The beginning of a robot-actor

Graduation Project Report

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1 Abstract

Robots in theatre are a new and upcoming concept which bring their own very unique challenges. The theatre group Sonnevanck is in need of a robot-actor for their upcoming traveling children theatre show. This graduation project aims to explore the possibilities for robot-actors and to figure out what the design criteria are for Sonnevanck's robot. This is done through several unique experiments and through the building of a prototype. Sonnevanck wants a robot that is emotionally expressive, capable of singing with the same quality as a human and can interact with the world. Furthermore, the robot is fully controlled by an actor who is the voice of the robot as well. This graduation project provides a host of design criteria and recommendations to be used to build Sonnevanck's robot-actor.

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Chapter 1

1 Introduction

The first time the term robot came into existence was the 1921 Rossum's Universal Robots theatre show by Karel Capek [1]. Here robots were represented by humans in a suit. Since then, more and more robotic representations have been appearing in theatre. Now theatre group Sonnevanck (the client) [2] has asked RAM [3] to design and build a robot for a children's show (6-8-year-old kids). They want to have a robot that takes a primary role within the show. The robot has to cooperate with an 8-year-old girl and her dad who are stuck at home during the covid-19 lockdown. The girl and the robot will become great friends, go on multiple adventures, do day-to-day activities and experience the lockdown together.

The core of this paper is the design cycle. In this paper, the entire design process is discussed and evaluated. This is done through two major goals. The first goal is to figure out what the client's vision is. At the start of this project, the client only had a concept of a robot that can sing and that can show emotions. The client didn't have any ideas of what the robot should look like or any other functions of the robot. In this paper, the vision of the client will be explored using several different and unique methods. The second goal is to bring this vision to life. This is done through design sketches/3D models and the building of a working prototype.

1.1 Research questions

The main research question of this gradation project is: *How to co-design a robot-actor for theatre?* To understand the field better and to answer the main question the following sub-questions have been asked.

Sub-RQ: What robot-actors have already been on stage?

To start getting an idea of what we are working on we first need to know what other robot-actors have been before us.

Sub-RQ: What purpose does a robot-actor have in theatre?

Why do we have/want robot-actors? Do we have robots just because they are cool or is there a more novel reason for their presence within theatre?

Sub-RQ: How can a robot show emotions?

The client wants to have a robot that can show emotions, thus we have to figure out how robots do that.

Sub-RQ: What does the client's vision of the robot-actor look like?

One of the major goals of this graduation project is to figure out what the client wants and what their ideal robot-actor is going to look like.

Sub-RQ: How does a robot sing?

The client wants a robot that can sign just like a human can and thus research has to be done about how robots can sing.

Sub-RQ: What aspects of the robot makes the voice of the robot believable as its own voice?

The client wants to that the robot has its own voice and that it is a believable voice that coming from the robot.

1.2 Structure of the report

This graduation project is structured in five parts. First, the state of the art of robot-actors is researched. Secondly, the ideation is given where multiple methods are used. Thirdly the realization of the prototype is discussed. Fourthly the validation of the prototype is discussed. Lastly, the results, conclusion, and recommendations are given.

Chapter 2

2 State of the Art

To better help, the client literature research has to be done. The first topic that will be discussed is other robots that have been on stage. This will help us get a baseline of options and can be used to give the client an understanding of possibilities. The second topic that will be discussed is why people want to have a robot on stage. Figuring out why other people have used robot-actors can help us to better understand the client. The third topic is about robot consequential sound. Since the robot will be on stage and the primary function of the robot is singing/talking we need to consider the effect that the sound of the motors and other moving components have on the experience. The last topic is about how robots show emotions. One of the key functions of the robot will be the fact that it can show emotions thus research has been done about other robots that can do this.

Before we continue a definition of what type of robot we are researching. A robot for theatre is rather broad. In our case, we want to have a robot that is on stage during the show. It has to interact with other actors and has to present itself as an actor on stage. To get a good definition for our robot let's take a look at the definitions of robot and actor.

Definition: Robot, any automatically operated machine that replaces human effort, though it may not resemble human beings in appearance or perform functions in a humanlike manner [4]

The definition of a robot involves the key part "*automatically operated machine*". Our robot is semiautomatic meaning that it does not qualify to be a robot by the standards of [4].

> Definition: Actor, someone who pretends to be someone else while performing in a film, play, or television, or radio programme [5]

The key part of the definition of actor is "pretends" which helps our machine to become a robot on stage. Even if our robot does not qualify to be a robot it is pretending to be a robot on stage. This means we can qualify our machine as both an actor and a robot, but only at the same time. A robot-actor.

Definition: Robot-actor, a machine that pretends to be a robot with human- or animal-like traits while performing in a film, play, or television, or radio programme as an actor.

This definition is not perfect, but it will help to clarify certain concepts/sections within this graduation project.

2.1 Robots in theatre

My Robot by The Barking Gecko theatre is about an 8-year-old girl who moves to a new city and doesn't fit in [6]. But she is an inventor and thus makes herself a friend, a robot friend. Together the two go on a lot of different adventures and learn more about each other. The robot in this play is there for one reason. It is cool to have a robot. Fun is an important factor for all robot-actors and should always be part of the purpose of the robot.



Figure 1 My Robot – The Barking Gecko Source: Adapted from [7]

Improbotics and the robot A.L.Ex have been working together in improvisation theatre [8,9]. A.L.Ex has a chatbot AI which responds to dialog given by human actors. He doesn't listen but gets a written

transcription of what was said. By the usage of a large database filled with different types of movies, books, and other data he comes up with multiple funny and withy responses. Then the person that feeds him the transcription picks one of the options and A.L.Ex speaks it aloud. This is not so much an example of a robot-actor, but more an example of a chatbot AI with the robot body as a medium. A.L.Ex is the centre of the HRI research being done by Mathewson and Mirowski [10].



Figure 2 The Improbotics robot A.L.Ex Source: Adapted from [11]

Gobsquad performed "My Square Lady" a twist on the classic opera "My Fair Lady" where the role of Eliza Doolittle was substituted by the robot Myon [12]. Myon has a very interesting role in this show, he isn't programmed to do anything specific and doesn't know that he is in a play. His AI is taking in everything that happens around him and responds to whatever he feels like and then the actors have to work with Myon to create a good show. The goal of the actors is to teach Myon about the importance of opera and emotions. My Square lady is a great example of a play where fun, HRI research, and exploration are central. They explore the capabilities of AI in a fun and live setting.



Figure 3 Theatre show "My Square Lady" Source: Adapted from [12]

Chaves and Borrajo [13] made two NAO robots interpret several Hamlet scenes. This includes them talking to each other, moving in appropriate ways. They aren't the first ones to do this, but they did a new novel aspect. Instead of hard coding everything into the robots they only deliver certain aspects and the robots interpret the rest. This is another great example of theatre robotics and HRI research as this is the first step towards letting robots interpret theatre scripts without human help.



Figure 4 NAO robots playing Hamlet Source: Adapted from [14]

The Copernicus Science Centre in Poland has created a robotic theatre. This means that there are no humans to be found on stage [15]. They control the entire show, robots, lights, and beamers alike through one operating system. It's a rather simple and accessible piece of software where anyone can create their own scenes and just click play to the let robots do their thing. The purpose of these robots is given by Engineered Arts Director Will Jackson, "Reason for the robots, is to try and bring some of the more abstract ideas to people in a very accessible way." [15, 1:04]. As this installation is located inside of a museum the main purpose is education. The robotics theatre is a beautiful look into the future of entertainment.



Figure 5 Robotic theatre in the Copernicus Science Centre Source: Adapted from [16]

In the play "Sky Sky Sky" an elderly woman named Joan in the year 2061 is sick and needs daily care which she receives from the robot PR2 [17]. The relationship between PR2 and Joan starts bad, but with time Joan becomes emotionally attached to PR2 and starts to rely on him physically and emotionally. This play perfectly embodies HRI research, they have an advanced robot which they make look even more advanced through some theatre tricks. Furthermore, Joan and the robot have an emotional dynamic that creates new insights for HRI research.



Figure 6 Sky Sky Sky Joan and PR2 Source: Adapted from [17]

The Texas A&M production of William Shakespeare's A Midsummer Night's Dream was supported by 7 drones, 6 small ones, and one large quadrotor drone [18]. Originally this show was just intended to be fun, but there were some aspects worthy of research. Sometimes the small drones crashed and landed in the audience. Depending on how far along they were into the play the audience reacted differently to the drones. If it was still very earlier and the drones flew by, the audience tended to swat the drones out of the air, and if they crashed the drones were simply thrown back onto the stage. If the show was a bit further along and the actor had shown love for the drones, the audience would do so as well. In this scenario, if the drones crashed, the audience would grab the drones and take care of them. This play is a great example of social proof. As the audience changed their behaviour towards the drones, mimicking the actors. This play serves as evidence that theatre can be a great place to teach people how to interact with robots.



Figure 7 A Midsummer Night's Dream and its flying drones Source: Adapted from [18]

There are a lot of different robot-actors and they can have very different goals in mind. Robot-actors can have multiple novel goals, but they can be there just because they are cool as well. We found that robot-actors can be a great driver for change. They can teach people about robotics, they can be used in HRI/social research, they can be used to teach how to interact with robots and robot-actors can teach us about the future.

2.2 Importance of robots in theatre

The next section will continue on the idea that robot-actors are a great driver for change. We will be discussing the HRI research applications, the educational value, and the social integration of robots.

HRI is a multidisciplinary field with three main subfields [19]. Firstly, robot technology development, the creation of new and better robots. Secondly creativity, the exploration of daring and novel robots. Lastly the understanding of human reactions towards robots. To work in all three fields at the same time is a rather daunting task. Understanding human reactions towards robots can require rather sophisticated robots. The creating of sophisticated robots requires a great understanding of human reactions towards robots. So, these two fields need the other field to be better, but that places the two in a loop. To combat this the Wizard-of-Oz method is very favourable within HRI research [19]. Here the researcher deceives the subject with a fake or partly fake robot. This allows the robot to look more intelligent than it actually is and thus less robot development is needed for HRI research. Because of the scripted nature of theatre, it is a great place for the Wizard-of-Oz method [17]. Everything can be precisely engineered, objects and scenes have their set location, and the podium will always be the same shape/size. This allows a robot to do things without knowing what it is doing. Instead of the robot grabbing a glass you put the glass in the location where the robot is grabbing something, which makes it looks like it grabbed the glass. Furthermore [10] mentions that theatre is a great place for HRI research, because of the audience. They provide instant feedback and can be analysed to better understand HRI. In conclusion about HRI research applications, we can say that the Wizard-of-Oz method combined with theatre lays the way for effective HRI research.

Children can learn a lot about robots and theatre through robot theatre, watching theatre, and making theatre. [20] and [21] have shown great use of robot theatre as a medium for teaching children about robotics and theatre. Robot theatre promotes creativity, cognition, computational thinking, and logical reasoning. Computational thinking is important to learn for children because a lot of the current challenges we face in the social and scientific field require a lot of machine calculations. Here computational thinking is vital so that you can understand how the computer came to its conclusion, how to use this conclusion and how to use the software [22]. Furthermore, interacting with a robot will always end up in the same way, the same input will always give the same output unless the robot has a learning AI. This type of interaction promotes logical reasoning [23]. Logic reasoning is a very important skill for children to have as it will help them in the future with education and other day-to-day activities. This method of teaching falls into the educational movement STEAM (Science, Technology, Engineering, Art and Math) which has shown great results with children [20]. All in all, children have a lot of different skills to learn and robot theatre is a great learning medium.

Robot theatre can help with the social integration of robots [24]. The major interaction people have had with robots is through pop-culture media [25]. But most of the time these robots have a bad stigma and/or are a lot more developed than the robots that are real. Lots of movies are about robots taking over the world or being indistinguishable from humans and this scares people [26]. However, this is not limited to movies, theatre is the one that started it all. The original 1921 robot theatre show "Rossum's Universal Robots" was about robots taking over the world and killing men kind [1]. This fear of robots is very important to address since it has been shown that fear of robots can decrease life satisfaction [27]. While this fear is real it's going to take some time before we have robots that can make these fears a reality. Two of the most advanced robots build, "Sophia" [28] and "Atlas" [29], aren't even close to the level of robots in most pop-culture media. Another aspect of social integration is how to interact with robots. Not everyone knows how to correctly interact with a robot and when they do, they can make mistakes. They might hurt themselves or damage the robot. To help robots integrate into our society, people need to learn how to interact with robots. Theatre is already a place of social influence and is thus a great place to learn how to interact with robots, to learn about the current state of the art of robots, and to elevate fears of robots [18, 24]. An important thing to note here is the fact that this is not limited to theatre. Well-made pop-culture media about robots could have an impact on the social integration of robots as well. As more people will get used to robots in a fun and entertaining way, robots should have an easier time integrating into our society.

2.3 Consequential sound

The consequential sound produced by a robot is one of the most overlooked aspects of robot design [30, 31]. Consequential sound is the unintentional sound produced by the moving parts of a robot. [30], [32] and [33] have started researching the effect of consequential robot sound. Generally, the

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sound a robot motor makes is unpleasant and harms areas of trust, aesthetics, and human likeness. A good example of this is the Boston Dynamics LS3 "Big Dog" military robot. This robot was cancelled because it was too loud and in the military stealth is one of the most important aspects [34]. Another example is [35] they tested if hugging a robot is weird and found that one of the major negative aspects in the interaction is the sound produced by the robot. At the same time sound produced by a robot is wanted. A robot that is interacting with humans is perceived as more competent if it makes a sound. In the Dutch children's TV show Klokhuis they had creative technologist Edwin Dertien visit [36]. Dertien made sure to pick all the best and most silent robot parts so that the robot was quiet, but the editors added robot sounds in post-production. Because of this, the context and type of sound have a very important role in how sound is interpreted. Now, where does all of this interlock with theatre? An important part of theatre is sound design. What sound does everything make? Interacting with a door makes a specific sound so does throwing a ball. Do we want to amplify those sounds or keep them as they are? For a robot-actor we have to ask ourselves this as well. Do we want the audience to hear the motors? Do we want to support the movement of the robot with extra sound? Some experimenting will have to be done to figure out what works and what doesn't work.

2.4 Robot emotion

In this section, several expressive robots will be discussed. As the goal is to have a robot that can show emotions we first need to see what other people have done with their robots to show emotions. This will be done by examining 5 different robots. The first robot, ERWIN(Figure 8), is a robot that shows emotions with two components. Firstly its mouth, ERWIN moves its tube mouth in different angles to show different emotions, however, with just the mouth the effect is rather minimal. To support the mouth two eyebrows have are moving into different positions to express certain emotions. ERWIN shows us that the usage of a mouth is not enough to show a large range of emotions and that a very minimal design is already enough to show emotions.



Figure 8 ERWIN

Source: Adapted from [37]

The computer animated movie "Luxo. Jr" (Figure 9) made by PIXAR Animation Studios is a good example of how anthropomorphism has a large impact on the interpretation of robots. In this animated movie you see two Pixar lamps play around with each other and a ball. Through the way they move and through the sound effect they appear to show interest in things, different emotions, and have a form of interplay. This animation shows us that movement and sound effects have a great correlation with emotion.



Figure 9 Pixar

Source: Adapted from [38]

The robot Reachy (Figure 10) has two interesting ways of showing emotions. Reachy can pan and tilt his head placing it in different angles to accommodate interest and some emotions. The pan and tilt doesn't do much on its own, however when you add the two antennas on his head the range of emotions increases by a lot. These antennas function kind of like the eyebrows of ERWIN and depending on the position of the antennas different emotions can be seen.



Figure 10 Reachy



The robot Furhat (Figure 11) goes about showing emotions in a different way than the previous three robots. Furhat has a project of a human face on his own face and thus has the same facial expressions that humans do. This way the range of emotions is as large as can be.



Figure 11 Furhat

Source: Adapted from [40]

The robot Cozmo (Figure 12) is very small, energetic, and emotional. Cozmo uses four different aspects to show his mood. Firstly, he uses the LED screen which portraits his face with emoticon-like shapes to show emotion. Secondly, he uses pan and tilt of his head to assist in his emotions. For example, he looks down to show he is sad and looks up to show he is happy. Thirdly he flails his one appendage around in certain ways to assist. Lastly, he uses the way he is orientated to show emotions as well. For example, he turns around when he is sad or shy and he spins around when he is happy or excited.



Figure 12 Cozmo

Source: Adapted from [41]

2.5 Conclusion

In this state of the art, we looked at the different types of robot-actors, we discussed the purpose/importance of robot-actors and we discussed the consequential sound of robots. Furthermore, we took a look at the different ways robots show can show emotions. In the first section, we found numerous amounts of different robot-actors which all had their own purpose. Some of the robots were there just for the fun, others exist for research and some are there for educational purposes. In the second section, we found that robots in theatre can have an impact on the social integration of robots with the help of social proof. Furthermore, we found that theatre is a great testbed for HRI research. Lastly, we found that theatre can be a great means of educating children about a multitude of important subjects and skills. In the third section, we found that the consequential sound produced by a robot can have good and bad consequences. Lastly, we found multiple different ways robots can show emotions and different aspects that can be used to show emotions.

Chapter 3

3 Ideation

3.1 The first experiment

The first thing that was done to start the design process is finding out what the client wants. This was done by having a meeting with the client. This meeting had 4 major goals. The first goal was to introduce the client to robot-actors that already exist. This will give the client a basic understanding of the possibilities and can help the client in developing his ideal robot-actor. The second goal was to inform the client about the possible types of robots. Examples of types are humanoid, flying, animal, on wheels, with legs, etc. The third goal was to streamline the client's expectations. The client needs to know what is and isn't possible with robots and the client needs to know what the scope of this project is. The fourth and most important goal is to just see what happens and pick up on everything the client says. The input of the client and random thoughts of the client can have a large impact on the design process.

3.1.1 Experimental setup

The meeting was set up as followed. The client, my supervisor, and I were online on a video conferencing tool. I held a PowerPoint presentation (Appendix A) while the client and my supervisor watched. The presentation has several images and videos which I talk about and then used to spark a discussion. The presentation was set up in 4 stages. The first stage was to explain my involvement during this project and to explain what they can expect from me. The second stage was a showcase of multiple robot-actors. The third stage was to discuss the difference between humanoid and non-humanoid robots and the pros and cons of both. The fourth stage was to discuss the implementation of the voice of the robot.

3.1.2 Findings

During the meeting, 6 important design criteria were found. Firstly, the client doesn't want to have a humanoid robot, but the robot does need to feel human. This means that the robot needs to have human traits and should be capable of showing human emotions. Secondly, the robot needs to be

very expressive. In theatre, it is important that the actors are overdramatic in their body language and this is important for the robot as well. Thirdly the robot needs to have a voice. The voice will be voiced by an actor who can't be seen or heard by the audience, but the actor can see the stage and the audience. The audio needs to be of high quality and can't be supported by the theatre's AP system. The robot needs to have a large sound range so that it can have a very deep and very high voice. Fourthly, several preferences of what the robot should look like were found. the client likes to have a skinny-looking robot. An example of skinny is the arms and neck of Wall-e (Figure 13). The robot needs to be about the size of a 6-8-year-old child(120cm) and lastly, the client would like it if the robot is clearly a robot. He wants to have motors, wires, etc. exposed.



Figure 13 Wall-e

Source: Adapted from [42]

3.1.3 The next experiment

For the next experiment, the sound aspect of the robot will be explored. The client made it very clear that the voice of the robot is an extremely important part of it and thus a basic understanding of voicing the robot needs to be created.

3.2 The second experiment

In the second experiment, the voice of the robot gets explored. The main research question of the experiment is "*What aspects of the robot make the voice of the robot believable as its own voice?*". The experiment was designed with three aspects in mind. Firstly, the experiment was conducted by using the philosophy of tinkering [43]. This means that it was a very unorganized experiment, but it gave the opportunity to investigate aspects that are deemed important by the researcher or the client at the time of the experiment. Furthermore, this allows to change the experiment without disturbing the experiment that is a starting point for the client so that the client can start thinking about their perfect robot in a more concrete way. The last key aspect of the experiment is the fact that we aren't necessarily looking for the best or most practical solution. We want the client to voice their opinion and tell us what they enjoy and then continue with that.

3.2.1 Experimental setup

For the experiment, we had the following equipment.

- 1. Qualitative speaker with the option to turn off the bass
- 2. Trolly that doesn't make a lot of sounds where the speaker can stand on top off
- 3. Portable sound-deadening room divider where the singer can stand behind
- 4. A microphone
- 5. A vocoder
- 6. Camera to record everything
- 7. A robot face representation, we used an eyePi
- 8. Cables to connect everything

The experiment was set up as followed. We had a sound-deadening wall with a microphone and the singer behind it. The wall was placed in such a way that the audience can't see or hear the singer. We had the microphone connected to a speaker which stood upon a trolly. This way we could move around the speaker to test different angles. The speaker on the trolly represents the robot. Next to the microphone, we had a vocoder on a table that was connected to the speaker as well.



Figure 14 Layout experiment 2

3.2.2 Findings

After the experiment, we were able to answer the following questions.

What is the impact of a subwoofer on the voice of the robot?

To answer this question, we simply turned the subwoofer on and off several times while the singer was singing. It was found that the usage of a subwoofer wasn't needed. This is because the sound doesn't change a lot when you use a subwoofer and the client found that without the subwoofer it sounded better. Another thing we tested for the subwoofer is what happens if you turn off everything but the subwoofer and move the robot around. We found that it doesn't matter where the robot is standing because all sense of direction is lost with only bass. This would mean that if we do want to use a subwoofer, we won't have to place one inside of the robot. The exclusion of a subwoofer will result in that the robot will be a lot lighter and could be a lot smaller.

Does the robot need a mouth to increase believability?

One major worry of the client is the believability of the mouth of the robot as the source of the sound. If the robot is just a speaker, the believability is rather low. It's just a loudspeaker after all. We

tested a total of 5 different mouths to try and increase the believability. The first mouth we tried was a simple hand mouth atop the speaker (Figure 15). We found that this way the source of the sound isn't connected to the mouth and thus the believability didn't increase a lot. The second mouth we tried was a simple hand mouth at the level of the source of the sound (Figure 16). This drastically increased believability. We found that what the mouth does isn't that important. It doesn't need to mimic the original singer or look like a normal mouth. It is important that the mouth is moving and that it is open when the robot is singing. Furthermore, we found that it is important that the mouth doesn't move too fast. Slower and more deliberate movement is better. The third mouth we tried was a real mouth (Figure 17). We playbacked the singer while standing next to the speaker. Here we found that it sounds like that the play backer is singing instead of the sound coming from the speaker. Even if you playback really bad, imagine just opening and closing your mouth like a fish, it still increased believability. The fourth mouth we tried is with the usage of two hands going up and down (Figure 18). Here we found again that it increased believability. If we only moved one hand and kept one hand in the same spot it didn't work as well. Furthermore, we found that the hands obstructed the sound. This altered the sound in a rather interesting way. In conclusion, we found that we need to make a representation for the mouth which is connected to the voice of the robot. It doesn't need to be spot on, but it does need to be believable. Lastly, the mouth needs to be placed where the sound is coming from.



Figure 175 Hand puppeteer mouth a top of speaker

Figure 16 Hand puppeteer mouth at sound source level Figure 17 Play backed sound

Figure 158 Two lips puppeteer with two hands

Does moving the robot around change the sound?

Moving *the* robot creates direction for the sound. If the robot turns around or moves to a different part of the room the sound bounces of different locations and thus changes the sound somewhat. However, it didn't have a large impact on the overall experience. If you turned the robot around and faced the speaker away the quality went down.

What is the effect if you listen to the robot with your eyes closed?

To see if the physical appearance of the robot has any influence on the perception of sound which the robot makes, we did a test with our eyes closed. The singer sings into the microphone and stops for 10 seconds every now and then. After about two minutes, the singer walked silently away from behind the sound-deadening wall towards the location of the robot and continued singing when he stood next to the robot. This way we have the sound coming from the same location at all times but the observers will not know if the sound is coming from the singer or the speaker. We found that the difference in sound between the singer and the robot is very minimal. The loudspeaker was a bit sharper in some of the tones, but most of it was the exact same. One of the major differences that were found was the volume. The loudspeaker was a bit lower in volume than the singer.

What happens to the believability of the robot if you can see/hear the original singer?

We found that when you can see the singer all the believability of the robot singing disappears. Furthermore, if you can hear the original singer, but not see him it becomes confusing and believability plummets as well.

Is the current sound deadening wall enough?

During this experiment, we used two sound-deadening walls [44] put on top of each other. The singer was standing behind the wall with a microphone. We found that if you placed the walls correctly, so that the audience doesn't see the singer and most of the sound the singer makes is directed towards the wall, that this is already enough. If the speaker was turned off you could hear the singer, but with the loudspeaker turned on you couldn't hear the singer anymore. Two problems we found with this setup are the fact that the singer can't see the stage and that the area the singer can stand is rather small. For the first problem, the singer can't see the stage so it is difficult to respond to what is happening. He has to fully rely on his ears. For the second problem, the singer accidentally stepped out of the booth and then the audience got distracted by seeing the singer. In conclusion, this sound deadening wall is already enough to mask the originals singer's voice, which means that we won't have to increase the amount of sound deadening. However, the size of the booth should increase. Furthermore, the singer should have a way of seeing the stage. This could be done with a one-way mirror or video cameras.



Figure 18 Sound-deadening wall

3.2.3 The next experiment

For the next experiment, I would like to have a presentation again. During this presentation, I want to figure out what type of robot mouths the client finds interesting and show them the different ways robots show emotions. After that, I want to start to build the prototype.

3.3 The third experiment

The third experiment was twofold. First, we discussed the findings of the second experiment and after that, I introduced the client to several robots that can show emotions. The meeting had 3 goals. The first goal is to show the client ways robots show emotions. The second goal is to show the client that robots don't only show emotions through their face. Anthropomorphism plays a huge role in human-robot empathy. The third goal is to figure out what the client finds interesting so that I can start creating a design and prototype.

3.3.1 Experimental setup

The meeting was set up as followed. The client, my supervisor, and I were online on a video conferencing tool. I held a PowerPoint presentation (Appendix B) while the client and my supervisor watched. The presentation was set up in 2 stages. The first stage was to show the findings of the first experiment. The second stage was a showcase of multiple robots that have an interesting form of showing emotions. To do this the presentation has several images and videos which I talk about and then use to spark a discussion.

3.3.2 Findings

During the third experiment, a lot of good design aspects have been found. Below you can find two tables which show these aspects. Table 1 is about all aspects that the client liked and finds important. Table 2 is about all the aspects that the client disliked.

Positive aspects	Explanation
-Looks	
Skinny	The client finds a skinny-looking robot attractive. Not necessarily the
	entire robot, but the limbs and neck are important.
Exposed components	The client likes it when you can see things like motors, wires, and
	other moving parts of the robot.
Modern feel	The client likes it if the robot is a bit Apple-like. Having a flush
	modern white look.
Asymmetric	The client likes it when the robot is asymmetrical, mainly its face.
Modular clothing	The client likes the concept that you can change the way the robot
	looks without a lot of trouble.
An organic organ	The client liked the idea of a part of the robot moving a bit
	organically as if that is what makes the robot tick.
Depth/layers	The client likes it if the robot has some depth to it.
-Emotion	
Big expressions	The robot needs to have a large range of emotions and the emotions
	need to be emotions over-exaggerated.
Eyebrows/antenna/ears	The robot needs to have eyebrows/antenna/ears which assist in the
	portraying of emotions.
Minimal mouth movement	The mouth shouldn't move too much. Just like a human mouth,
	when we talk it doesn't open and close all the time. It's primarily just
	open with small movements.
Sound effect	Sound effects could possibly have a great impact on the robot but
	need further testing.
-Function	
Speed	The robot's movements need to be fast and snappy.
Movement	The robot needs to be capable of moving around. What form of
	moving around is up to debate and up to the client. It might need to
	roll around on its own or need the assistance of the actors to move
	around.
World interaction	The robot needs to be capable of interacting with everything around
	him.

Table 1 Positive design aspects

Negative aspects	Explanation
Motor Sound	The sound of motors is rather distracting and annoying.
LED emotion	LED screen that shows facial expressions/emotions is disliked.
Humanoid	A humanoid robot is disliked.
Cartoon/doll-like	Cartoon/doll-like apparency of the robot is disliked.
Human face/eyes	A human face is too far away from it being a robot and the robot
	should be a robot. Furthermore, human eyes are disliked.
Emotion through	The usage of emoticons is very disliked.
Emoticons	

Table 2 Negative design aspects

3.3.3 Conclusion

In conclusion, we found a large number of different design criteria that can be used to start the prototyping of the robot. Furthermore, with the usage of these criteria, we can start sketching and 3D modelling possible designs of how the robot-actor could look like in the end.

3.4 Design discussion

Because of covid and the agenda of the client, we couldn't plan in a lot of meetings and thus we did a lot via email. These emails are mainly to figure out the looks of the robot. For this part of the design process, two methods were used. Sketches (Appendix E) and 3D models/animations (Appendix F) were made. Here the important findings are given.

First off, the client liked the idea of the eye of the robot is capable of moving out of the robot (Figure 20 & Figure 21). This gives the robot an extra level of expression and looks a bit like Pixar. Furthermore, this allows the robot to show interest in things by looking at them with a lot more freedom. Furthermore, the client mentioned that he would love to see Figure 20 together with antennas on the eye and an arm. Then the arm and eye can together create something of dance to show their emotions/mood in conjunction with the mouth. Lastly, the client mentioned that he is charmed by the triangular shape of Figure 21.

In my sketchbook, I asked the question to myself if the robot needed a mouth. The client firmly reassured me that a mouth is extremely important. He said that the mouth needs to be the centrepiece, the soul of the robot. This is mainly the case because the robot will talk and sing a lot and the client wants to have a clear location where the sound is coming from.



Figure 19 Balbot design



Figure 20 Triangular design

The client had two interesting comments about Figure 22. First off, he enjoys the looks of two plates moving up and down to create a mouth, but it does need to be a bit more subtle. The moving mouth I presented is too big and might scare the audience. Furthermore, if it becomes too large it starts to become more of a talking wall and that is too far away from a humanoid mouth.



Figure 21 Square mouth design

Throughout the entire this entire email conversation there was one very important topic that was mentioned multiple times. The client kept on talking about the usage of antennas on the robot (Figure 23). Whenever I didn't draw them on a robot they mentioned that they would like to see them there. Whenever I did draw them, they mentioned that they like the look of it.





3.4.1 Conclusion

In conclusion, the client likes it if the robot has an eye that can move around a bit like Pixar. The client would like to see an expressive antenna on the eye. The client would like to see more options for the plates moving up and down to create a mouth. Lastly and most importantly the mouth needs to be present. The mouth has to become the soul of the robot.

Chapter 4

4 Realization

The realization of this project is the creation of a prototype robot (Figure 24 & Figure 25) with which the client can play around and so that the client can get a better grasp of the robot-actor that will hit the stage. The goal of the prototype is to create the beginning of the robot-actor that will hit the stage. Furthermore, it is used to show the client two of their favoured robot mouth designs in real life. The first section is about why we choose certain components and the second section is about choices made of the code and a delay calculation. For more in-depth information about how the prototype is built take a look at appendix C.





Figure 23 Prototype one wooden mouth

Figure 25 Prototype one tube mouth

4.1 Physical components

4.1.1 Mouth

The two mouths that have been created were choices, because of the interests of the client. The tube mouth was chosen because the client showed a lot of interest in figure 8 that uses a tube as well. The wooden mouth was chosen because the client showed a lot of interest in the concept of two plates as a mouth (Figure 22).

4.1.2 Size

The size of the prototype has been chosen because of 2 practical reasons and 3 design reasons. The first practical reason is that the prototype needs to be large enough to make it easy to work with. The second practical reason is that it has to be large enough to fit a speaker and a power supply and still have space left to fit the servos. The first design reason is the fact that the prototype needs to be large enough so that you can clearly see the antennas and mouth changing in position when sitting about 15 meters away. The second design reason is the fact that the client has shown the wanted size with his hands multiple times and that roughly correlates with the size of the prototype. The last design reason is that the mouth of the robot needs to be the soul of the robot and thus needs to be rather large.

4.1.3 Servos

One important decision for the robot is which servos to use. For this prototype, it was decided that the servos have two requirements. Firstly, the speed of the servo needs to be relatively fast. The used MG996R Servo has a no-load speed of 0.14 sec / 60 degrees at 6 volts. With that speed, the mouth can open and close 2.5 times per second. Furthermore, the mouth can go from closed to fully extended in about .26 seconds. Secondly, 2-DOF brackets need to be availed to make the antennas. One key aspect that we decided not to consider when choosing a servo is the sound that it makes. This is because the goal of the prototype is the visualization of emotion and that silent or almost silent servos are about 100 times as expensive as the one we used. Because of those two reasons, it was deemed ok to have noisy servos.

4.1.4 Speaker

The sound quality of the prototype is less important than for the final robot because the goal is the visualization of emotion. Thus, the speaker has been chosen with two requirements in mind. The first requirement is the fact that it needs to be loud enough to have an audible impact. The second requirement is that the speaker and amplifier can be placed inside the prototype.

4.1.5 Arduino

The robot is controlled with an Arduino. It was decided that we would control the robot with an Arduino because it allows for rapid testing and rapid prototyping. Furthermore, we decided not to use a Raspberry PI, because those have a long start-up time.

4.1.6 User control

Two ways of controlling the robot have been implemented. The most important way of controlling the robot is facial recognition. This is a very simple way of controlling, since all the user has to do is sit in front of a camera and voice the robot. The second form of control is the usage of several keyboard keys. By pressing down these keys different emotions can be activated.

4.2 The code

The robot is controlled through a python script (appendix D) which uses OpenCV [45] and MediaPipe [46] to track the face of the user (Figure 26). It was decided that we wouldn't use the Arduino code environment, because that would increase the complexity of the code. This is because we would have to use two different code languages and make the two codes communicate with each other. The OpenCV facial recognition AI has been chosen, because it is easy to use, free, open-source, and well-trained AI. MediaPipe has been chosen to handle the landmarks calculations because it is a welldocumented, open-source, and has lightweight model architectures [47] which makes sure most devices are capable of running the program. Communication with the robot has been done through Arduino with the Firmata library and the StandardFirmata code.



Figure 24 Facial recognition software landmarks

4.2.1 Mouth movement

The code changes the angle of the mouth in a very simplistic way. The code calculates two landmarks on the face of the user. One at the top middle of the upper lip and one at the bottom middle of the lower lip, the two red dots in figure 26. The distance between these two points is used to open and close the mouth. Because not everyone is always sitting at the same distance and doesn't have the same size mouth the code can calibrate the minimal and maximal distance between the two points. And then translate that to fully open and fully closed on the robot's mouth. Lastly, the mouth is movable/changeable with certain keyboard keys. This way the user can active different emotions
that the robot will show. When doing that the mouth movement of the user still has an impact on the position of the robot mouth but to a lesser extent.

4.2.2 Antenna

The code handles the antenna in two ways. First off, the antennas move in conjunction with the mouth. The second way of moving them is by pressing buttons to have them move in different patterns.

4.2.3 Delay

One important aspect of the robot is that the movement of the user needs to be in sync with the movement of the robot. Because of this, the delay between the two has been measured. We did this by filming with a 60-fps camera and recording the user and the robot at the same time (Figure 27). We then analysed the video frame by frame to see how many frames are in between the movement of the robot and the user. To test for deviations in the number of frames between movements we analysed three different movements and every time the same number of frames were found. Lastly, after every measurement, the code was altered to decrease delay. A total of three code iterations have been measured. For code 2 the number of landmarks calculated was reduced from 468 to 2. For code 3 several calculations were improved reducing the number of needed computations and the drawing of the face mesh was turned off.

	Code 1	Code 2	Code 3(current code)
Delay	9 frames/150ms	6 frames/100ms	5 frames/83ms

Table 3 Calculated delay user-robot



Figure 25 Setup delay measurement

Chapter 5

5 Validation

To validate the realization one last showcase meeting with the client was held. The goal of this meeting was to show what the robot can do and to give the opportunity to the client to play around with the result. To keep the meeting light and give the client as much time as possible to play around with the prototype I weaved certain questions into the conversation that were held so that I could get the needed data for the validation of the prototype. In Table 4 the results are shown.



Figure 26 Client using the prototype

Prototype	Client response	
component		
Size	The size is good.	
Shape	The shape of the robot is a bit lacklustre. However, the shape does work well	
	with the current build. A more elegant and rounded shape is preferred.	
Speed	The movement of the mouth is super-fast and snappy. Furthermore, the	
	mouth is very sensitive which is a good thing.	
Tube mouth	The tube mouth has a very clear range of emotions, however, since their just	
	tubes it has a lot of empty space around them which	
Wood mouth	The wooden mouth fits perfectly with the current square design of the robot;	
	however, the emotions don't have the same impact as the emotions shown by	
	the tube mouth.	
Antenna's	The antennas are ok. They help with the showing of emotions. It would be	
	good if the antennas are a bit more flexible. The control over the antenna is	
	very minimal as well, a bit more options would be nice. Instead of just	
	enhancing emotions it would be nice if they could point towards things to	
	show interest.	
Speaker sound	The quality of the speaker is not good, however, that is something that can be	
	fixed in a later stage.	
Consequential sound	The consequential sound of the robot is way too much. The servos make a lot	
	of noise as does the power supply. Furthermore, the wooden plate the servos	
	are mounted to functions like a sounding board which makes it even worse.	
Emotion	The extend of how the emotions are shown is nice and its very clear which	
	emotions the prototype is showing.	
Control	The controlling of the robot is easy enough right now, however, the usage of a	
	lot of buttons might be a bit too much to control during the show.	
Degree of freedom	The robot is rather stationary it just looks ahead. It would be nice if the robot	
	can look around and turn its head. Having a pan, tilt, and rotation would be a	
	nice addition.	
Overall experience	The overall experience of the client was very good. They enjoyed the	
	prototype a lot and were very pleased with this as the starting point of their	
	robot-actor.	

Table 4 Results validation session

5.1 Conclusion

In conclusion, the prototype was a success. The prototype is a great starting point for the future of the robot-actor that will hit the stage. It gave the client a lot of inspiration and a lot of information that they can work with. Furthermore, the validation session was very useful to validate design criteria that the client enjoys.

Chapter 5

6 **Result & conclusion**

6.1 Recommendation

The result of this graduation project is twofold. First off design criteria have been found through multiple methods. The second result is the methods themselves. Below you can find table 5 which shows all the recommendation about the looks of the robot. Furthermore you can find table 6 which has all the design criteria and recommendation concerning components, functions and capabilities of the robot. Finally table 7 shows all the aspects of the robot that should be avoided. these tables should be consulted by the next person that is going to work on the robot.

Looks	Explanation
Skinny	The client finds a skinny-looking robot attractive. Not necessarily
	the entire robot, but the limbs and neck are important.
About 120cm tall	The client wants the robot to be about 120cm
Motors, wires, etc. exposed	The client likes it when you can see things like motors, wires, and
	other moving parts of the robot.
Asymmetric	The client likes it when the robot is asymmetrical, mainly its face.
Modular clothing	The client likes the concept that you can change the way the robot
	looks without a lot of trouble.
Depth/layers	The client likes it if the robot has some depth to it.
Pixar	The client loves the look of the Pixar lamp. Firstly, because it is
	skinny and secondly because of the way it can move around. It can
	look at things.
Modern	The client likes it if the robot is a bit Apple-like. Having a flush
	modern white look.
An organic organ	The client liked the idea of a part of the robot moving a bit
	organically as if that is what makes the robot tick.
Antenna	The client loves the idea of antennas and the way they look. They
	should become a key part of the robot.
Mouth	The client liked the tube mouth and the wooden mouth. However,
	both had their flaws and more mouths should be created to find a
	better mouth.

Table 5 Table of looks recommendations

Subject	Explanation
Voice	The voice has to become the soul of the robot and is thus the most
	important aspect of the robot.
Very expressive	The robot needs to have a large range of emotions and the emotions need
	to be emotions over-exaggerated.
Humanoid traits	The robot needs to have humanoid traits through anthropomorphism.
Speaker	The speakers need to be of high quality and need to be in perfect sync with
	the rest of the robot. The robot needs to sound as if the singer is standing
	on stage.
Antenna	The robot needs to have antennas that assist in the portraying of
	emotions.
Mouth	The mouth needs to be the most prevalent part of the robot. As the voice
	is going to be the soul of the robot the mouth needs to be part of that.
Sound effect	Sound effects could have a great impact on the robot but need some
	further testing.
Minimal mouth	The mouth shouldn't move too much. Just like a human mouth, when we
movement	talk it doesn't open and close all the time. It's primarily just open with
	small movements.
Sound source	It is very important that the source of the sound made by the robot is
	clearly its mouth.
Speed	The robot's movements need to be fast and snappy.
Movement	The robot needs to be capable of moving around. What form of moving
	around is up for debate and up to the client. It might need to roll around
	on its own or need the assistance of the actors to move around. However,
	the client isn't interested in legs.
World interaction	The robot needs to be capable of interacting with everything around him
Usability	The robot needs to be as simple as possible to use. It is very important that
	the actor that is going to control the robot doesn't need to think about it
	too much and is capable of singing, playing the piano, and controlling the
	robot at the same time.
Function over form	It is important that the robot is functional and can do everything the client
	wants to do before the looks of the robot will be determined.
Location	When building the robot, the location of where it is going to be used needs
	to be kept in mind. The robot is going to be used in a host of different
	locations, such as a school gym, outside, a classroom, a theatre, etc.
body language	The body language of the robot needs to be exaggerated and needs to
	function as a supporting role for the robot's emotions.
believability	One of the key aspects of the robot is that it is going to be a believable
	source of life. It should look like the robot is alive and everything it does
	originates from the robot.

Table 6 Table of recommendations and design criteria

Negative aspects	Explanation
Motor Sound	The sound of motors is very disliked by the client.
LED emotion	A LED face is very disliked by the client
Humanoid	A humanoid robot is interesting, but the robot shouldn't be
	humanoid. However, it should have humanoid traits.
Cartoon/doll like	The client doesn't like it when the robot because cartoonish or doll
	like.
Human face/eyes	The client doesn't want to have human eyes or a human
	face/head. It should clearly be its own being.
Emotion through Emoticons	The client doesn't like it when the robot shows its emotions
	through emoticon-like forms or with screens.

Table 5 Table of aspects disliked by the client

6.2 Method

The methods used within this project are rather unusable methods for a graduation project. The amount of interaction and discussion with the client was very prevalent and had a great impact on the design cycle. Furthermore, the fact that we were capable of having multiple meetings in real life during these times of COVID-19 is rather unusual. In the end, we had 3 experiments and a validation session. Two of these experiments were held through a video conferencing tool and the other experiment and the validation session were held in real life. Next to this, there was a large amount of e-mail contact, a couple of phone calls, and an introductory video call. Another very impressive part of these meetings is the fact that most took about 3-4 hours and that when people couldn't show up, we filmed/recorded everything to show to them afterward. Some people even joined in through video calls during physical sessions. Lastly, the sheer amount of people the client brought to these sessions was honouring. Because of these reasons, I would like to go over all the methods used and discuss some of their important aspects.

The first and third experiments were both digital video meetings where I held a presentation and presented several things. These were the most basic of the sessions we had but were very impactful because I was capable of showing a lot of information and create instant discussion about them. The fact that multiple people on the client's side showed up and that everyone present had a very large interest in talking about the subject and willingness to discuss it helped.

The first physical experiment was held in a theatre room which in itself is already a very special opportunity. This was the most elaborate experiment we had and was extremely successful.

Everyone present could play around with the robot and give their input to then instantly try new things out. Everyone could discuss whatever they felt like and use those discussions directly to test out new things. The fact that we had multiple people of different disciplines (Director, technician, decor maker, robot engineer, singer, and music specialist) helping and advising during the session gave almost too much data to work with and if we didn't record the session, I would have never been capable of boiling everything down to this paper.

The validation session was very nice and lightweight. Here we just had some fun with the prototype with almost everyone present. I think that the method I use to find validation of the prototype was a good way of going about it, however, I think that it might have been useful to have a more dedicated interview with the client about it or a simple survey. Just to have a bit more concrete data.

One of the key aspects of every method is the amount of opinion-based influence. Everything that has been found is in the end an opinion of the client. This has some difficulties during some of the sessions, because sometimes things just aren't technological possible or are against my own opinion. However, I think that didn't have any impact on the project or result. Very much so because of the openness of the client and how I was a true part of the group and not some student doing some work.

6.3 Code limitations and possible improvements

The code has several limitations and possible improvements. One limitation is the fact that mediaPipe combined with OpenCV limits the frame rate of the used webcam to 30 fps. Changing to a different facial recognition software that doesn't limit the fps might be a good way to decrease the delay. However, no free facial recognition software that does this has been found. An improvement would be to use a different code to pass the python data to the Arduino. Right now, StandardFirmata has been used on the Arduino and this is a rather bulky program. Using a different lighter program will most likely decrease the delay. Another improvement would be to change the python code to a more object-based code. Changing the code to be more object-orientated and thus functioning better with python will make a better looking, faster, and more reusable code. One more thing to look into would be to see if you can run the facial recognition program within the Arduino environment because then we don't have to use an external computer and can fully run everything on the Arduino.

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8 Appendix

8.1 Appendix A PPP1



Figure 27 Page one PPP1



Figure 28 Page two PPP1 Source: Robot vs. Opera Project, gobsquad, <u>https://www.gobsquad.com/projects/my-square-lady/</u> accessed 02/06/2021



Figure 29 Page three PPP1 Source: Youtube: Komische Oper Berlin, Berlin, "My Square Lady | Trailer | Komische Oper Berlin", June 25, 2015, Accessed: 02/06/2021[Online Video]. Available https://www.youtube.com/watch?v=jWBN9627mSg



Figure 30 Page four PPP1 Source: Youtube: Matthias Kubisch, "Berlin Myon Robot Walking (NRL 2011)", March 4, 2021 Accessed: 02/06/2021[Online Video]. Available https://www.youtube.com/watch?v=pNCZ6_Phc0E



Figure 31 Page five PPP1 Source: Youtube: RS TECH, LLC., "NAO V5 Robot Dancing to Gangnam, Eagle, Mr. Funk, TaiChi, & Thriller", May 22, 2018, Accessed: 02/06/2021[Online Video]. Available https://www.youtube.com/watch?v=aycAd2oTNgE&t=232s



Figure 32 Page six PPP1 Source: Makoto Ishida, "Geminoid HI", Robots, <u>https://robots.ieee.org/robots/geminoidhi1/</u> [accessed 16 Jul, 2021] & Source: Perspectives on Social Robots: From the Historic Background to an Experts' View on Future Developments - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/The-Sophia-Robotfirst-shown-in-2015-by-Hanson-Robotics-Courtesy-of-Hanson-Robotics_fig4_326009520 [accessed 16 Jul, 2021]



Figure 33 Page seven PPP1 Source: Youtube: David Lu!!., "Sky Sky Sky: Exploring End-of-Life Care Through Theatrical HRI", march 30, 2017, Accessed: 02/06/2021[Online Video]. Available https://www.youtube.com/watch?v=umfBHokD5n0

Sky Sky Sky – Liza Birkenmeier



Figure 34 Page eight PPP1 Source: V.L. David, W.D. Smart and A. Pileggi, "Sky Sky Sky: Exploring End-of-Life Care Through Theatrical HRI", in International Conference on Human-Robot Interaction, Washington, 2017, pp. 411 & Source: "PR2", Robots, <u>https://robots.ieee.org/robots/pr2/</u> Accessed: 02/06/2021



Figure 35 Page nine PPP1 Source: Vimeo: Boat Rocker Entertainment, "My Robot - trailer - Barking Gecko Theatre Co", Accessed: 02/06/2021[Online Video]. Available https://vimeo.com/262250147



Figure 36 Page ten PPP1 Source: Vimeo: Boat Rocker Entertainment, "My Robot - trailer - Barking Gecko Theatre Co", Accessed: 02/06/2021[Online Video]. Available <u>https://vimeo.com/262250147</u> & "My Robot", BarkingGecko, https://www.barkinggecko.com.au/performances/past-performances/past-performances/my-robot/



Figure 37 Page eleven PPP1 Source: Youtube: Yi Huang, HUANG YI & KUKA - A DUET OF HUMAN AND ROBOT", Februari 5, 2013 Accessed: 02/06/2021[Online Video]. Available https://www.youtube.com/watch?v=7moBSpAEkD4&t=101s



Figure 38 Page twelve PPP1 Source: Gallery, https://improbotics.org/gallery/ Accessed: 02/06/2021

A Midsummer Night's Dream - Texas A&M



Figure 39 Page thirteen PPP1 Source: B. A. Duncan, R. R. Murphy, D. Shell and A. G. Hopper, "A Midsummer Night's Dream: Social proof in HRI", ACM/IEEE International Conference on Human-Robot Interaction, Osaka, Japan, 2010, pp. 91-92



Figure 40 Page fourteen PPP1

8.2 Appendix B PPP2

Findings

Subwoofer Verschil speaker/zanger Sound deadening wall Mond/localisation

Figure 41 Page one PPP2



Figure 42 Page two PPP2



Figure 43 Page three PPP2 Source: "CURV 500® SERIES", LDsystems, <u>https://www.ld-systems.com/en/series/curv-500-series/</u> Accessed: 02/07/2021



Figure 44 Page four PPP2

Robot + Emotie?

Figure 45 Page give PPP2



Figure 46 Page six PPP2 Source: Youtube: keukpa, "ERWIN - Emotional Robot", August 10, 2008. [Online Video]. Available: https://www.youtube.com/watch?v=5YqcxKeTkk0 Accessed 17/06/2021



Figure 47 Page seven PPP2 Source: Youtube: Lukas blabla, "Pixar Animation- Luxo Jr.", July 31, 2009. [Online Video]. Available: https://www.youtube.com/watch?v=D4NPQ8mfKU0 Accessed 17/06/2021



Figure 48 Page eight PPP2 Source: Youtube: Video City, " The world's cutest robot, Anki Cozmo", October 22, 2016 . [Online Video]. Available: https://www.youtube.com/watch?v=cjFA531qJNEAccessed 17/06/2021



Figure 49 Page nine PPP2 Source: Youtube: New Scientist, "Robot head puts on your friend's face", March 27, 2014 . [Online Video]. Available: https://www.youtube.com/watch?v=oqazH93RqH0 Accessed 17/06/2021



Figure 50 Page ten PPP2 Source: Youtube: Pollen Robotics, " Introducing Reachy the new open source interactive robot - 2020", Januari 3, 2020. [Online Video]. Available: <u>https://www.youtube.com/watch?v=iSL39WFxCLE</u> Accessed 17/06/2021



Figure 51 Page eleven PPP2 Source: Youtube: IEEE Spectrum, " Haru Robot: Telepresence Early Concept", February 12, 2020 . [Online Video]. Available: https://www.youtube.com/watch?v=SfEmwqxxpYg&t=24s Accessed 17/06/2021



Figure 52 Page twelve PPP2 Source: Youtube: Domótica DaVinci, "Emotional Robot at Innorobo Lyon 2013", August 31, 2014 . [Online Video]. Available: <u>https://www.youtube.com/watch?v=2fP69q2zrUk</u> Accessed 17/06/2021



Figure 53 Page thirteen PPP2 Source: Youtube: TRT World, " The Social Robot", December 29, 2017 . [Online Video]. Available: https://www.youtube.com/watch?v=wt_xzlqVrUs Accessed 17/06/2021



Figure 54 Page fourteen PPP2 Source: otto DIY, " New Otto DIY robot with emotional Eyes using LED matrix, programmed with Arduino", November 4, 2019 . [Online Video]. Available: <u>https://www.youtube.com/watch?v=w7lcB6HTTqM</u> Accessed 17/06/2021



Figure 55 Page fifteen PPP2 Source: IEEE Spectrum, " Robot That Makes Humans Laugh", June 3, 2019 . [Online Video]. Available: https://www.youtube.com/watch?v=v09-n4buwYE Accessed 17/06/2021



Figure 56 Page sixteen PPP2 Source: bred, " Wall-E, but it's just Mo", November 16, 2019 . [Online Video]. Available: <u>https://www.youtube.com/watch?v=iiMFRMoxxEl&t=1s</u> Accessed 17/06/2021



Figure 57 Page seventeen PPP2 Source: Viddsee, " Changing Batteries - A Robot "Son" Couldn't Replace The Emptiness In Her Heart // Viddsee.com", May 2016, 2019 . [Online Video]. Available: <u>https://www.youtube.com/watch?v=iCWWyr3MwnU</u> Accessed 17/06/2021

8.3 Appendix C How to build the first prototype

8.3.1 Materials

8x MG996R Servo

 $2x\ 2\ \text{DOF}\ 180^\circ$ Servo Bracket Kit for MG996R Servo

4x MG996R Servo bracket

Arduino Uno

Breadboard

12V 9A Power supply

5V power supply

Loudspeaker

Amplifier

Assortment of cables

Assortment of tools

8.3.2 Step one: creating of the frame

The first step that has to be taken to build this robot is to create a frame. I used two pieces of 30x30x1cm plywood(Figure 32). Which I connected with three pieces of 5x11x1cm plywood(Figure 32 FV1 & SV1). The layer of plywood has 5 holes in it. Three small circular holes for cable management(Figure 32 TL1) and two square holes of 2.1x4.2cm to fit the servos into(Figure 32 TL2). The bottom layer of plywood has two cut-outs at the corners of 2.5x4cm so that the servos can move their full 180°(Figure 32 BL1). We do not want to put the frame together yet. If you do that now you will have a lot of difficulties with later steps. Connect the top and bottom layer after step three.



Figure 58 Plywood frame drawings

8.3.3 Step two: Creating of the antenna

The second step that has to been taken to the antenna of the robot. To do this you need 4 servos and two 180° servo bracket kits. If you attach these correctly you will get something like Figure 33. I added a couple of straws to act like the antenna. Important thing to note here is that when you attach the two servos together you need to keep the orientation in mind since servos only have a 180° range. For the best result you should set both servos to 180° and mount the servos together in the orientation of figure 34. While mounting you need to keep the servos powered on since then they won't turn.



Figure 59 Antenna



Figure 60 Orientation antenna servos

8.3.4 Step Three: creating of the mouth

The third step that has to been taken is the creation of the mouth. For this we need 4 servos, four brackets to mount the servos to the frame and a tube. The servos need to be mounted as shown in figure 35. When mounting the servo bracket to the wood you need to keep in mind that the screws you use need to be rather short. Since the servos are above each other the screws are in the same location. If they are too long and too wide they will hit each other. A way of circumventing this problem is by only using one screw instead of two screws for the mounting.

To attach the pipe/mouth we need to do 2 things. First you need to cut a pipe into two pieces of the same length. I cut it into two pieces of 50cm. Then we need to attach the pipe to the servo. I hot glued the pipe to an servo attachment piece(Figure 36). Before I applied the hot glue I sanded the inside of the tube. If I didn't do that the glue would harden and then simply slide out of the tube. Here you need to keep in mind the orientation so that the servo attachment piece can be attached correctly. See figure 37 for the end result.

Lastly when attaching the tube to the servo you again need to keep the orientation in mind. The best way of correctly attaching it is by turning the servos to 90° and while they are power on attach the tube pointing outwards see Figure 38 for the orientation.



Figure 61 Servo mounted for mouth



Figure 62 Servo attachment attached to a tube



Figure 63 End result of the tube



Figure 64 90° setting mouth

8.3.5 Step four: Add the loudspeaker

Adding the speaker is quite easy. All you need to do is get any speaker with an amplifier and hook it up to a microphone.

8.3.6 Step five: wiring

The wiring is quite simple. It entails 8 servos connected to a Arduino with a separate power supply to power the(Figure 39)



Figure 65 Robot schematic



Figure 66 Mouthless robot

8.4 Appendix D Code

```
# libraries
import mediapipe as mp
import time
import keyboard
import svs
import math
from pyfirmata import Arduino, SERVO
# All needed arduino ports
port = 'COM3'
servoPinLeftTop = 4
ServoPinLeftMid = 5
servoPinLeftBot = 6
servoPinLeftBotBot = 7
servoPinRightTop = 8
ServoPinRightMid = 9
servoPinRightBot = 10
servoPinRightBotBot = 11
board = Arduino(port)
# Declaration of what type of device the port are controlling
board.digital[servoPinLeftTop].mode = SERVO
board.digital[ServoPinLeftMid].mode = SERVO
board.digital[servoPinLeftBot].mode = SERVO
board.digital[servoPinLeftBotBot].mode = SERVO
board.digital[servoPinRightTop].mode = SERVO
board.digital[ServoPinRightMid].mode = SERVO
board.digital[servoPinRightBot].mode = SERVO
board.digital[servoPinRightBotBot].mode = SERVO
board.digital[servoPinLeftBot].write(90)
board.digital[servoPinLeftBotBot].write(90)
board.digital[servoPinRightBot].write(90)
board.digital[servoPinRightBotBot].write(90)
board.digital[servoPinLeftTop].write(90)
board.digital[ServoPinLeftMid].write(90)
board.digital[servoPinRightTop].write(90)
board.digital[ServoPinRightMid].write(90)
# global variables
previousAngle = 0
mouthDistanceMinV = 35 # distance in pixels between upper and lower lip when
mouthDistanceMaxV = 105 # distance in pixels between upper and lower lip when
mouth is fully open.
mouthDistanceMinMax = 70 # mouthDistanceMaxV - mouthDistanceMinV
antennaDirection = False
antennaAngle = 90
wood = False # If this is true the impact of the user one the mouth is halved
scale = False # If this is true the impact of the user onm the mouth is changed
```
```
smoothValue = 3 # The minimal change in angle the mouth can make
def rotateServo(angle, leftTop, rightTop, leftMid, rightMid, leftBot, rightBot,
leftBotBot, rightBotBot):
    board.digital[servoPinLeftTop].write(leftTop)
    board.digital[servoPinRightTop].write(rightTop)
    board.digital[ServoPinLeftMid].write(leftMid)
    board.digital[ServoPinRightMid].write(rightMid)
    board.digital[servoPinLeftBot].write(leftBot)
    board.digital[servoPinLeftBotBot].write(leftBotBot)
    board.digital[servoPinRightBot].write(rightBot)
    board.digital[servoPinRightBotBot].write(rightBotBot)
    time.sleep(0.001)
    return angle
def happyFace(angle, maxRotate):
    global previousAngle
    global antennaDirection
    global antennaAngle
    if abs(angle - previousAngle) < smoothValue: return # if the change in angle</pre>
    angle = (((angle - mouthDistanceMinV) * (maxRotate - 0)) / (mouthDistanceMaxV
 mouthDistanceMinV)) + 0
    if antennaDirection:
        antennaAngle += 8
    elif not antennaDirection:
        antennaAngle -= 8
    if antennaAngle >= 110 or antennaAngle <= 30:</pre>
        antennaDirection = not antennaDirection
    leftTop = antennaAngle
    rightTop = antennaAngle
    leftMid = antennaAngle
    rightMid = antennaAngle
    leftBot = 100
    rightBot = 180 - 80
    leftBotBot = 30 - angle
    rightBotBot = 180 - 30 + angle
    rotateServo(angle, leftTop, rightTop, leftMid, rightMid, leftBot, rightBot,
leftBotBot, rightBotBot)
```

```
time.sleep(0.001)
    previousAngle = angle
def sadFace(angle, maxRotate):
    global previousAngle
    if abs(angle - previousAngle) < smoothValue: return # if the change in angle</pre>
is too small stop
    angle = (((angle - mouthDistanceMinV) * (maxRotate - 0)) / (mouthDistanceMaxV
 mouthDistanceMinV)) + 0
    sadBaseline = 70
    leftTop = 10
    rightTop = 180 - 10
    leftMid = sadBaseline
    rightMid = 180 - sadBaseline
    leftBot = sadBaseline
    rightBot = 180 - sadBaseline
    leftBotBot = sadBaseline - angle
    rightBotBot = 180 - (sadBaseline - angle)
    rotateServo(angle, leftTop, rightTop, leftMid, rightMid, leftBot, rightBot,
leftBotBot, rightBotBot)
    previousAngle = angle
    time.sleep(0.001)
def angryFace(angle, maxRotate):
    global previousAngle
    if abs(angle - previousAngle) < smoothValue: return # if the change in angle</pre>
is too small stop
    angle = (((angle - mouthDistanceMinV) * (maxRotate - 0)) / (mouthDistanceMaxV
 mouthDistanceMinV)) + 0
    leftTop = 15
    rightTop = 180 - 15
    leftMid = 150
    rightMid = 180 - 150
    leftBot = 120
    rightBot = 180 - 120
    leftBotBot = 120 - angle
    rightBotBot = 180 - (120 - angle)
    rotateServo(angle, leftTop, rightTop, leftMid, rightMid, leftBot, rightBot,
leftBotBot, rightBotBot)
    time.sleep(0.001)
```

```
previousAngle = angle
```

```
def surpriseFace(angle, maxRotate):
    global previousAngle
    global antennaDirection
    global antennaAngle
    if abs(angle - previousAngle) < smoothValue: return # if the change in angle</pre>
    angle = (((angle - mouthDistanceMinV) * (maxRotate - 0)) / (mouthDistanceMaxV
 mouthDistanceMinV)) + 0
    if antennaDirection:
        antennaAngle += 5
    elif not antennaDirection:
        antennaAngle -= 5
    if antennaAngle >= 110 or antennaAngle <= 80:</pre>
        antennaDirection = not antennaDirection
    leftTop = 90
    rightTop = 90
    leftMid = antennaAngle
    rightMid = antennaAngle
    leftBot = 160
    rightBot = 180 - 160
    leftBotBot = 20
    rightBotBot = 180 - 20
    rotateServo(angle, leftTop, rightTop, leftMid, rightMid, leftBot, rightBot,
leftBotBot, rightBotBot)
    time.sleep(0.001)
    previousAngle = angle
def huhFace(angle, maxRotate):
    global previousAngle
    global antennaDirection
    global antennaAngle
    if abs(angle - previousAngle) < smoothValue: return # if the change in angle</pre>
    angle = (((angle - mouthDistanceMinV) * (maxRotate - 0)) / (mouthDistanceMaxV
 mouthDistanceMinV)) + 0
    leftTop = 45
    rightTop = 45
    leftMid = 45
    rightMid = 130
```

```
leftBot = angle + 90
    rightBot = 90^{\circ} - angle
    leftBotBot = 90 - angle
    rightBotBot = 180 - (90 - angle)
    rotateServo(angle, leftTop, rightTop, leftMid, rightMid, leftBot, rightBot,
leftBotBot, rightBotBot)
    time.sleep(0.001)
    previousAngle = angle
def yesFace(angle, maxRotate):
    global previousAngle
    global antennaDirection
    global antennaAngle
    if abs(angle - previousAngle) < smoothValue: return # if the change in angle</pre>
    angle = (((angle - mouthDistanceMinV) * (maxRotate - 0)) / (mouthDistanceMaxV
 mouthDistanceMinV)) + 0
    if antennaDirection:
        antennaAngle += 8
    elif not antennaDirection:
        antennaAngle -= 8
    if antennaAngle >= 80:
        antennaAngle = 80
        antennaDirection = False
    elif antennaAngle <= 30:</pre>
        antennaAngle = 30
        antennaDirection = True
    # Antenna angles
    leftTop = 70
    rightTop = 70
    leftMid = 45
    rightMid = 135
    leftBot = antennaAngle
    rightBot = 180 - antennaAngle
    leftBotBot = antennaAngle
    rightBotBot = 180 - antennaAngle
    rotateServo(angle, leftTop, rightTop, leftMid, rightMid, leftBot, rightBot,
leftBotBot, rightBotBot)
    time.sleep(0.001)
    previousAngle = angle
def noFace(angle, maxRotate):
    global previousAngle
    global antennaDirection
```

```
global antennaAngle
    if abs(angle - previousAngle) < smoothValue: return # if the change in angle
is too small stop
    # Change the range of the angle
    angle = (((angle - mouthDistanceMinV) * (maxRotate - 0)) / (mouthDistanceMaxV
 mouthDistanceMinV)) + 0
    # Change the angle of the antenna every loop
    if antennaDirection:
        antennaAngle += 3
    elif not antennaDirection:
       antennaAngle -= 3
    if antennaAngle >= 80:
        antennaAngle = 80
        antennaDirection = False
    elif antennaAngle <= 30:</pre>
        antennaAngle = 30
        antennaDirection = True
    leftTop = antennaAngle
    rightTop = 180 - antennaAngle
    leftMid = 45
    rightMid = 135
    leftBot = 110
    rightBot = 180 - 110
    leftBotBot = 110 - angle
    rightBotBot = 180 - (110 - angle)
    rotateServo(angle, leftTop, rightTop, leftMid, rightMid, leftBot, rightBot,
leftBotBot, rightBotBot)
    time.sleep(0.001)
    previousAngle = angle
def freeFace(angle, maxRotate):
    global previousAngle
    global mouthDistanceMaxV
    global mouthDistanceMinV
    if abs(angle - previousAngle) < smoothValue: return # if the change in angle</pre>
is too small stop
    # Change the range of the angle
    angle = translate(angle, mouthDistanceMinV, mouthDistanceMaxV, 0, maxRotate)
    if angle > maxRotate:
        angle = maxRotate
    leftTop = 45 + angle / 3
    rightTop = 135 - angle / 3
    leftMid = 90
    rightMid = 90
```

```
leftBot = angle + 90
    rightBot = 90 - angle
    leftBotBot = 90 - angle
    rightBotBot = 180 - (90 - angle)
    rotateServo(angle, leftTop, rightTop, leftMid, rightMid, leftBot, rightBot,
leftBotBot, rightBotBot)
    time.sleep(0.001)
    previousAngle = angle
def hoiFace(angle, maxRotate):
    global previousAngle
    global antennaDirection
    global antennaAngle
    if abs(angle - previousAngle) < smoothValue: return # if the change in angle</pre>
    angle = (((angle - mouthDistanceMinV) * (maxRotate - 0)) / (mouthDistanceMaxV
 mouthDistanceMinV)) + 0
    if antennaDirection:
        antennaAngle += 3
    elif not antennaDirection:
        antennaAngle -= 3
    if antennaAngle >= 80:
        antennaAngle = 80
       antennaDirection = False
    elif antennaAngle <= 30:</pre>
       antennaAngle = 30
        antennaDirection = True
    leftTop = antennaAngle
    rightTop = 180 - antennaAngle
    leftMid = 45
    rightMid = 135
    leftBot = angle + 90
    rightBot = 90 - angle
    leftBotBot = 90 - angle
    rightBotBot = 180 - (90 - angle)
    rotateServo(angle, leftTop, rightTop, leftMid, rightMid, leftBot, rightBot,
leftBotBot, rightBotBot)
    time.sleep(0.001)
    previousAngle = angle
def mouthDistanceMin(distance):
    # This function update the minimal distance between the lips
    global mouthDistanceMinV
    global mouthDistanceMaxV
```

```
global mouthDistanceMinMax
    mouthDistanceMinV = distance
    mouthDistanceMinMax = mouthDistanceMaxV - mouthDistanceMinV
def translate(value, leftMin, leftMax, rightMin, rightMax):
    # Figure out how 'wide' each range is
    if wood:
        rightMin = rightMin * 2
        rightMax = rightMax / 2
    leftSpan = leftMax - leftMin
    rightSpan = rightMax - rightMin
    valueScaled = float(value - leftMin) / float(leftSpan)
    returnValue = rightMin + (valueScaled * rightSpan)
    if scale and returnValue > 1:
        returnValue = math.sqrt(mouthDistanceMinMax) * math.sqrt(returnValue)
    return returnValue
def mouthDistanceMax(distance):
    global mouthDistanceMaxV
    global mouthDistanceMaxV
    global mouthDistanceMinMax
    mouthDistanceMaxV = distance
    mouthDistanceMinMax = mouthDistanceMaxV - mouthDistanceMinV
def work():
then stop the program
    leftTop = 0
    rightTop = 0
    leftMid = 0
    rightMid = 0
    leftBot = 90
    rightBot = 90
    leftBotBot = 90
    rightBotBot = 90
    rotateServo(90, leftTop, rightTop, leftMid, rightMid, leftBot, rightBot,
leftBotBot, rightBotBot)
    sys.exit(0)
def smoothValueChange():
    # changes the smooth value if scale is turned on
    global smoothValue
    value = int(round(mouthDistanceMinMax / 23))
```

```
if scale:
        smoothValue = int(round(value * 1.6))
        smoothValue = value
def control(angle):
    global wood
    global scale
    global smoothValue
    if keyboard.is_pressed('q'):
        happyFace(angle, 30)
        return
    if keyboard.is_pressed('w'):
        sadFace(angle, 60)
    if keyboard.is_pressed('e'):
        angryFace(angle, 60)
        return
    if keyboard.is_pressed('r'):
        surpriseFace(angle, 20)
        return
    if keyboard.is pressed('t'):
        huhFace(angle, 60)
        return
    if keyboard.is_pressed('y'):
        yesFace(angle, 20)
    if keyboard.is_pressed('u'):
        noFace(angle, 50)
        return
    if keyboard.is_pressed('i'):
        hoiFace(angle, 50)
    if keyboard.is pressed('1'):
        wood = not wood
print('wood is ', wood)
        time.sleep(.5)
    if keyboard.is_pressed('2'):
        scale = not scale
        smoothValueChange()
        print('scale is ', scale)
        time.sleep(.5)
        return
    if keyboard.is_pressed('9'):
        work()
    if keyboard.is_pressed('z'):
        mouthDistanceMin(angle)
    if keyboard.is pressed('x'):
        mouthDistanceMax(angle)
        return
```

```
if keyboard.is_pressed('esc'):
        sys.exit(0)
    freeFace(angle, 80)
class FaceMeshDetector():
    def init (self, staticMode=False, maxFaces=2, minDetectionCon=0.5,
minTackCon=0.5):
        self.staticMode = staticMode
        self.maxFaces = maxFaces
        self.minDetectionCon = minDetectionCon
        self.minTackCon = minTackCon
        self.mpDraw = mp.solutions.drawing utils
        self.mpFaceMesh = mp.solutions.face_mesh
        self.faceMesh = self.mpFaceMesh.FaceMesh(self.staticMode, self.maxFaces,
self.minDetectionCon, self.minTackCon)
        self.drawSpec = self.mpDraw.DrawingSpec(thickness=1, circle_radius=1)
    def findFaceMesh(self, img, draw=True):
        self.imgRGB = cv2.cvtColor(img, cv2.COLOR BGR2RGB)
        self.results = self.faceMesh.process(self.imgRGB)
        self.distance = 0
        if self.results.multi_face_landmarks:
            for faceLms in self.results.multi_face_landmarks:
                face = []
                for id, lm in enumerate(faceLms.landmark):
                        ih, iw, ic = img.shape
                        x, y = int(lm.x * iw), int(lm.y * ih)
                        # cv2.putText(img, str(id), (x, y),
                        if id is 0:
                            self.distance = self.distance + y
                        if id is 17:
                            self.distance = y - self.distance
                            # print(self.distance)
                            control(self.distance)
                            break
                            # happyFace()
                    face.append([id, x, y])
            return img, face
def main():
    cap = cv2.VideoCapture(1, cv2.CAP DSHOW)
```

```
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```

```
pTime = 0
detector = FaceMeshDetector(maxFaces=2)
cap.set(cv2.CAP_PROP_FRAME_WIDTH, 1920)
cap.set(cv2.CAP_PROP_FRAME_HEIGHT, 1080)
while True:
    success, img = cap.read()
    img, face = detector.findFaceMesh(img)
    cTime = time.time()
    fps = 1 / (cTime - pTime)
    pTime = cTime
    cv2.putText(img, f'FPS: {int(fps)}', (20, 70), cv2.FONT_HERSHEY_PLAIN, 3,
(0, 255, 0), 3)
    cv2.imshow("image", img)
    cv2.waitKey(1)
if __name__ == '__main__':
    main()
```

8.5 Appendix E Sketches

Beweegende peaker Mön probleen met dit is dat het gezicht kmond los van elkaar zijn. Helemaal als de Arm/neck reel Kan bewegen.

Figure 67 Sketchbook page one



Figure 68 Sketchbook page two



Figure 69 Sketchbook page three



Figure 70 Sketchbook page four



Figure 71 Sketchbook page five



jets met Antenna

Figure 72 Sketchbook page six



Figure 73 Sketchbook page seven







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Figure 74 Sketchbook page eight



Figure 75 Sketchbook page nine



Figure 76 Sketchbook page ten



Figure 77 Sketchbook page eleven



Figure 78 Sketchbook page twelve



Figure 79 Sketchbook page thirteen



Figure 80 Sketchbook page fourteen



Figure 81 Sketchbook page fifteen



Figure 82 Sketchbook page sixteen



Figure 83 Sketchbook page seventeen



Figure 84 Sketchbook page eighteen



Figure 85 Sketchbook page nineteen

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Figure 86 Sketchbook page twenty



Figure 87 Sketchbook page 21

bak als mond.



Dit is lasting Televen 3 D Joen. (filmpje van mee gestaard)

Figure 88 Sketchbook page 22



Figure 89 Sketchbook page 23

8.6 Appendix F 3D models

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Figure 64 3D model one



Figure 90 3D model two



Figure 91 3D model three


Figure 92 3D model four



Figure 93 3D model five



Figure 94 3D model six