	0%
Unknown	0%	2%	2%	2%	6%	6%
Success rate	100%	46%	46%	72%	66%	62%

Figure A.2: User study of robustness

B

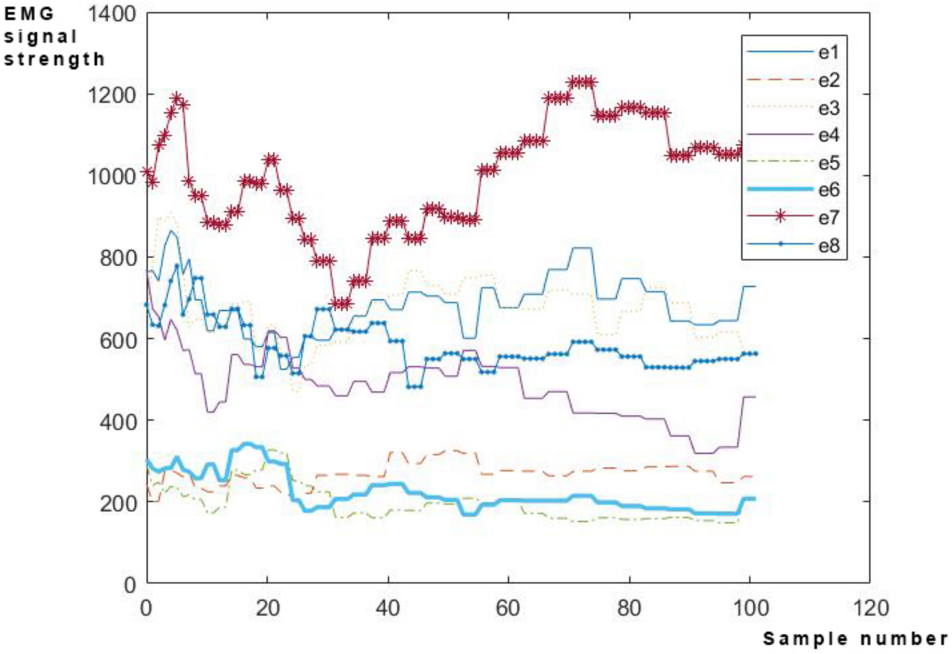


Figure B.1: Fist

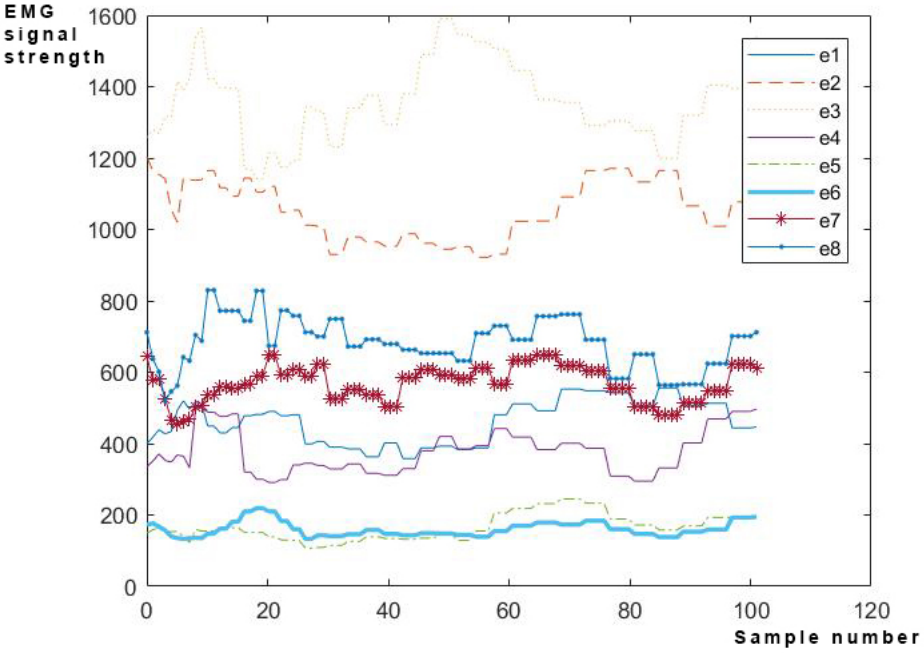


Figure B.2: Finger spread

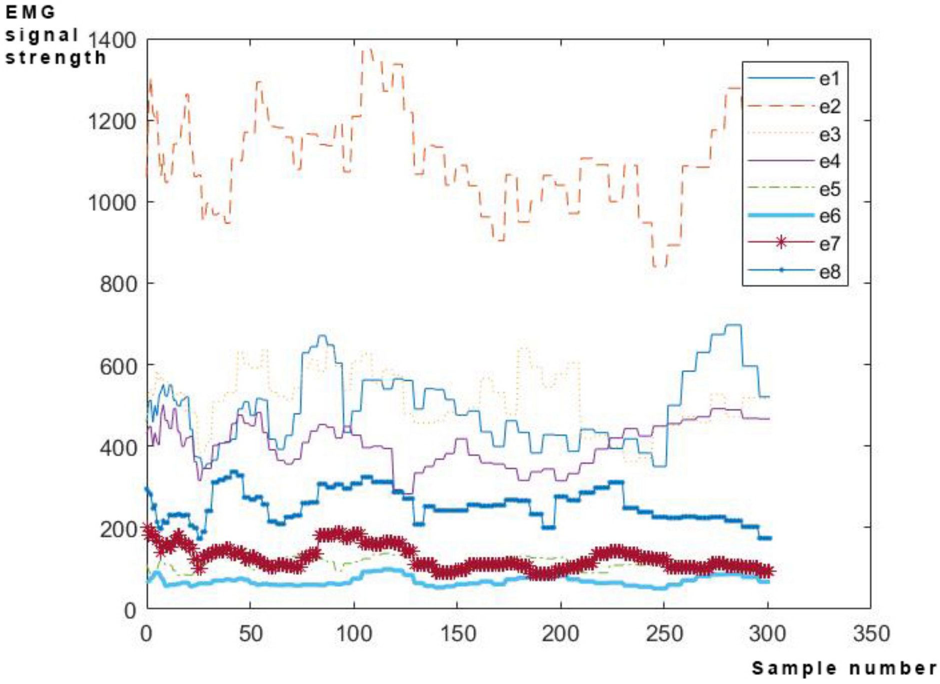


Figure B.3: Thumb to pinky