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ASTROBOT – THE FAR END OF PERSUASION

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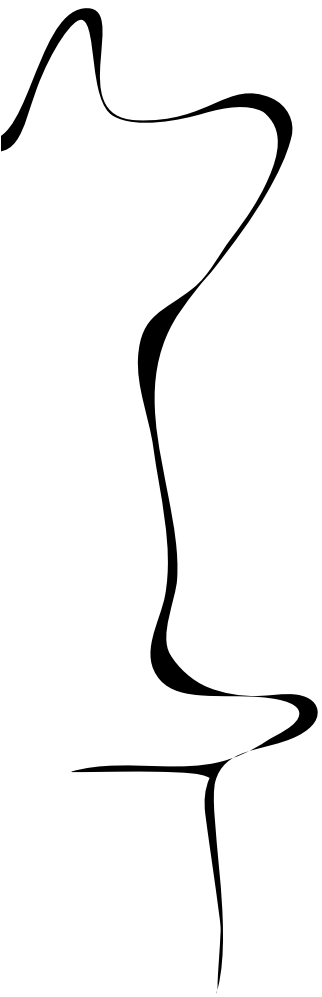
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Abbreviations

ABS	Acrylonitrile butadiene styrene
ADC	Analog to digital converter
API	Application programming interface
CPU	Central processing unit
DoF	Degree of Freedom
FDM	Fused deposition modeling
FPS	Frames per second
GPU	Graphical processing unit
HRI	Human robot interaction
IxD	Interaction design
OS	Operating system
PC	Personal computer
PSU	Power supply unit
PLA	Polylactic acid or polylactide
RRI	Robot robot interaction
STT	Speech-to-text
TTS	Text-to-speech

Summary

Nowadays social robots are becoming more popular due to their potential to assist human beings. Social robots engage in social interaction with human beings. The success of this interaction can be determined by the persuasion ability of a social robot. The core of persuasiveness is based on anthropomorphism principles. Human-like features of social robots attract the attention of human beings and help to deliver the message.

The roles of social robots include but are not limited to a storytelling robot, teaching robot, robot-receptionist, etc. However, there is limited research available about the future roles of social robots. There are few cases of robots who overtake a role (of a spiritual guide) which is traditionally associated only with humans. It is argued that social agent theory still applies when designing such type of robots. This project is an attempt to design a social robot Astrologist. The robot is designed relying on the critical design notion and conventional system design methodology. Another aspect of this project is the exploration of rapid prototyping and open source technology. In other words, the robot should be build using the available open-source platform within a low budget.

The platform used in the design is InMoov robot. The software and hardware necessary for it to function according to design requirements is designed from scratch. The robot is designed to maximise the persuasive ability. The outcome of the project is human adult size, human-shaped and fully 3D printed social robot. This robot is able to sustain gaze, blink, breath and perform human-like gestures. Basic dialogue can be executed between the robot and users according to the interaction flow.

The evaluation was conducted at the “RobotLove” festival. Random people interacted with the robot and the feedback was collected using questionnaires. Afterwards, the robot was improved based on the feedback from the first iteration. The second evaluation was conducted using a short movie showcasing the potential of the robot. The collected data indicated a high level of trust to the robot regardless of people’s attitudes towards astrology. The robot attracted a lot of attention and users indicated that they enjoyed the experience. Majority of users would like to have more/deeper discussions with the robot. Some indicated concerns regarding their privacy. Use of an open-source platform was successful, however, included a lot of tuning and adjusting during setup. Moreover, the design has a limited range of motion and some joints need an upgrade to achieve the desired velocity.

Preface

Stranded in the overflow of information about education and career I knew one thing for sure - the best investment is expanding your knowledge and expertise. While working in a company on a day to day basis I felt comfortable, however, after a few months of such work I started feeling how my brain stopped evolving. This freeze was caused by the limited intake of new information and knowledge and was severely paralyzed by daily routine tasks. At that moment it was clear to me that the only way to solve this problem is to continue my education and go for Master Degree.

My main problem but also my strength is the ability to dive into any task, so deep that I even forget to eat. The lack of enthusiasm, however, will cause stagnation and procrastination, which will slowly drift into depression. This often is caused by the absence of meaning and lack of creativity in the task. This was my first assignment, it quickly became my fearest enemy and almost made me quit Msc degree if not a suggestion from Edwin Dertien, who at the time was my employer and I was his Teacher Assistant in Creative Technology. Together we came up with an amazing assignment which was brave, interesting, one of a kind and incorporated all the technical bits, I wanted to learn at the time. I have been always keen on Astrology and studied it for a few years as a hobby. It seemed to me that people who believe in it, regardless of it being true or not, simply seemed to be happier and in control of their life. And here an idea struck my mind: What if the Astrologer would be a robot?

Looking back at the project now I can say that it still was a great challenge, however, it was my challenge, which I chose and no one told me to do it. During my thesis, I learned probably more than during my the entire Msc degree and I have learned things that are practical and useful and not just blank theory which will never be applied in real life. Most importantly I realized that getting a Msc degree is no joke and requires any person a great discipline of oneself. In other words no matter how difficult the task you should still keep going and fighting with your mind to stuff it with as much knowledge as it needs to achieve the success!

Contents

1	Introduction	6
1.1	Context	6
1.2	Assignment Goal	6
1.3	Approach	7
1.4	Report Outline	7
2	Analysis	8
2.1	Social Robots	8
2.2	Persuasion	9
2.2.1	Communication modalities	9
2.2.2	Form	9
2.2.3	Behaviour	10
2.3	Critical Design	10
2.3.1	Psychological background	11
2.3.2	Existing robots	11
2.3.3	Ideation	12
2.4	Social robot platform	14
2.4.1	Summary of existing platforms	15
2.5	Summary	16
3	Specifications	17
3.1	Critical Design	17
3.1.1	Evaluation methods	17
3.2	Interaction design	18
3.2.1	Evaluation methods	18
3.2.2	Interaction flow	18
3.2.3	Setting	20
3.3	System Design	20
3.3.1	Block diagrams	20
3.3.2	Functional breakdown	21
3.4	Summary	22
4	Design and Implementation	24
4.1	Critical Design	24
4.1.1	The Future role	24
4.2	IxD	25
4.2.1	Dialogue flow	25
4.2.2	First experimental setup	26
4.2.3	Second experimental setup	27
4.3	System Design	27
4.3.1	Robot configuration	27
4.3.2	Hardware	28
4.3.3	Software platform	29
4.3.4	Servo control	30
4.3.5	Image processing and human face tracking	30
4.3.6	Voice recognition	31
4.3.7	Speech generation	32
4.3.8	Control of the robot	32
4.3.9	Manufacturing process	34

5	Results	36
5.1	The Astrobot	36
5.1.1	Gestures and Movements	36
5.1.2	Motion and fluency	40
5.2	First experiment	44
5.2.1	Setup	44
5.2.2	Questionnaire data analysis	45
5.2.3	Comments	46
5.3	Second experiment	48
5.3.1	Questionnaire data analysis	48
5.4	Interview	51
6	Conclusion and Further Work	52
6.1	Conclusions	52
6.2	Further work	54
	Appendices	55
A	Questionnaire test 1	56
B	Data summary test 1	57
C	Questionnaire test 2	58
D	Data summary test 2	59
E	Bill of Materials	60
F	Movie Scenario	61

Chapter 1

Introduction

Robotics with the help of artificial intelligence in the past decade transformed robots from devices and machines, which are limited to a single function into partners and social entities. Humans interact with such types of robots in the same way as with other people [1]. This category of robots is also called social actors due to the fact that they often imitate or "act out" human-like or anthropomorphic behavior. The core functionality of social actors is ranging from engaging people in social interactions to *adhering to social norms in order to fulfill a range of tasks in human-inhabited environments* [2]. They are aimed to assist people in different fields such as teaching children, guiding and supporting mental functionality, improving human live and performing work which would require a real person [3]. The performance of social robots is primarily evaluated by their ability to persuade people. This includes mediation of desired information with high chance of users understanding it [4, 5]. The persuasion ability of social robots depends on different aspects e.g. behavior, quality of information mediated and ability to understand users and give them feedback [6].

1.1 Context

Human-Robot Interaction (HRI) is a field of study dedicated to *understanding, designing, and evaluating robotic systems for use by or with humans*. Social interaction is a type of proximate human-robot interaction and is the scope of this research. This category involves social, emotive, and cognitive aspects of interaction. In social interaction humans and robots often interact as peers or companions. One of the goals of social robots is to persuade humans and deliver a certain message or intention. In recent years social robots have become more popular and began crossing the border along with science and spirituality. The research in this field is limited, therefore this work is aimed to explore how such robots should be designed. Current research about social robots suggests that having verbal and nonverbal cues, physical embodiment and human-like gestures can substantially impact persuasion [4], [5], [7], [8] and [9]. The scope of this project includes selection, utilization and evaluation of the existing social robot persuasive abilities.

1.2 Assignment Goal

The general goal of this project is to create a social robot and assign it a role, the execution of which was traditionally associated only with humans. This goal consists of three major sub-tasks, dividing work into critical design exploration, design of interaction and systematic design of a social robot.

- Goal 1: Explore the critical design of a provocative social robot scenario which is aimed to trigger and facilitate discussions about the future roles of robots.
- Goal 2: In order to achieve Goal 1, it is necessary to realize an interactive experience with a social robot which will have all necessary characteristics such as being communicative, believable and persuasive.
- Goal 3: In order to achieve Goal 2 (and 1), it is necessary to build a social robot which will have functionality, mechanics and components needed for it be persuasive.

The research questions are formulated based on the goals mentioned above. They are similarly divided into three distinct categories.

- Can a critical design methodology be used as a tool to explore and evaluate persuasiveness and what is the applicability of this method?
- Which characteristics and performance criteria of a social robot have the highest impact on persuasion and believability?
- To what extent is it possible to use open source tools and rapid prototyping to realize the software and hardware of a social robot?

1.3 Approach

In order to achieve the goals of this project, a critical design methodology will be explored to create an appropriate scenario using state-of-the-art social robot technology. Some insight of psychology and sociology will be used as well, however, it is beyond the scope of this project to do in-depth research in these fields. Interaction design will be used to support the ideas generated in critical design and implement them into a solid interaction experience. The technical side will be tackled using standard system design approach. The duration of the project is limited to one MSc thesis.

- Using **Critical Design** method, the social robot interaction is designed in such a way, that it increases awareness on social, cultural and ethical issues by asking questions to the public. An evaluation of this method is showcasing this project at the artistic event(s), subsequently responses through social media and questionnaires and interviews with people, who are experienced in the fields of spirituality, robotics and philosophy.
- **Interaction Design** methodology is used to understand and specify how the robot should behave in order to deliver a smooth and pleasant experience to the user. This method involves modelling potential users, possible interaction scenarios and environment, in the end delivering fluent interaction experience. This method is often evaluated using questionnaires directed towards the likability and fluency of the experience.
- **System Design** includes the technical design of the fluent system with enough power and complexity to perform required processes. It involves a study of research material on existing social robot platforms as well as key elements which impact persuasion and their practical implementation. These include, but are not limited to, verbal and non-verbal cues during the interaction, human-like gaze and embodiment of the robot.

1.4 Report Outline

The second chapter contains background information on the topics of social robots and some of the state-of-the-art social robot platforms. This chapter shows analysis of existing research on persuasion, which shapes the design characteristics. The third chapter expands the information from the analysis chapter and overlays it to create a guideline for the system and interaction design. It contains summary of specifications which are necessary to achieve the goal of this project. Chapter 4 shows the design and implementation in details. It addresses the questions about how the robot is constructed and which design decisions were taken and implemented, based on the specifications drawn in the previous section. Hence, the fifth chapter contains the results and data collected during experiments as well as evaluation of Astrobots performance. Finally, in the last chapter conclusions are drawn, explaining how well the goals were met, and possibilities for future work are suggested.

Chapter 2

Analysis

2.1 Social Robots

Traditionally robots were associated with autonomous machines which are designed to perform a simple and repetitive operation with minimal interaction with humans. However, the technological revolution allows creating more complex robots. These advanced robots are not limited to a single function and often exhibit the behaviour and appearance of a socially active entity. According to T.Fong social robot is a robot, which is able to *engage in social interactions* [7]. Humans can interact with these types of robots as they would with any other *socially responsive creature* [7]. Such robots are designed to *produce effects of sociality and agency*. Besides that, they are made to function as believable interaction partners [10]. Their visual appearance has been very well summarized and evaluated in *Robot Facebook* work done by E.Velt et al. [11]. Performance of social-robots heavily relies on the ability to communicate with humans clearly and understandably. A general pattern can be seen where more simple robots, like the DeskLight (Figure 2.1) only convey an intention or a simple emotion. On the other side of the social robot, persuasion spectrum are robots, which are a bio-mechanical copy of human beings, for example, Sophie (Figure 2.2). More often humanoid types of robots are being used as persuasive agents due to the fact that humans easier interpret complex actions and intentions of a kind similar to their own. Human-like design of the robot activates areas in the brain which are responsible for social-cognitive processing, helping robot to become an intentional social agent[11]. Figure 2.3 shows five general categories of humanoid robot types. The form of the social robot is adjusted depending on the application. The process of shaping social robots is described in details in further sections.



Figure 2.1: Pixar DeskLight designed by R. Cobos Mendez[12].

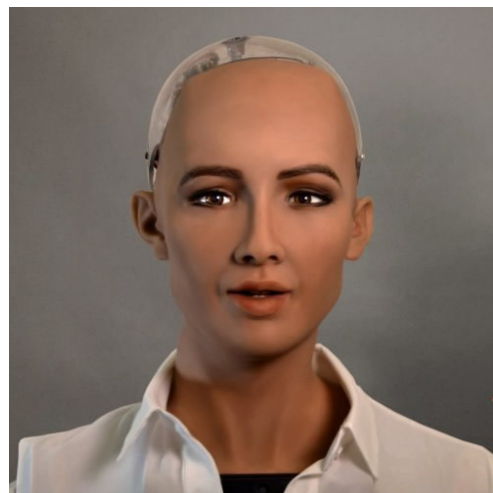


Figure 2.2: Most advanced humanoid robot Sophie by Hanson Robotics¹.

¹<https://www.hansonrobotics.com/sophia/>

²<http://robotfacebook.edwindertien.nl/>

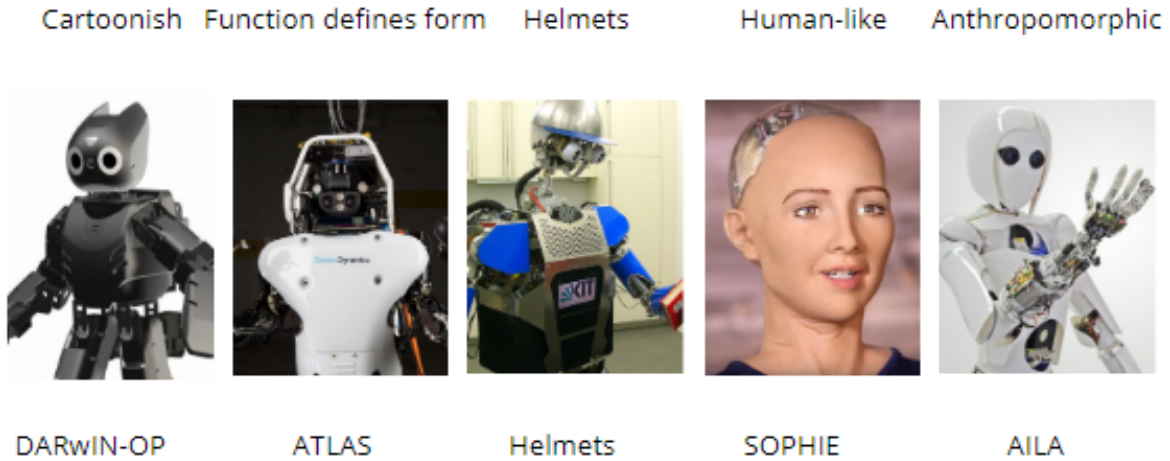


Figure 2.3: Human like social robots according to Velt et al., *Robotfacebook*².

2.2 Persuasion

Persuasion involves one or more persons who are engaged in the activity of creating, reinforcing, modifying, or extinguishing beliefs, attitudes, intentions, motivations, and/or behaviours within the constraints of a given communication context [13]. According to social agent theory the more persuasive abilities social agent has, the more persuasive it becomes [14]. In other words, in order to maximize persuasion, it is necessary to employ every aspect which can make a social robot persuasive.

2.2.1 Communication modalities

Persuasion can only occur through one of the communication channels. Communication is a process where certain information is delivered from one human to another. Based on principles of A. Mehrabian communication modalities are divided into three main categories: Verbal, Para-Verbal and Non-Verbal, depicted in figure 2.4. Everything we describe using language or words is categorized as verbal communication and takes only about 7%. The voice characteristics such as tone, speech rate and type are considered a para-verbal type of communication and reassemble 38%. Non-verbal communication is most commonly used and delivers the most amount of information (55%) and typically is communication by other means like eye contact, body language, gestures, postures, etc. Emphasising communication channels other than verbal will greatly enhance robot's performance, however, they should be natural and understandable by human-beings [13]-[15].

2.2.2 Form

The embodiment of information mediator plays an important role. A lot of research has been conducted, proving that the *physical presence* of a robot is an advantage [8]. Physical presence has a significant effect on behavioural response and attitude. Robots who were physically present made a more friendly impression. It can be concluded that in order to have a stronger effect of persuasion and strengthen the bond between robot and human, the physical embodiment of a robot is preferable. Even though robots do not have a *gender*, it is still possible to simulate one by changing the look and body type of the robot. The research in this field indicates that *male* robots are likely to influence humans more [13]. This leads to a further design choice of a robot having a *male voice*. Another important property of the embodiment of the robot is its *shape and size*. The trend is to make robot look *human-like*, which is more natural for human beings and therefore more effective. On the other side according to Duffy et. al, it is not that simple. *Peoples expectations based on strong anthropomorphic paradigms in HCI overly increase a users expectations of the systems performance*. Therefore the design should not necessarily be a synthetic human. The key is in *balance of illusion that leads the user to believe in the sophistication of the system in areas where the user will not encounter its failings, which the user is told not to expect* [17].

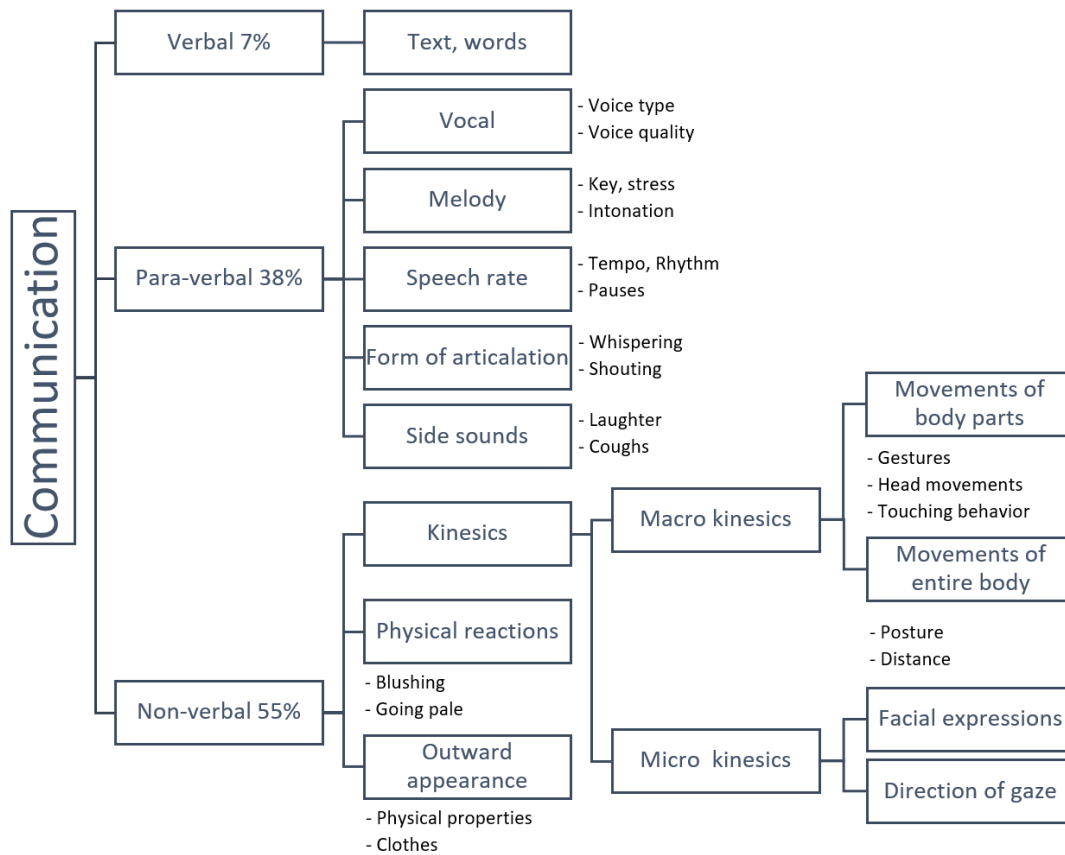


Figure 2.4: Schematic of communication modalities described by A.Mehrabian[16]

2.2.3 Behaviour

Research shows that human-like behavior such as breathing, gazing, blinking and etc. strengthen the image of the social entity and *increase anthropomorphism* [17]. Social robots *gazing* at people and maintaining an *eye contact* for a natural of time amount while telling a story proven to be an effective persuasion technique. *Blinking* remains part of the natural gaze since staring at the user will result in the feeling of discomfort and therefore lower the persuasion [15]. Other studies show an increase in retention when being gazed at by a storytelling robot [18]. There are numerous studies prove that *gestures* performed by robots help to convey information to the user [19]. Moreover, it is not just limited to pointing in a certain direction to attract attention, but also includes more *complex choreography* during a guided tour in the museum. *Human like breathing*, looking around and other similar movements are part of the natural behaviour of a human being. Mixing autonomous and semi-autonomous behaviour also impact persuasion [20].

2.3 Critical Design

Critical design is an alternative view on the design, the goal of which is to *find problems by asking questions* [21]. The ideation center is a scenario of a provocative social robot in the role of advanced guides. Therefore critical design is used to achieve this goal and is aimed to develop a provocative scenario, uncovering potentially hidden agendas and exploring alternative design values [22]. Prototypes developed using critical design *are typically designed to challenge the assumptions*, in comparison with a conventional way where *prototype is intended to be a potential product*. Another tool used in this method is *speculation about the future and projections based on current trends* [23]. In order to create a provocative design, it was decided to speculate on the future role of robots in a spiritual context. It is also critical to compose the environment accordingly to facilitate the story. Ambient sound, incense and light or other effects can be utilized to further amplify the image conveyed. Status of social entity is a natural way to empower the mediator. Appearance and posture of *wise personality* will create an image of someone who possesses valuable information. *Cultural references* will be used to strengthen the image of a social agent. These environmental aspects are necessary to create a fulfilling experience and are also part of interaction design methodology [24].

2.3.1 Psychological background

In order to justify the design choice of a provocative social robot scenario, the use of purely technical criteria might be not a good idea. It is first important to understand the motivation behind increasing complexity of robots and tasks that humans delegate to them. It is also relevant to know what might be the origin of social behaviour. This helps to answer the question; how exactly human beings understand and decode behaviours, messages and symbols. The exact process of communication is rather complex and is not fully covered in this report. However, many processes are often happening automatically or unconsciously.

Carl Jung was a founder of analytical psychology and he studied unconscious behaviour among humans [25]. Jung's student, Erich Neumann first introduced existence and a concept of archetypal unconscious structures by simply comparing internal organs to "psychic organs". *Just as a body is structured by organs which are largely formed prior to birth, so the mind possesses psychic organs which structure it, i.e., the archetypes* [26]. Jung theorized that the source of archetypes has evolutionary roots. He states that *man possesses many things which he has never acquired but has inherited from his ancestors*. The most interesting archetype for this project is "The Self" [27]. Carl Jung claimed that symbolic representation of various religious figures, for example, Gods, was a projection of different aspects of the Self. This theory can explain why people are so attracted to Astrology, Tarot and other types of predictions. These might be just methods or mediums through which a human can see The Self as if one looks in the mirror of his own subconsciousness. This theory will be used as a justification for a role in the design social robot.

It is a common tendency of the human brain to simplify and automate as many processes and patterns as possible to concentrate on more sophisticated tasks. It is "neurologically expensive" to analyze all data incoming from human organs, therefore these patterns become instincts or unconscious. This means a lot in the design of a social robot since these subconscious automated patterns are studied by scientists and can be applied to determine most efficient communication modality.

2.3.2 Existing robots



Figure 2.5: Top left: Xian'er, the Buddhist robot monk in China¹. Bottom Left: Pepper performing a funeral ceremony in Japan². Bottom right: Android Mindar performing sermons at the temple in Kyoto³. Top Right: 450 Years old clockwork monk⁴.

Social robots interacting with humans are already well known to science [7]. However, there are very few studies about robots in context and spirituality or religion [28], leaving plenty of room for exploration and formation of new ideas and concepts. Absence of research doesn't not mean there are no social robots in the field of religion and spirituality. Moreover, there are numerous examples (see Figure 2.5) of such technology, for example, little robot Monk Xian'er that has been designed to patrol the Buddhist temple in China and convey ancient knowledge of Buddhism [29]. Another similar case is social robot Pepper performing a funeral sermon in Japan[30] and robot Mindar broadcasting Heart Sutras in Kodaji Temple[31]. The Automatons tied to spirituality date back to 16th century e.g. the Clockwork Monk (see Figure 2.5), which is meant to be an earthly miracle in return for Kings Philips II son miraculous recovery from death illness [32].

2.3.3 Ideation

The topics of astrology and soothsaying come from an old cultural reference known as Zoltar soothsayer. Even though his appearance did not imply any living entity inside, it still managed to attract a lot of attention. It can be seen that Zoltar (figure 2.6) besides looking like a human has cultural symbols and attributes, such as, tarot cards, glowing orb and costume, which suggest the presence of sorcery and mysticism, therefore symbolism in this application plays a very important role.

Astrology as fortunetelling first appeared around 1400BC in ancient India and was called Jyotisha Vedanga [33]. Even though considered a pseudoscience elsewhere in the world, many Indian universities offer BSc and MSc courses in astrology⁸. Interaction design suggests that well-designed environment and visual effects attract more attention and increase trust from the users, therefore symbolism mentioned in Figures 2.7, 2.8 and 2.9, is a part of the ambience designed around the robot. It includes postures of the robot (Figure 2.9), general atmosphere around fortune telling (Figure 2.7) and some symbols commonly used in astrology (Figure 2.8).



Figure 2.6: Zoltar Fortuneteller ⁷

³<http://en.people.cn/n3/2016/0407/c98649-9041284.html?>

⁴<https://www.theverge.com/2017/8/24/16196752/robot-buddhist-priest-funeral-softbank>

⁵<https://www.japantimes.co.jp/news/2019/08/15/business/tech/kyoto-temple-robot-priest/.Xh3VPMhKguU>

⁶<https://www.vintag.es/2020/01/1560s-mechanical-monk.html>

⁷<https://zoltar.org/>

⁸<https://collegedunia.com/courses/bachelor-of-arts-ba-astrology>



Figure 2.7: Left: Crystal gazing⁹. Middle: Common fortuneteller looks¹⁰. Right: Sorcerer in a cape¹¹.



Figure 2.8: Left to right: Tarot cards, astrological charts, yantras, zodiac signs



Figure 2.9: Different postures of meditation.

2.4 Social robot platform



Figure 2.10: iCub



Figure 2.11: Pepper



Figure 2.12: Nao



Figure 2.13: Jimmy

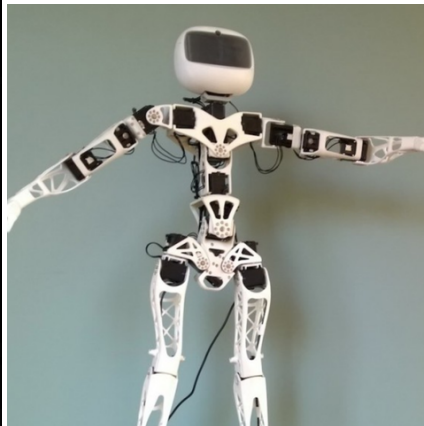


Figure 2.14: Poppy

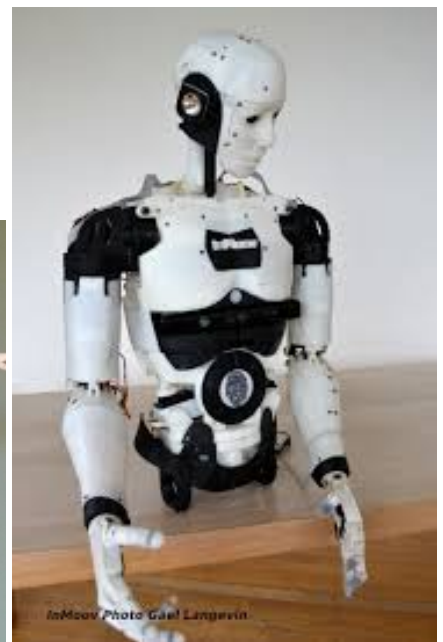


Figure 2.15: InMoov

Due to the time constraints and the need for a flexible design, it was decided to focus on open-source technology. In figures 2.10 - 2.12 are illustrated multiple social robot platforms, which are available on the market, varying in shape, size and functionality. First, three social robots are the most simplistic and fully customizable. Further, the complexity is increased with semi-customizable robots from Softbank. The list is concluded with the most complex and expensive robot, showing a full range of social robots.

Jimmy (see Figure 2.11) is the first robot designed by 21CRobot ¹² in collaboration with Intel. According to 21CRobot, *"Everything about Jimmy is open source and fully customizable."* His skeleton, featuring 5052 airplane aluminium brackets, can be reconfigured, and redesigned according to the requirements. It is fully 3D printed and based on Linux open-source C++ framework. Poppy Humanoid (see Figure 2.14) integrates

¹²<https://www.21stcenturyrobot.com/about-jimmy>

Robot Specification	iCub	Inmoov	Nao	Pepper	Jimmy	Poppy
DoF	54	38	20	24	10	25
Size	Child	Life-size	Small	Adult	Small	Small
Price	250k	2k	7k	25k	1.6k-16k	10k
Gaze	+	+	-	-	-	+
Image recognition	+	+	-	+	+	-
Speech generation	+	+	+	+	+	-
Speech recognition	+	+	+	+	+	-
Open source	-	+	-	-	+	+

Table 2.1: Summary of existing social robot platforms

advanced robotic features in a modular and easy-to-use open-source platform. Based on advanced Robotis actuators and neat 3D printed parts, it allows for anyone (artists, educators, developers or scientists) to freely use it and hack it in their very own way¹³. InMoov (see Figure 2.15) is a personal project of a french designer Gael Langevin. According to Gael¹⁴ *"It was initiated in January 2012 as the first open source prosthetic hand and since then has lead to projects like Bionico, E-Nable, and many others."* InMoov is the first Open Source 3D printed life-size robot. Replicable on any home 3D printer with a 12x12x12cm area, it is conceived as a development platform for universities, laboratories, hobbyists, but first of all for makers. Its concept, based on sharing and community, gives him the honour to be reproduced for countless projects throughout the world. It is commonly run using Raspberry Pi or open-source Linux operating systems.

According to information on the website of NAO¹⁵, it (see Figure 2.12) is *"the first robot created by SoftBank Robotics. Famous around the world, NAO is a tremendous programming tool and he has especially has become a standard in education and research. NAO is also used as an assistant by companies and healthcare centres to welcome, inform and entertain visitors"*. His appearance and hardware can not be adjusted however his behaviour and dialogue can be easily programmed using Choreographer software. The second robot in this category is Pepper, who as claimed by Softbank¹⁶ (see Figure 2.13) *"is the worlds first social humanoid robot able to recognize faces and basic human emotions. Pepper was optimized for human interaction and is able to engage with people through conversation and its touch screen."* Pepper is used in more than 2,000 companies around the world as an assistant to welcome, inform and guide visitors in an innovative way. Same as in Nao, Pepper's physical appearance is fixed, however, the behaviour can be adjusted accordingly.

According to IIT¹⁷ *"the iCub (see Figure 2.10) is the humanoid robot developed at IIT as part of the EU project RobotCub and subsequently adopted by more than 20 laboratories worldwide."* It has 53 motors that move the head, arms and hands, waist, and legs. Moreover, it can see, hear and has the sense of proprioception based on integrated gyroscopes and accelerometers. It is currently still being improved, to get a sense of touch and exerted force on the object. It is the most advanced amongst all platforms, however, also limited in hardware and software customization.

2.4.1 Summary of existing platforms

Table 2.1 shows a summary of existing open-source social robot platforms. Most important characteristics are drawn based on the number of persuasive abilities. Properties like DoF, Size, presence of verbal communication have the highest influence in the selection of used platform. It can be seen that Nao, Jimmy and Poppy severely fall behind in functionality and lack even an option of having a gaze and any kind of human eye simulation. Their size is also not matching well with the expectation since the desired height of the robot astrologist should be roughly human size according to previously mentioned research. iCub, on the other hand, is an overkill for this project since its complexity will limit the functionality and many features are not necessary and will never be used. Besides the steep price tag which runs way above the budget of this project, his size is similar to a child and does not match the expectations as well. Pepper and InMoov are the two strongest candidates and may both be used as a platform, however from the critical design point of view robot should have an image of mysticism. In this scenario, InMoov has a much greater value of taking shape of a mystic rather than Pepper which was originally designed to act as a friend and look as friendly as possible.

¹³<https://www.poppy-project.org/en/>

¹⁴<http://inmoov.fr/>

¹⁵<https://www.softbankrobotics.com/emea/en/nao>

¹⁶<https://www.softbankrobotics.com/emea/en/pepper>

¹⁷<http://www.icub.org/>

2.5 Summary

This chapter analyzed key elements which are necessary for the social robots to be persuasive. It also shows where the idea of a robot as a spiritual guide originates and which aspects of this application are critical. In addition to that, some state-of-the-art open-source social robot platforms are analyzed. Based on the analysis suitable robot platform is selected. Next chapter will specify necessary hardware, software and functionality specifications of the social robot.

Chapter 3

Specifications

This chapter is based on the previous sections and contains derivation and summary of specifications and requirements, which shape the robot's appearance, behaviour and interaction flow. Furthermore, they are divided into three main categories: Critical design, Interaction design and System design. In the design of a believable social robot, both its appearance and functionality are of great importance. It is also necessary to design the environment of the robot in a way that it is provocative and resembles chosen cultural references mentioned in the previous section. In order to have a better understanding of the final design some design work is done in this chapter as well. Interaction design parts are the main addition since it lays the foundation of the design resulting in exact specifications and requirements.

3.1 Critical Design

Critical design approach leads to several conditions, which need to be fulfilled. First of all, the performance of the robot should be *provocative and trigger discussion* about the robots who will take on the role of a spiritual guide. This requires to *assign the role of a spiritual guide* to the robot which is *correctly translated by the users* and society. Furthermore, is required to *shape the environment* around the robot to *strengthen the role, by using cultural attributes*. The critical design also sets the theme of the interaction according to the chosen role of the robot. In this project *the theme is a robot who predicts one's future* based on the date of birth. These critical design elements are based on the previous section.

3.1.1 Evaluation methods

It is also important to choose a method on how to evaluate the critical design. The experiments conducted for the *evaluation of critical design* should accumulate user opinions which will give an insight about whether or not the design was successful. Success is not the only criterion since it is also interesting which consequences and discoveries the application of this method evokes. A suitable method for doing that is direct feedback from the user, who expresses his or her opinion by answering questions in written or verbal form. The metric which shows the success of the design critically can be the following:

- Presence of emotional responses to open question, which is often subjective but can be measured e.g. counting exclamation signs.
- The level of understanding of the concept and the message delivered in the experiment.
- Attitude towards the robot, who is taking the role of a spiritual guide.
- Importance of the environment.
- Additional comments from the users which are not in the questions.
- Additional insight from interviews with people associated with the field of spirituality and philosophy.

3.2 Interaction design

In order to complete a critical design, it is important to use another methodology which is aimed at the design of solid interaction experience. Using principles of IxD it is possible to design necessary interaction experience in a structured way. IxD approach includes a description of the possible users and interaction scenarios, which are later used to create interaction and dialogue flow. This project is aimed to design user experience and provoke discussions around the social robot, therefore it is first of importance to define a scenario and interaction routine between the user and the robot. The possible description of users interacting with the robot can give a good insight in which parts of the design are most important.

3.2.1 Evaluation methods

The evaluation of IxD design also relies on feedback from the users. Questions asked to the users from an interaction design point of view should be aimed at *general satisfaction from the experience* or, in other words, *if the user enjoyed the interaction*. The evaluation also should show whether or not users are willing to repeat the procedure. The ability of the robot to be persuasive and believable is also part of the IxD evaluation. User feedback about the believability of the robot and experience will indicate the success of the IxD design.

- Enjoyment and satisfaction of the experience.
- Believability of the robot.
- Fluency of the interaction.
- The level of engagement with the robot.

3.2.2 Interaction flow

The facilitate the design choices interaction design methodology often employs the use of personas. This will lay the foundation for the setting, appearance and interaction flow. Below four different personas and their possible ways of interaction with the robot are described. Chosen personas are of different age, gender and social status to give a full range of possible users and interaction scenarios as well as show strengths and weaknesses.

- 21, Mark, Student: Mark represents the younger generation. He is a student in University and studies Industrial design. Interacting with modern technology is his daily routine. Any new tech is evaluated on an intuitive level and requires very little time to get used to due to the fact that most of the modern technology is similar in behaviour and functionality. He notices the Astrobot and it immediately gets his attention since it is state of the art technology. By getting closer to the Astrobot he already presumes how to interact with it. He has heard about astrology and did some tests on Facebook on his future, therefore open-mindedly interacts with the robot. His expectations are blank, thus he needs a little to believe in the power of astrology.
- 35, Sonya, Mother: Sonya is a mother of two kids (five and twelve years old). She has a smartphone and knows, how to use a laptop. She has never interacted with any robot before, however, she has seen some videos on the new age of robots from Boston Dynamics and was really impressed on how far the technology went in the past decades. Her older son showed her how to use google voice commands to ask for the weather and set appointments, however, she prefers to do it manually. Seeing the Astrobot causes mixed feelings in her and she does not really know what to expect. The robot should take the initiative by guiding her.
- 47, Michael, Car mechanic: Michael is passionate about cars. He works in the same garage for the past 18 years and he loves his job. In free time he restores old cars and watches football with his favourite team. His wife frequently attends yoga lessons and one of her friends told her about the recent visit to an astrologist. After that wife told him, how effective astrology actually is and, how astrologist gave very precise comments on the life of her friend. Michael is not at the front of modern technology, however, he is familiar with robotics and knows that they play a major part in the machine industry. Human related robotics is also of his interest since he was really amazed by what a man with bionic arms could do when he saw the show on a Discovery channel. Seeing Astrobot causes spark of interest and he approaches it and initiates interaction. Realizing that robot act as medium delivering information from an astrological point of view causes even more interest.
- 72, Karl, Lawyer, now retired: Gardener Karl has a house in the outskirts of the city and since his retirement, he is busy with gardening since it was his hobby past twenty years. Now he spends most of his time reading books, playing with his grandchildren and gardening. He could keep up with modern technology and still uses a phone with buttons and a small screen. Rarely he turns on his laptop since

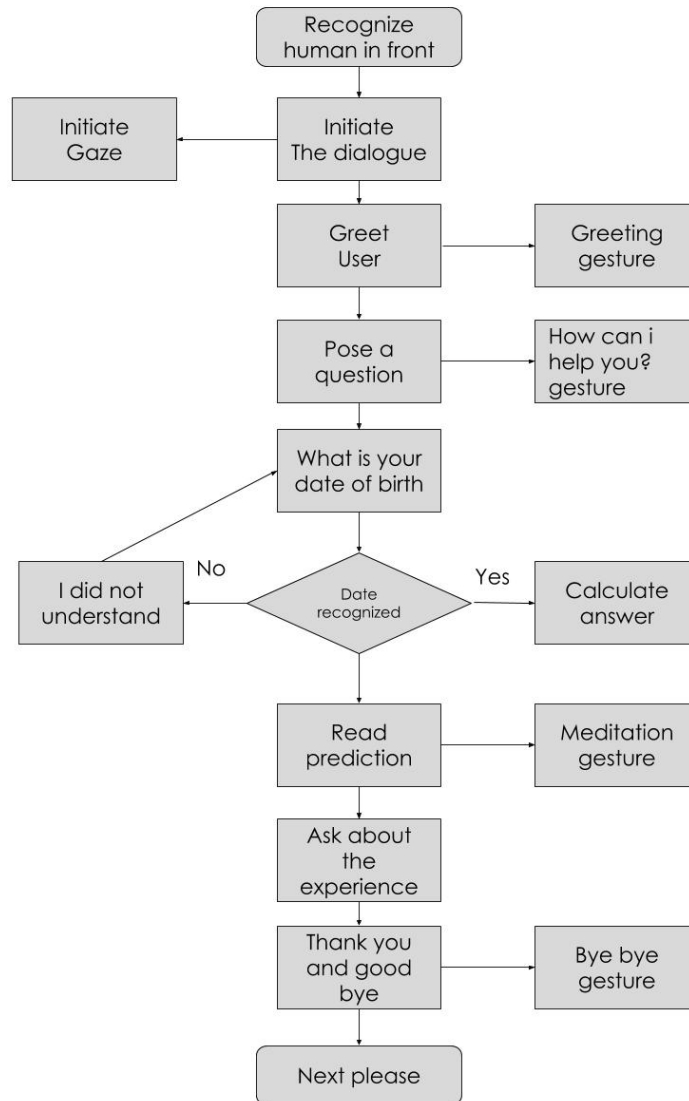


Figure 3.1: Interaction flow used in the project.

the need for it disappeared after the retirement. When noticing the robot at the festival, the chances he will initiate interaction with it are really low. He is very sceptical about any pseudoscience and mostly believes in things, that he has seen with his own eyes or knows, how they work. Seeing something that is way too complicated to figure out its functionality and, moreover, connected with science, which he does not believe makes any sense, causes him to doubt any further investigation. Convincing these type of people will be very hard due to the absence of bonding between computer and human and much higher than average scepticism threshold.

Figure 3.1 shows possible dialogue and interaction which will occur between the user and the robot. Based on the action one of the following gestures could be triggered (see Figure 3.2). The robot should always start with greeting new user and introducing oneself. This should be accompanied by a greeting gesture. Further in the dialogue robot asks a question about the date of birth, which is used to calculate the prediction. If the answer was not clear, the user is asked to repeat the answer until it is in the correct format. As soon as the date of birth is recognized correctly, the robot goes into mediation mode which is mainly going into the meditation pose for some time. The next part is the prediction itself which is given to the user in the form of a speech. User feedback to the robot is an optional part of the dialogue since the robot is only designed to recognize the date of birth. However, it may improve the experience by asking the level of satisfaction. The session ends with the robot saying "Goodbye" and doing a wave gesture.



Figure 3.2: Gesture prototypes and sketch of the robot enacting them.

3.2.3 Setting

The setting of the experiment must be designed to give a sense of comfort and safety. The user will be facing the robot in an enclosed space by a curtain to create a feeling of comfort and private conversation. The curtain will also help to limit distractions, disturbances and noises of the environment and help the user to focus on the interaction. In front and on the robot will be attributes which are aimed to boost the image of the robot being a mystic. During the experiment and interaction with the robot, the user will be facing it approximately in 1m distance. The operator will be sitting next to the setup to observe and steer the robot if necessary. The robot will initiate the dialogue sequence himself and should be fully autonomous. There should be no visible input from the operator to avoid any distractions and maintaining users immersion in the interaction.

3.3 System Design

The system design methodology is applied in the design of the hardware and software of the robot in a way that it can perform all necessary tasks required for the designed interaction. This includes functionality and configuration of the robot. The robot should be able to enact gestures, maintain gaze, speak and understand the user according to the interaction flow.

3.3.1 Block diagrams

Figure 3.3 illustrates a general layout with the required functionality on a basic level. Figure 3.4 shows more in depth construction of the required social robot. This section only shows a general description of each element in the social robot. The actual components and methods used during the project are described in the implementation section. Natural language from the user and users image is used as the only inputs for the robots. Using data gathered from these two inputs robot is able to support a dialogue by generating speech while sustaining natural gaze at the user and moving accordingly to the modelled behaviour.



Figure 3.3: Abstract functional block diagram, illustrating inputs and outputs.

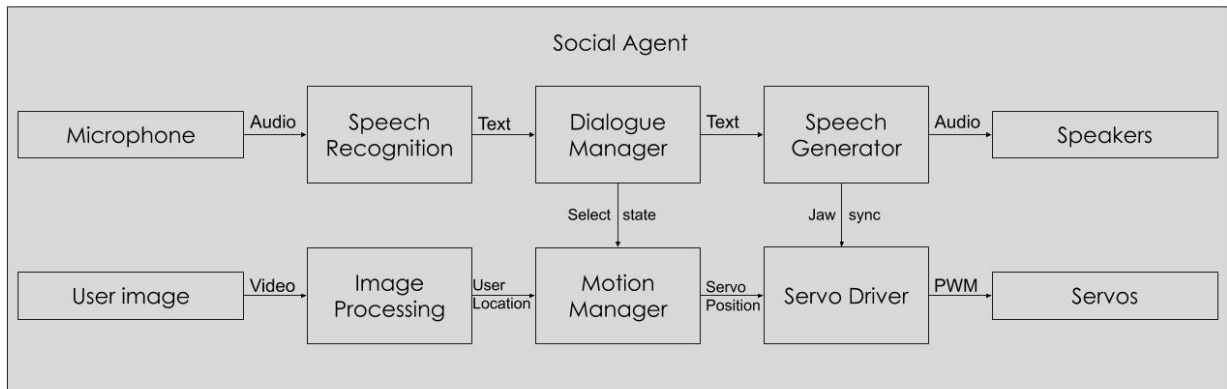


Figure 3.4: Functional block diagram with physical layer.

3.3.2 Functional breakdown

User Localization

In order to sustain a gaze and track the user in a fluent manner, the robot requires images processing at least 10fps (acceptable) and preferably at 30 FPS (fluent) and a minimum resolution of 240p as mentioned in the research during gaze development of the iCub [34]. Gaze detection in this research was developed in 3D which enables the robot to look at the object far away and close by in a different way. However, during this project 2D tracking in X and Y axis is enough, because the user stays stationary during the interaction sequence. The image should be captured and processed giving out human face position in X and Y coordinates which will be processed by the motion engine.

Speech

The robot should be able to recognize natural language and extract necessary data according to the questions that the user answers in the dialogue. Back of the envelope calculation give approximate maximal latency of 3-5 seconds after the user initiates interaction. Higher latency may result in corrupted experience. Since the astrological prediction is unique for each zodiac sign and changes every day it is essential to have a speech engine embedded into the robot instead of having prerecorded messages. It should be clear what the robot is saying, therefore, either headphones or loud enough speakers should be used.

Motion

Figure 3.5 shows basic joints necessary for the robot to perform desired gestures. Motion engine is the heart of the robot since it is monitoring servo positions, launching gesture sequences based on the dialogue and controls gaze. Figure 3.5 shows the minimum amount and arrangement of joints, which is needed to perform the necessary gestures previously shown. The design also requires easy and robust control of all joints since the gestures must be created from scratch. Moreover, this approach requires a unified communication protocol among all joints, which will allow reliable robot control. In order to implement all these software and hardware design choices in one platform it is important to choose an operating system which can support required functionality. This implies some degree of open-source operating system which allow soft-real-time processing.

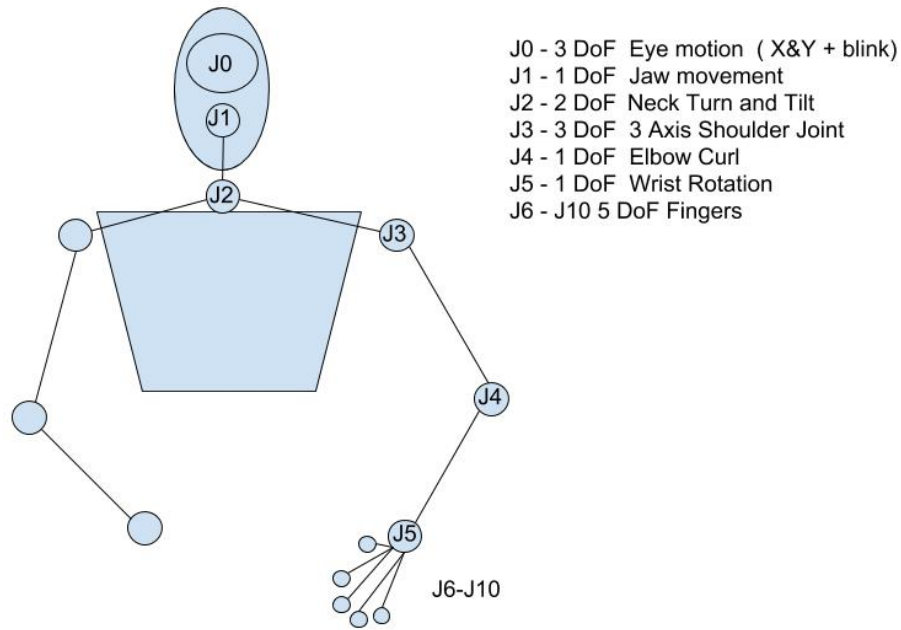


Figure 3.5: Configuration of the robot with joint location

Besides having human-like joint configuration the robot should also maintain similar movement speed, range and fluency. In order to maintain gaze, the robot needs at least 2 DoF in the eyes for horizontal and vertical eye movement. The desired eye movement speed is set to $300^\circ/\text{sec}$, which is according to human natural eye movement speed [35]. Two other joints need to simulate blinking behaviour by using 3D printed eyelids. An average human blink rate is 15 times per minute and duration ranges from 100-400ms [36]. The neck can be simplified to two DoF and have average neck angular speed of around 20-30 degrees per second and range of 40-50 degrees accordingly [37]. Shoulder joints require special attention since every gesture involves shoulder joint. The minimal requirement for shoulder joints is 3 DoF per shoulder. Angular velocities of shoulder motion should be around 40-50 degrees per second. Back of the envelope calculations show that it is normal speed for slow human hand movements. Hand joints can be simplified from 27 DoF like in human hand to minimum of 6 DoF, which allows performing basic hand gestures used in the design, however, this approach is still limited and can be improved.

3.4 Summary

Translation of the above into specifications is summarized in Table 3.1. There is a clear division between these specifications. They are sorted into three categories, Critical, IxD and System Design. This is done in order to separate the philosophical side of the project and technical parts both regarding interaction and purely technical aspects. The first part of specifications resembles the theme and idea behind this project in terms of critical design. IxD specifications show which characteristics the social robot should have in order to convey the message described in the critical design section. System design requirements are purely software and hardware requirements of the robot and they are needed to perform necessary functionality based on the characteristics of IxD.

Specification Type	Specification	Value
Critical	Provoke Discussions On topic	Robot role in future
Critical	Image of robot astrologist	True
Critical	Role	Spiritual guide
Critical	Use cultural references to speculate on future role of robotics	True
IxD	Shape	Life-size
IxD	Shape	Human proportions
IxD	Behaviour	Human-like
IxD	Maintain Gaze	True
IxD	Blink	True
IxD	Execute gestures in Figure 3.2	True
IxD	Speech recognition	English
IxD	Speech generation	English
IxD	Speech recognition	Soft-real-time
IxD	Speech generation	Soft-real-time
System Design	Support gesture editor	True
System Design	Eye saccade angular speed	300°/sec
System Design	Eye blink duration	200ms
System Design	Eye blink rate	15/min
System Design	Neck angular speed	30°/sec
System Design	Neck range	50°
System Design	Image processing	Human face
System Design	Image processing	Soft-real-time
System Design	Image resolution	240p
System Design	Fluent user localization	>10FPS
System Design	Open source hardware	True
System Design	Operating system	open-source
System Design	Flexible Design	True
System Design	Cost	<2k
System Design	Upper limb joint velocities	2 rad/s
System Design	Speech processing delay	< 4s
System Design	Recording proximity	1 m
System Design	Audible proximity	1 m

Table 3.1: Summary of all requirements

Chapter 4

Design and Implementation

This chapter describes how exactly the robot was built and programmed in full detail. Here is also explained the design of experiments and questionnaires. The chapter begins with the critical design part, where the main focus is speculation on the future role of robots. The second part of this chapter describes the interaction and experimental setups. Last part describes robots configuration, hardware and software used as well as a behaviour implementation.

4.1 Critical Design

4.1.1 The Future role

Speculation about the role of robots in the future is the key element in critical design. There is plenty of sci-fi literature, games and movies about the robots overtaking the world e.g. Terminator franchise, “*Detroit: Become Human*”, “*I am mother*”, “*I, Robot*”, “*Avengers: Age of Ultron*” etc. Stories, where robots have personality and treated as if they were humans, are also quite popular, for example, “*H.E.R.*”, “*Bicentennial man*”, “*Ex-Machina*”, “*Westworld*” (TV series), “*Chappie*” etc. However, robots as spiritual guides are rarely mentioned anywhere except in *The Hitchhiker’s Guide to the Galaxy* written by Douglas Adams. The all-knowing robot “*Deep Thought*” in this book was a supercomputer specially design to know the “*Answer to the Ultimate Question of Life, The Universe, and Everything*”. Another author, Isaac Asimov, also often speculated on the future of the robotics and how would they interact with humans. Majority of the modern movies such as ‘*The Bicentennial Man*’ and ‘*I, Robot*’ where loosely adopted on his books, especially the use of “*Three laws of robotics*”. Below are mentioned two roles of the robot, on which critical design is based on. Their main difference is an extent to which robot influences human being. On one hand, hand, the robot takes the role of a full-blown spiritual guide, giving elaborate comments on human lives, among which, some lines might be even shocking to the user. On the other hand, the robot can have a role of a humble messenger and only say a thing, which is either neutral or does not require any action from the user and treated more as a suggestion.

A humble messenger: The Astrobot takes the role of the messenger and his only function is to deliver information to the user without any added input. He is not interested in helping anyone just delivering the message is his sole purpose. In this scenario, the robot has limited responsibility due to inability of giving a proper evaluation of the situation in which the user is in at the moment.

Advantage: Inaction of a robot limits responsibility. Little to no harm is posed from the robot to human.

Disadvantage: As first low robotics states: “*A robot may not injure a human being or, through inaction, allow a human being to come to harm*” [38]. Given that, a complication may arise because not giving any instruction may cause harm to the user.

Guide: Information which Astrobot posses is carefully presented to the user taking in consideration his/her ability to use it in the right way. Astrobot not only presents information but also gives an instruction or a suggestion. Based on the data available to him he will generate a path for the user to minimize negative influence and maximize strong sides which are specific to the user. The robot will be programmed to have an interest in helping the user to achieve a greater version of himself and avoid complication.

Advantage: Influence human lives in a positive way. Give more than just a description of a situation but also instruction.

Disadvantage: Complication will begin with the first law of robotics, because giving a wrong instruction may cause harm to the user.

4.2 IxD

Interaction design is used to create a dialogue and motion flow. First part is to derive a dialogue flow according to the flow chart in requirements in the previous section. The experimental setups and settings are also part of IxD and are described in the following subsection.

4.2.1 Dialogue flow

The core of robots performance is based on the interaction between robot and human. The interaction begins by user getting close (within 1 meter) to the Astrobot, where the users face can be tracked and dialogue can be initiated. The dialogue is mentioned below and consists mainly of prerecorded messages. The only part, which is changed depending on the user is the prediction texts itself because it is different for every zodiac sign and date.

- A: *Hello, my name is Astrobot and I am robot Astrologist. What is your name?*
- U: *My name is Jessie!*
- A: *Nice to meet You! I welcome you into this experience and hope you will enjoy it.*
- A: *I want to make a prediction for you. Please tell me your date and month of birth.*
- U: *23 of August*
- *A1: *Could you please repeat your date and month of birth?*
- *A2: *You said 23 of August. Is that correct?*
- U: *Yes*
- A: *Initiating meditation mode... I see that your Zodiac Sign is Leo.*
- A: *Stars say that: Your mood should be good today, Leo, although you should be careful not to rub it in other's faces. If people don't feel like being cheerful, don't force it on them.*
- A: *Oh. By the way. An important sense of duty is prominent and should be obeyed at all costs. Give your adventurous nature some sort of practical grounding that you can use to be more effective regarding whatever it is you do.*
- A: *Hope you enjoyed it! Thank you and goodbye. I am now resuming my meditation.*

4.2.2 First experimental setup

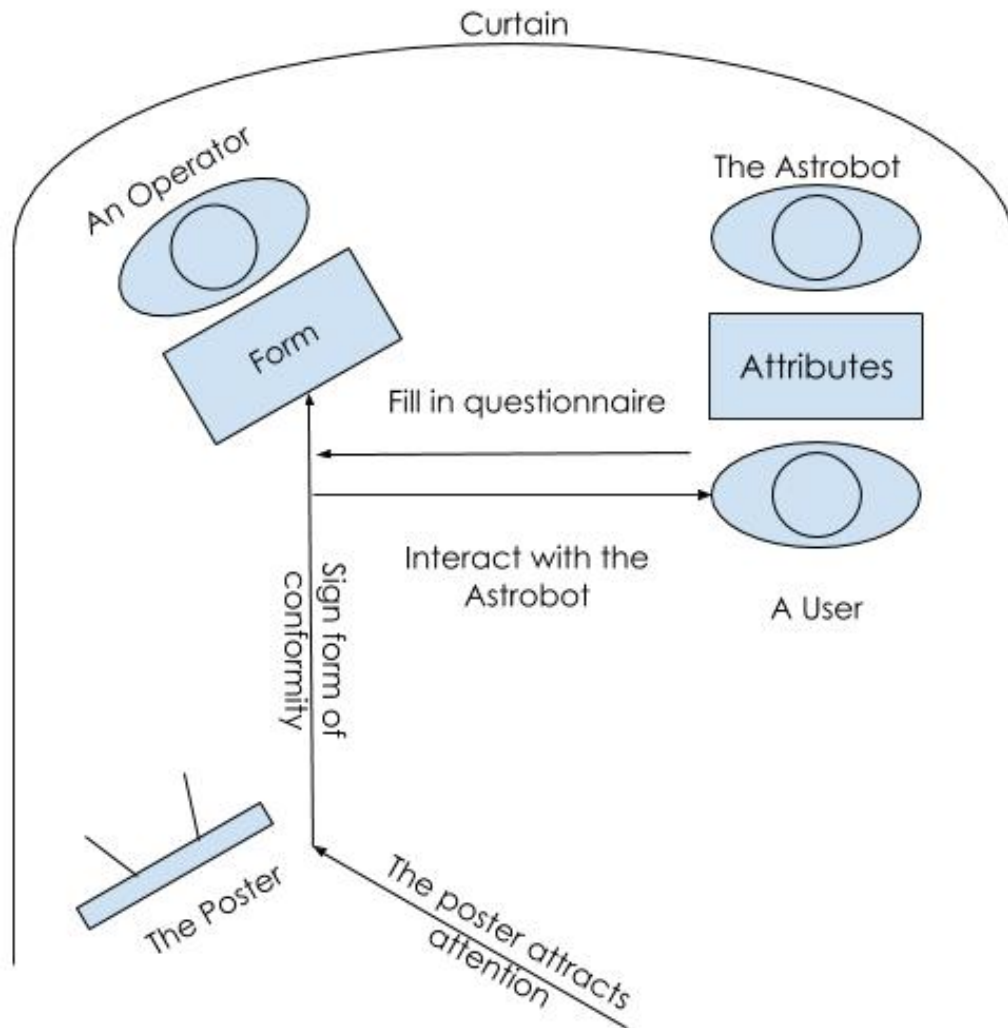


Figure 4.1: Setup of the first experiment

Objective: Get a general impression of the robots persuasive ability. Show weaknesses to be excluded in following iterations.

Procedure: The setup schematic is shown in figure 4.1. The Astrobot was placed in an enclosed room during the festival. There was a poster motivating people to try the interaction experience with the robot. People passing by immediately notice the robot and can interact with it. After signing conformity form to participate in the experiment the user begins the interaction. The participant puts headphones on and listens to what the robot has to say about one's future. After a short interaction with the robot, the user fills in the questionnaire.

Evaluation: Questionnaire in Figure A.1 the questionnaire used during this experiment is shown. It contains questions about robots looks, performance and believability. Any extra comments are used to improve the Astrobot in the second iteration.

4.2.3 Second experimental setup

Objective: Create a short movie about the Astrobot in order to trigger and facilitate discussions in society about the future roles of robots. Collect feedback for evaluation of second iteration of the robot.

Procedure: A short 1.5-minute long movie is directed and shot starring the Astrobot. The scenario mentioned in Appendix F is designed in such a way to showcase the performance of the robot as close as possible to original, where the Astrobot performs a single session of fortunetelling. Further, this movie is posted in social media after watching the movie, participants fill in a questionnaire and/or leave a comment. Collected data is further analyzed to make conclusions.

Evaluation: Questionnaire in Figure C.1 is used during second experiment. In comparison with the first questionnaire, it is more extensive. Additional questions are added addressing believability and some critical design aspects. Any additional comments about the robot are collected as well. The amount and intensity of comments that people make about the robot indicate how well it is triggering discussions indicating critical design performance.

4.3 System Design

4.3.1 Robot configuration

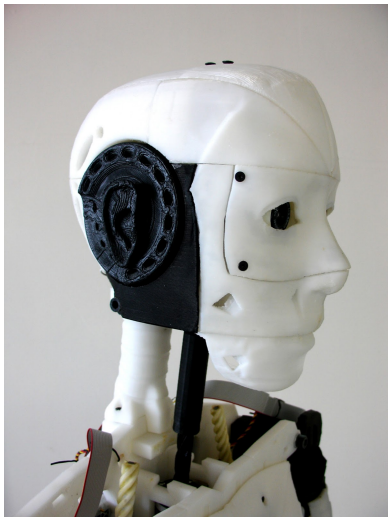


Figure 4.2: InMoov with realistic ear¹.



Figure 4.3: InMoov with functional speaker-ear.



Figure 4.4: Web camera with wide angle magnetic lens attached, in the middle of the robot torso.

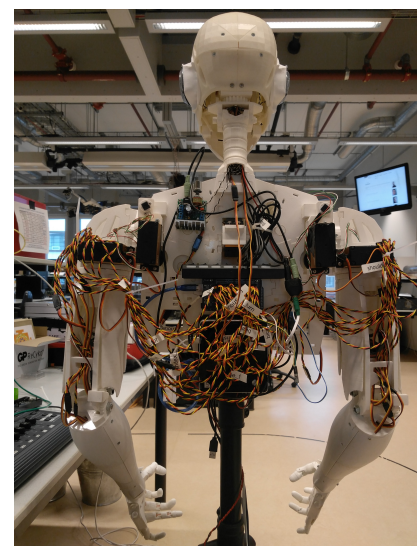


Figure 4.5: Back view of the robot, with wires routed to the controller.

¹<http://www.inmoov.fr/imold/1.bp.blogspot.com/DSC06015.JPG>

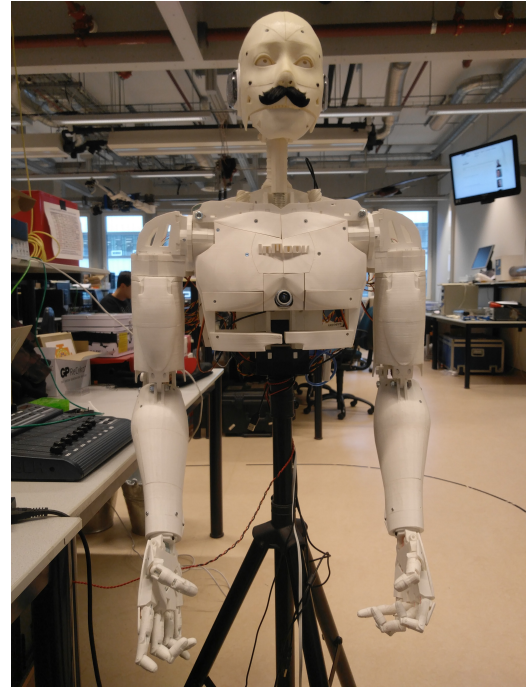


Figure 4.6: Full size assembly of the inMoov robot². Figure 4.7: Upper body used in the inMoov project.

The inMoov robot was used as the platform for the design. This social robot is open source and has the same DoF specifications as derived in previous chapter. It was not necessary to use the entire robot (see Figure 4.6) with legs and stomach part, therefore only the torso part of the robot (see Figure 4.7) was used during the project. In order to give the robot the ability to sustain gaze and blink, the stock eyes were replaced with animatronic eyes (see Figure 4.8 and 4.9). Another configuration deviation from standard inMoov was a set of speakers embedded in the head of the robot shown in Figure 4.3. Substituting human-like ears (Figure 4.2) with speakers allows loud and clear communication with the user. Last but not least modification was a wide-angle camera used in the middle of the torso shown in Figure 4.4. This allowed reliable user localization in front of the robot, regardless of the head or eye position.

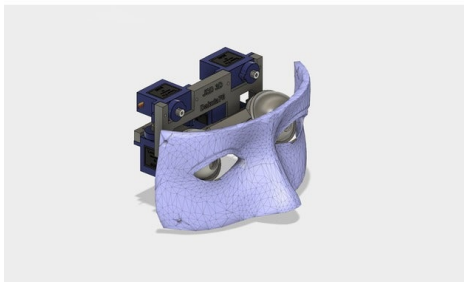


Figure 4.8: 3D printed animatronic eyes used in the Astrobot, with the face plate.³

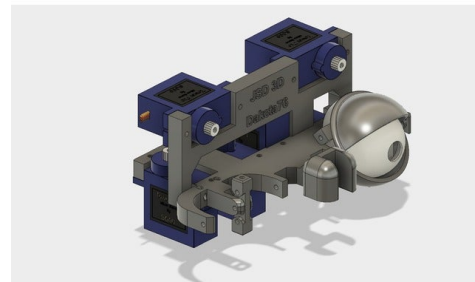


Figure 4.9: 3D printed animatronic eyes used in the Astrobot, without the face plate.⁴

4.3.2 Hardware

The hardware used in the robot is shown in the schematic in Figure 4.10 and bill of materials is provided in Appendix E. The Astrobot has in total 29 servos out which, 6 are used in the eyes with specially dedicated controller - Arduino Nano. These servos are micro-servos HK15179 and they are responsible for eye tilt and turn as well as eyelid movement. 12 out of 29 servos are standard size MG996R Towerpro servos with a stall torque of 10kg. These servos are much more powerful, than eyes servos, and are used in all fingers as well as both wrists, to have a fast and firm gesture performance. The rest of the servos are large PDI-HV2060MG

²<http://inmoov.fr/wp-content/uploads/2016/09/photo3.jpg>

⁴<https://www.thingiverse.com/thing:2548952>

⁴<https://www.thingiverse.com/thing:2548952>

servos, with a torque of 60 Kg. Such power is necessary at the shoulders, biceps and head of the robot, in order to move heavy body parts. All servos accept animatronic eyes, are controlled using Arduino Mega with Mega Sensor Shield. Control algorithms for the servos of the robot are explained in the following sections. The brain of the robot is Intel NUC Kit NUC5i5RYB, a compact mini PC with powerful Intel Core i5-5250 processor with an on-board Intel HD embedded GPU. The system is powered through a lab power supply, delivering 7.4 Volts to all standard size and large size servos. Eye servos are powered from the USB of NUC and use 5.0V. Simple USB camera with 2.0 Mpix and professional Rode microphone is used to capture video and sound. All servos are wired using standard extension cables designated for servo motors. All wiring is labelled and routed at the back of the Astrobot (see Figure 4.12), where the main processor is located. Both Arduinos controlling all servos of the robot are always connected to the main processing unit and can be reprogrammed at any instance of time. As an additional equipment control panel, mouse, keyboard and monitor are used. They are necessary only during the setup and choreography implementation. During experiments additional equipment is removed.

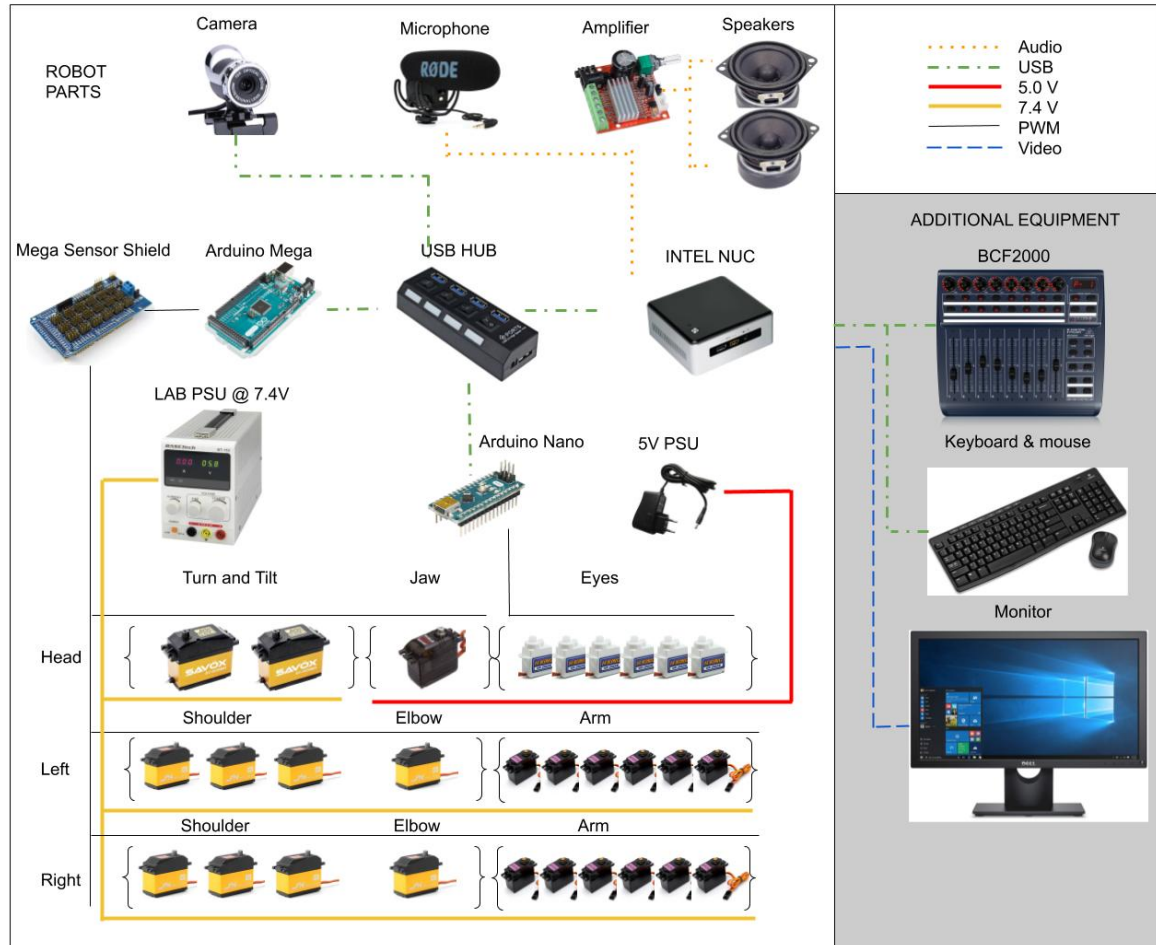


Figure 4.10: Hardware map of the designed robot

4.3.3 Software platform

The backbone for all the software used in the Astrobot is the open-source operating system Debian 9.4.4 with Raspberry Pi Desktop on it. This OS allows full access to open-source codes and hardware used in the project. Main code is made in a single program with separate dedicated functions using Python 3.6 programming language. This allows parallel execution of multiple functions of the robot without freezing or locking other processes. Arduino IDE is also available on Debian and was used to write the code in C/C++ programming language.

4.3.4 Servo control

Arduino Mega + Mega Sensor Shield

Arduino Mega with Mega Sensor Shield was used to connect and control most of the servos except the eye servos (see Figure 4.12). All controls were done using an array of 26 Values `Servo_position[26]`, where each value corresponds to a certain servo, controlling each DoF of freedom. Several optimisation algorithms were used to avoid servo damage and sharp movements of the robot joints, as well as increase life-time of the servos. In order to limit servo position and protect from damage both servos and mechanical parts of the joints two arrays are used. They contain minimum and maximum allowed angle of each joint, which is calibrated accordingly. All limit calibration occurs using `Servo_Max[]` and `Servo_Min[]` arrays, by initialising them during boot in `servo.attach(min,max,pin_number)`. Each servo is controlled using internal timers of Arduino `servo.writeMicroseconds(microseconds)` instead of standard `servo.write(angle)` function. This approach is possible due to the nature of the servo control protocol, which uses PWM signal. Using microsecond control allows much more smooth control of each servo ranging from 544 to 2400 versus the standard angle control ranging from 0 to 180 degrees. In addition to servo range limitation additional function `servo.detach()` is used. This function disables any servo after 3 seconds of idling, preventing constant, unnecessary strain, which often causes overload and premature damage of the electronics inside a servo.

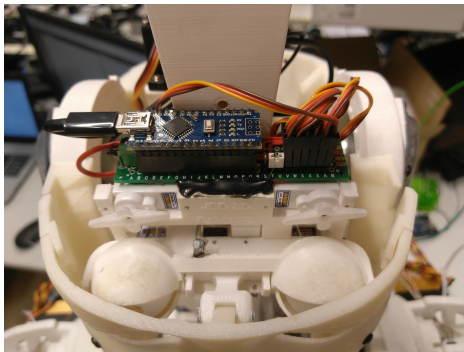


Figure 4.11: Arduino Nano with custom PCB in the robots head.

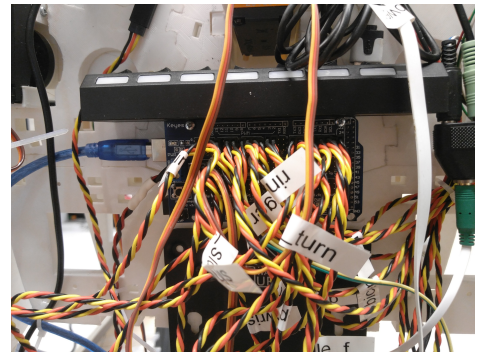


Figure 4.12: Arduino Mega with Shield and servo wires attached.

Arduino Nano + Custom PCB Shield

Arduino Nano in conjunction with custom PCB designed for easy and stable control of 6 micro servos, takes care of animatronic eye motion (see Figure 4.11). Similarly to Arduino Mega it has servo limits for each servo as well as 4 control values. Turn and tilt of the eyes is calibrated and inverted in such a way that eyes are controlled only with two values X and Y, which corresponds to vertical and horizontal motion of both eyes. Upper and lower eyelids are controlled independently, using the remaining control values. Another feature implemented in the Astrobot is human-like blinking. With the random interval between 3-7 seconds, both eyelids are closed for 200ms and then open again. This is a background routine and it runs regardless of eye position mimicking human behaviour.

4.3.5 Image processing and human face tracking

In order to give the Astrobot the ability to see and follow human using animatronic eyes open-source image processing software was used. OpenCV [39] is commonly used for such tasks due to the fact that it is fast, relatively simple and easy to use software package based on Python. OpenCV offers pre-trained Haar-cascade algorithms [40], which allow fast and reliable face detection. For this project `haarcascade_frontalface_alt.xml` was used, as it showed the most stable performance among other provided algorithms. Figure 4.13 shows an example of, how the human face is recognized and a box is drawn around it to show the location on a two-dimensional plane. In order to achieve smooth eye movement, a stable frame rate of at least 20FPS is required. This is achieved by using `cv2.resize()` function and resizing image from 640x480 which delivers sub 15FPS to a 320x240 with a stable frame rate of above 25FPS. Figure 4.14 show how exactly and in which sequence was this task realized. Face detection function mentioned below is responsible for entire routine and is enabled and disabled using specially dedicated switch on the fader panel.

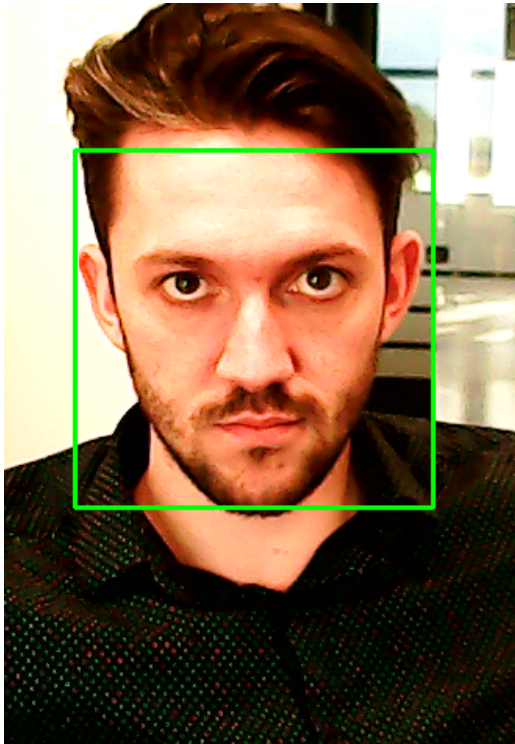


Figure 4.13: Image frame after application of Haar-Cascade using OpenCV.

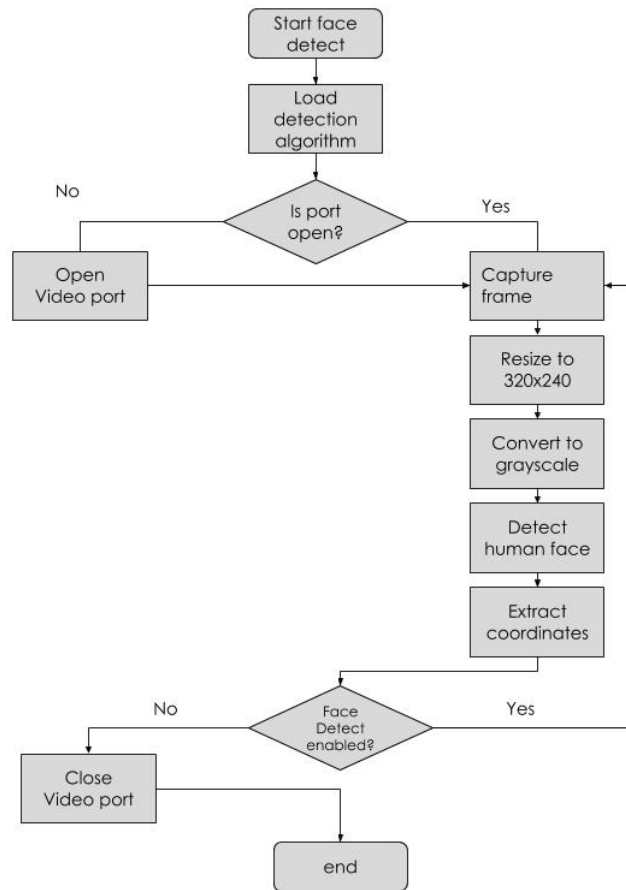


Figure 4.14: Image processing flowchart.

```

ret, frame = video_capture.read() #capture frame
dim=(320,240) #custom dimensionn
frame = cv2.resize(frame, dim, interpolation =cv2.INTER_AREA) #resize
height, width, channels=frame.shape
gray = cv2.cvtColor(frame, cv2.COLOR_BGR2GRAY) #convert to grayscale
faces = faceCascade.detectMultiScale( #faces array contains the required location
    gray,
    scaleFactor=1.1,
    minNeighbors=5,
    minSize=(50, 50),
)
cv2.imshow('Video', frame) #Show frame
  
```

4.3.6 Voice recognition

Google speech to text (STT) API is used to transform recorded response from the user to the text which is used by the Astrobot in the dialogue manager. Google STT⁵ is cloud based and requires a stable internet connection. `Listen()` function takes care of speech to text conversion. Using microphone attached to the audio input port on NUC, first volume calibration is initiated to eliminated noise using `r.adjust_for_ambient_noise()`. Afterwards speech is recorded to an audio file, with the duration of no longer than 4 seconds. The audio is then converted using `r.recognize_google(audio)` function and response is produced as a text string. When receiving a date response user may say it in many ways mixing up the location of date and month or adding year and other information. This is handled by `dateutil`⁶ library allowing almost any input to be converted into desired format.

⁵<https://pypi.org/project/SpeechRecognition/>

⁶<https://dateutil.readthedocs.io/en/stable/>

4.3.7 Speech generation

Astrobots speech engine is based on IBM Watson⁷ and implemented in Python. Selected voice is male en-US. Special function `say_it(text)` takes care of text to speech processing. TTS is online based and requires internet connection. This function converts any text in English into a .wav file with 44.1KHz sampling rate. After text to speech conversion is complete `play_it(name)` function plays the file using the official VLC bindings in Python. IBM Watson API is not free and in order to limit unnecessary queries most of the phrases are converted only once and only their converted .wav files are played back. The actual TTS only occurs during presence of new text, for example, the daily astrological prediction. Code below shows both functions used in the text to speech processing.

```
# generate speech from text
def say_it(text):
    with open('temp.wav', 'wb') as audio_file:
        audio_file.write(
            text_to_speech.synthesize(
                text,
                voice='en-US_MichaelVoice',
                accept='audio/wav',
                rate='44100'
            ).get_result().content)
    play_it('temp.wav')
# play speech file

def play_it(name):
    player=vlc.MediaPlayer(name)
    player.play()
    Ended = 6
    current_state = player.get_state()
    while current_state != Ended:
        current_state = player.get_state()
    print("vlc play ended")
```

4.3.8 Control of the robot

In order to simultaneously control all robots servos and in the same time avoid over-complication of the design a midi protocol was used. This allows to use a single midi panel to control and enable all features of the robot. The main program of the Astrobot consists of five separate routines (Figure 4.15), which run as parallel threads to avoid any dependency on each other. This non-locking code approach allows independent functioning of each control routine by evenly splitting processing load on the computer. `Face_detect()` function was already described above and is used only for image processing. It was isolated as parallel thread due to high CPU usage (about 70-80%), causing stutter and lag in all the other parts of the program. BCF2000 midi control-panel

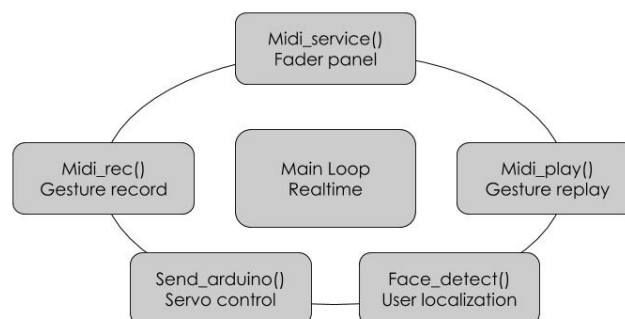


Figure 4.15: Main sub-routines inside the main program.

(see Figure 4.16) was used to control the robot, where each fader was assigned to a certain joint of the robot. `Midi_Service()` is responsible for instant message read out from midi panel and decoding it into a usable format consisting of parameter ID and parameter Value. This allows to run image processing, gesture control and servo driver communication to work in soft-real-time. All parameters are stored in the dynamic memory of the PC in an array called `Servo_position[]`. In order to record certain gestures special routine `Midi_Rec()`

⁷<https://github.com/watson-developer-cloud/python-sdk>



Figure 4.16: BCF2000 Fader panel used as a control panel for the Astrobot.

was implemented. After the recording is started, a text file with file number selected on the panel is created in the main program directory. With a sampling rate of 50Hz all the data from the midi panel is recorded into a `file_number.txt` file until recording is stopped. In order to replay a file `Midi_Play()` function is used. In the same way after selecting `file_Number.txt` file and pressing replay button gesture is played back. Important feature embedded in this Record and Replay routine is the ability to record/correct gesture, while it is played back. It is possible to overwrite the values in the gesture file if corresponding servo rewrite enabler is turned on on the midi panel. This allows fast and easy tuning of any gesture of the social robot. Finally `Send_Arduino()` routine takes care of reliable data transfer using Fast Serial Interface at 115200 Baud rate to both Arduinos controlling servos. The data of the servo position is only sent, when there is a new shift in the servo position, in this way avoiding serial interface overload and improving CPU performance.

4.3.9 Manufacturing process

Another important part of the design is the manufacturing process itself. The robot is completely 3D printed using TEVO Tarantula, Ultimaker 2 and Ultimaker 3 FDM 3D printers. The chosen filament is Tough PLA which is not as durable as ABS, however, it is much more resilient to deformation during printing caused by heat. The total amount of filament used is about 3.5 KG and total printing time is roughly estimated to 350 hours. Addition difficulties are caused due to the fact that the settings of each printer are unique. This is especially problematic when printing tight-fitting parts such as worm gears, pistons and rotational gears. The mismatch between expected and delivered sizes of printed parts lead to poor performance or even fractured parts (see Figure 4.17). In order to solve this problem, part scaling was used. As the parts were slightly bigger than they should be it was decided to scale down the inner parts until they fit perfectly inside the need part. Figures 4.18 - 4.21 show how parts were scaled-down. Scaling was done only once for each type of part since the other parts in the robot where the same shape only varying in the thread direction. The scaling for gears with many threads e.g. piston gears should be only done in X and Y direction. The length of the piston should always remain the same to avoid complications.

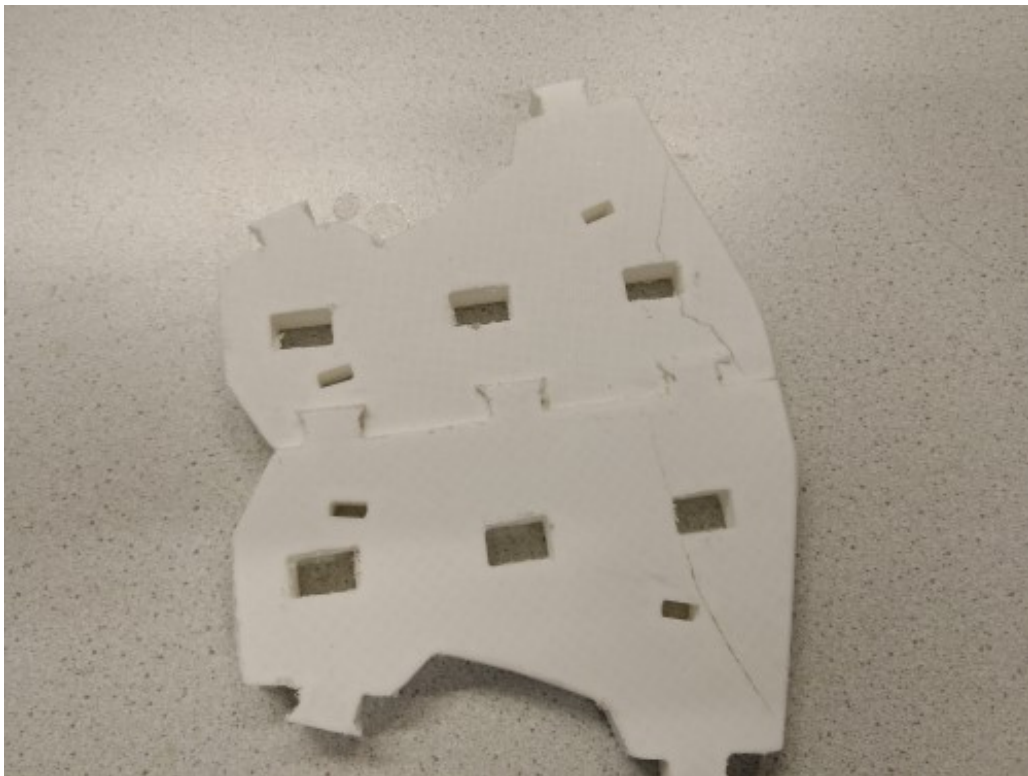


Figure 4.17: The chest piece which shattered during assembly due to the excessive amount of plastic on the connecting elements.



Figure 4.18: Side view of the 3D printed worm gears scaled to 93% 95% 97% and 100% accordingly.



Figure 4.19: Top view of the 3D printed worm gears scaled to 93% 95% 97% and 100% accordingly.

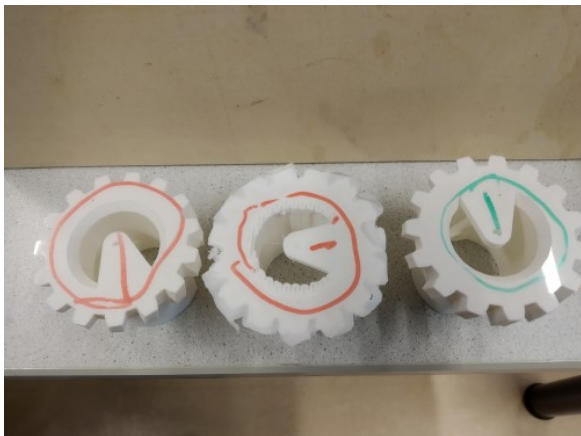


Figure 4.20: 3D printed rotation gears to 96% 100% and 98% accordingly.

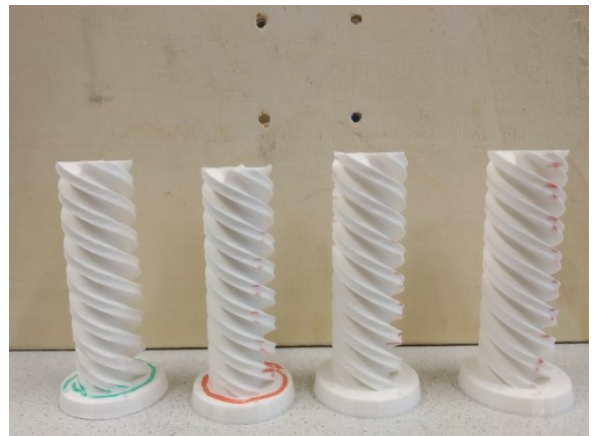


Figure 4.21: 3D printed piston gears scaled to 96% 93% and 98% 100% accordingly.

Chapter 5

Results

This chapter presents the outcome of the design. It is divided into three sections. The first section contains the final design of the social robot with technical specifications and parameters. The second and third sections describe the two experiments conducted for the research and illustrate the collected data. The last chapter contains the interview from three different specialists and serves as an addition to the two experiments.

5.1 The Astrobot

The final version of the social robot is shown in figure 5.1. According to the design characteristics the robot resembles a robot fortuneteller with all necessary attributes. It is a full-size humanoid robot with human-like body type and face. He can talk and understand human speech on the required level. He has a camera embedded in the body to track human face and maintain gaze. All wires and servos are hidden behind the coat to maximize the immersion. His movements and gestures are described and shown in the section below in full detail. The



Figure 5.1: Final version of the Astrobot. Photo made during the shooting of the movie.

core of the robot is based on InMoov except for the animatronic eyes, webcam location and modified range of motion and velocity of several joints. The astrobot also features custom software written from scratch to match the desired behaviour.

5.1.1 Gestures and Movements

There are three main categories of movements occurring in the Astrobot: eye motion and blinking (Figure 5.2 - 5.9), head motion and jaw opening (Figure 5.10 - 5.15) and finally hand gestures (Figure 5.16 - 5.19). These movements are prerecorded and are launched at the desired times based on the dialogue. The gesture set is not limited to the one shown in figures and new gestures can be easily recorded and replayed.

Using animatronic eyes the Astrobot can simulate human-like eye motion in all directions allowing him to track human face anywhere in his sight. In order to simulate human-like blinking, the robot uses merged lower and upper eyelids by closing 5.3 and opening 5.2 them. The entire process takes about 200ms which is within a range provided in the requirements section. The intervals between blinking are based on the interaction type. In normal mode, the interval is set to the random duration of 2-10s, similarly to how humans blink. However, in a long session where the robot is in active mode for longer periods of time, this interval is increased to 8-15 seconds to protect wear of the eyelid servos. The average angular velocity of the eye during a saccade is around 250 degrees per second, which also fits the requirements well.

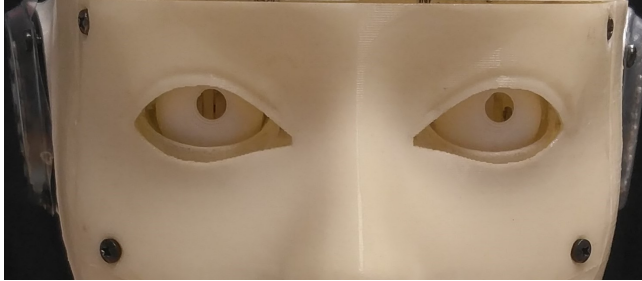


Figure 5.2: Neutral eye position



Figure 5.3: Eyelids closed

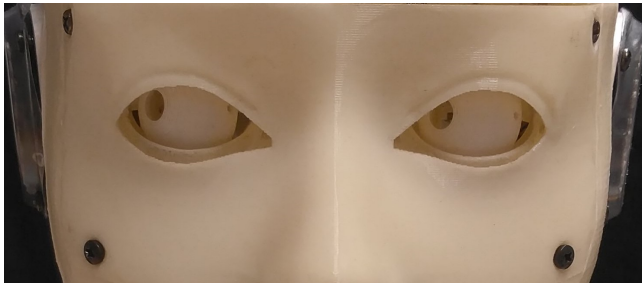


Figure 5.4: Left eye position



Figure 5.5: Right eye position

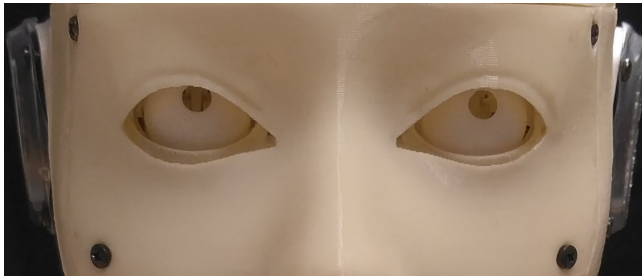


Figure 5.6: Upward glance

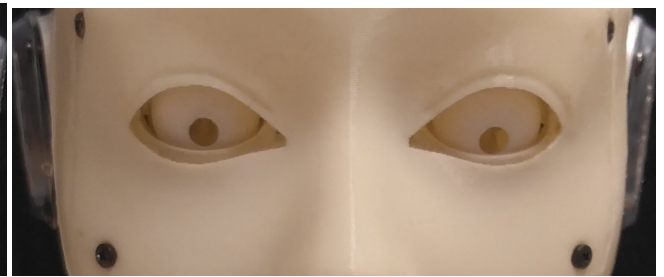


Figure 5.7: Downward glance

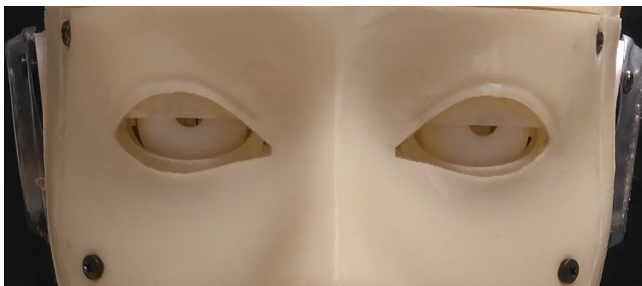


Figure 5.8: Upper eyelids closed

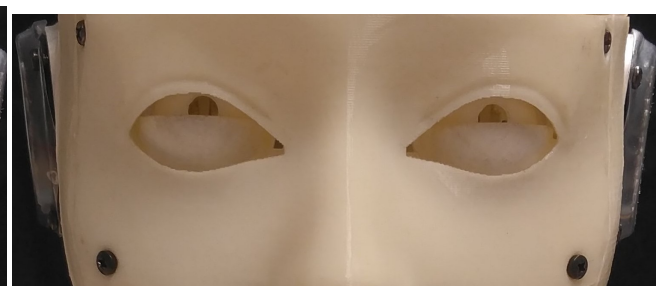


Figure 5.9: Lower eyelids closed

The range of motion of the neck is different than in humans since there is no side tilt option in the Astrobot and it has only 2 DoF instead of 3. However, for the chosen movements range 2 DoF in the neck is sufficient. The maximum speed of neck flexion (Figure 5.12) and extension (Figure 5.10) is reduced to match required human-like behaviour at normal speeds reaching about 30 degrees per second. The same is applied for left (Figure 5.13) and right (Figure 5.15) motion of the neck reducing speed to 50 degrees per second. Range of motion is also reduced to match natural human-like posture described in previous chapters. The jaw of the robot has only one DoF and can be anywhere between open (Figure 5.11) or closed (Figure 5.14) state. Having a human-like jaw motion when talking is an incredibly complex task and was not a part of the design. The goal of the jaw motion is to indicate whether or not the robot has started or finished his dialogue part. Speakers



Figure 5.10: Head tilted up

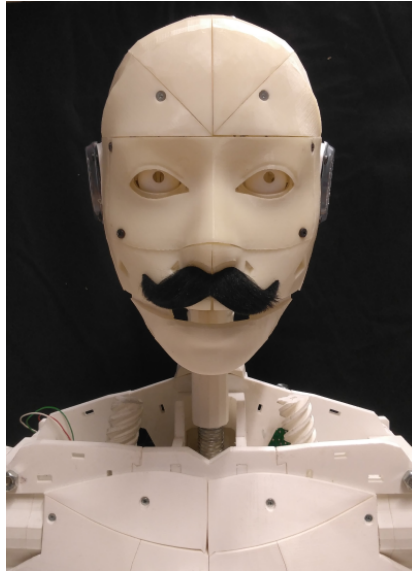


Figure 5.11: Jaw fully opened



Figure 5.12: Head tilted down

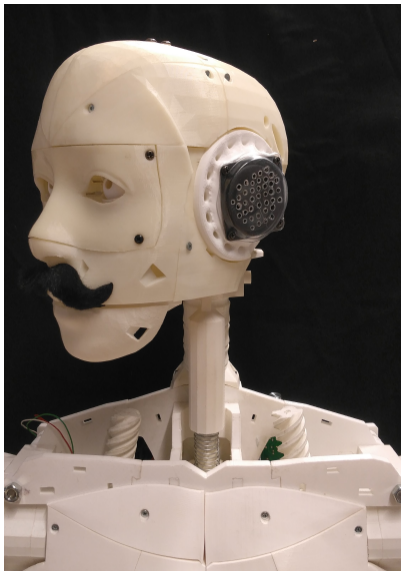


Figure 5.13: Head turn left

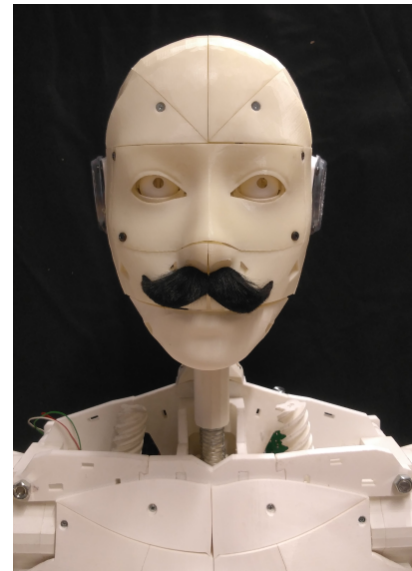


Figure 5.14: Neutral position

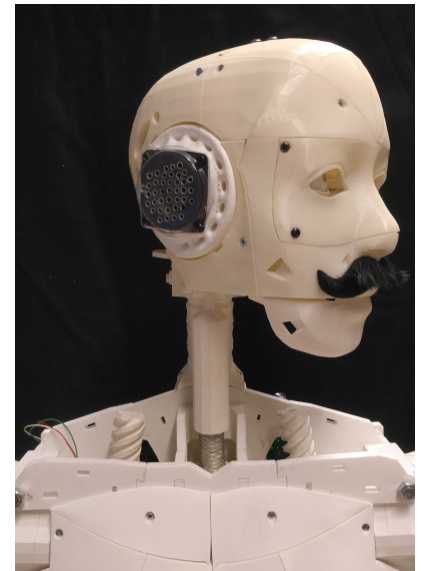


Figure 5.15: Head turn right

used to deliver the sound are placed in the robot's ears in this way the illusion is created as if the sound comes from his mouth.

Lastly, the robot has a selection of gestures used during the interaction. These gestures are recorded using midi panel and are easily adjusted if necessary. During the idle state the robot uses breathing (Figure 5.17) to make an impression of a living being. This is an example of autonomous behavior increasing persuasion through anthropomorphism. The “*Namaste*” and “*Thinking*” gestures were excluded from the design due to the limited range of motion the elbow.

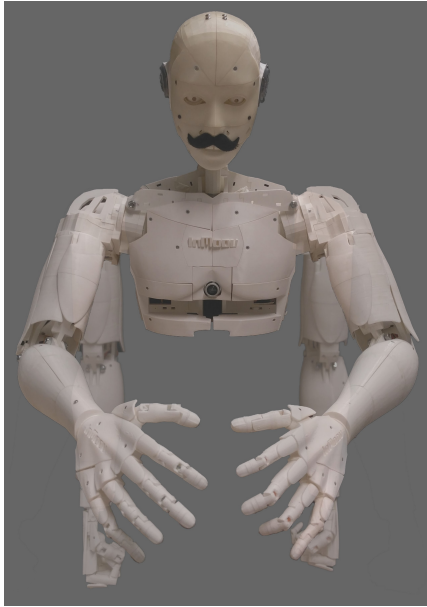


Figure 5.16: Gazing into the orb gesture

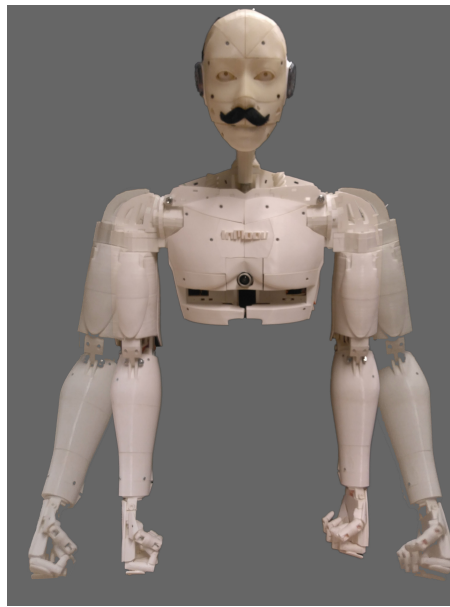


Figure 5.17: Human-like breathing motion



Figure 5.18: Lifting arm gesture

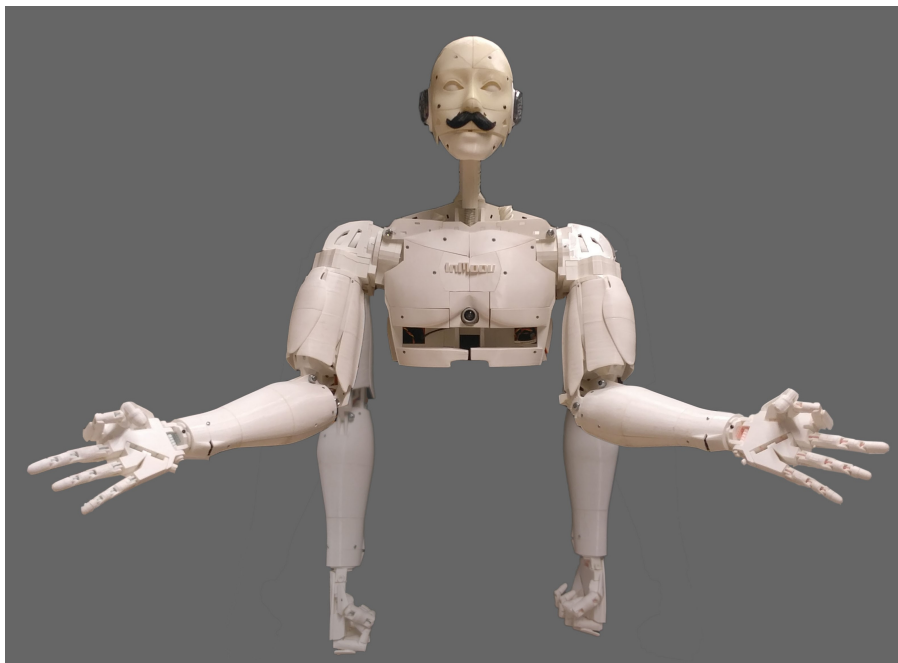


Figure 5.19: Meditation pose

5.1.2 Motion and fluency

Elbow Joint

Besides the gesture set used by the robot, it is also important that their execution is stable, reliable and fluent. Not all joints are described here but only the most important and unique. Figure 5.22 illustrates the performance of the elbow joint when going through the full range of motion, beginning with fully flexed (Figure 5.20) and ending with fully extended elbow (Figure 5.21). As can be seen from the graph, the position is lagging the setpoint, however, the calculated delay between a setpoint and start of the motion is only 170ms and lies well within the requirements. Other key parameters are angular velocity and range of motion of the joint, which in this case are 33 deg/s and 45 degrees respectively.

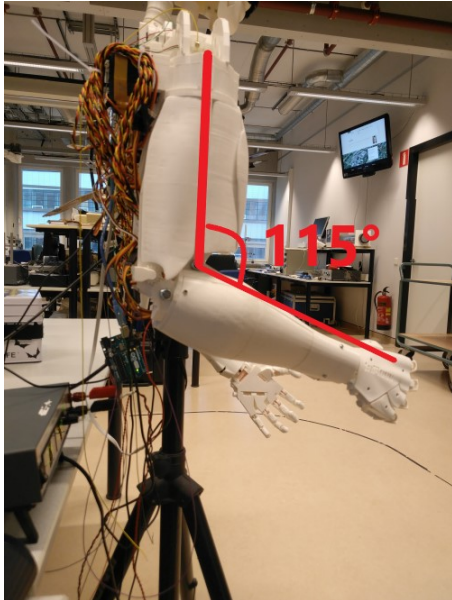


Figure 5.20: Full elbow flexion.

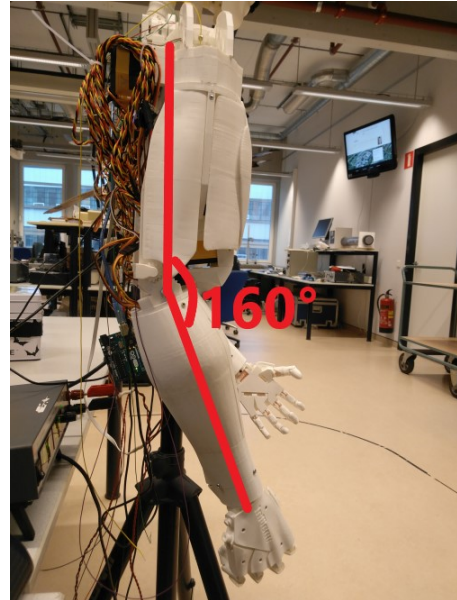


Figure 5.21: Full elbow extension.

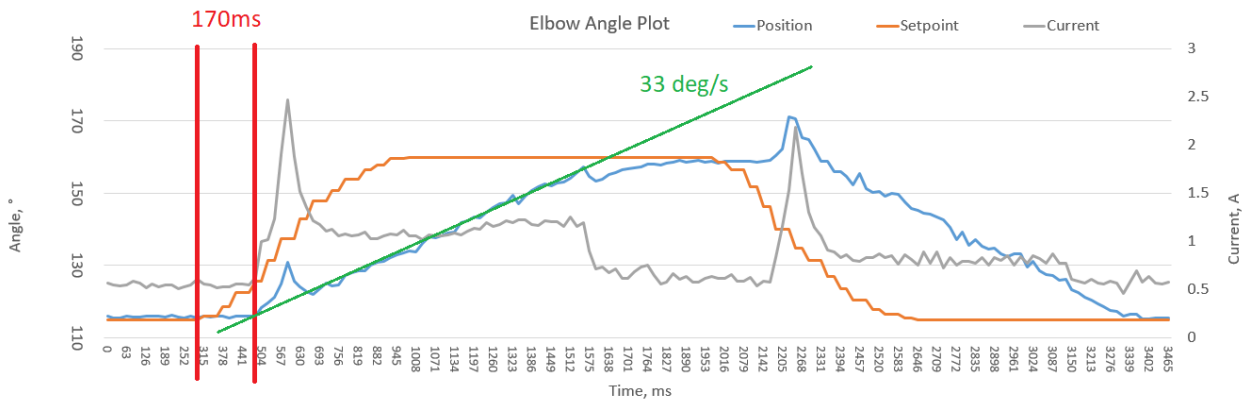


Figure 5.22: Graph showing position, setpoint and current of the elbow joint.

Shoulder Lateral Joint

Shoulder adduction (Figure 5.23) and abduction (Figure 5.24) have a range of motion of 55 degrees and are similar to human lateral shoulder motion. The delay between the setpoint and actual movement is around 210ms and angular velocity is 22 deg/s, which can be seen in the graph (Figure 5.25). This joint uses piston gear similar to the elbow joint and is capable of lifting the entire arm weighing about 3Kg. The disadvantage of such a setup is the fact that the servo needs to be continuously powered to keep the hand on a certain height. This is caused by the weight of the arm pulling downwards and might result in much faster degradation of the servo compared to the other joints. However, this configuration allows increased angular velocity compared to the worm gears of the vertical shoulder motion described further.

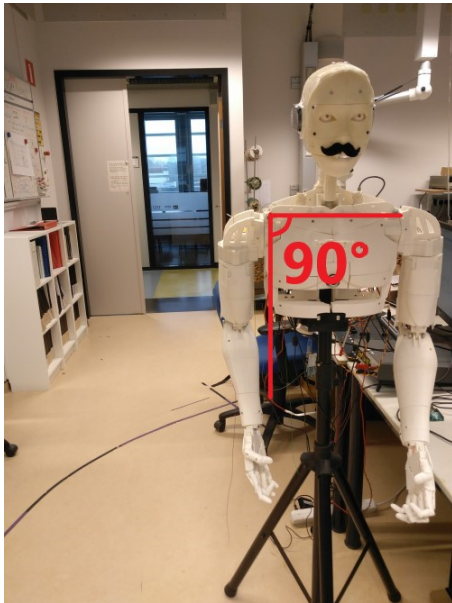


Figure 5.23: Full shoulder adduction.

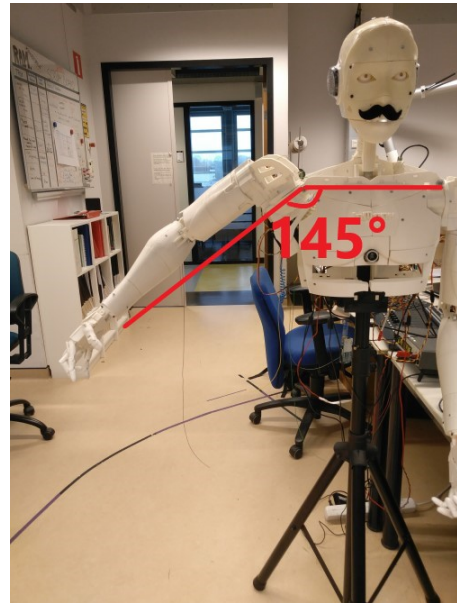


Figure 5.24: Full shoulder abduction.

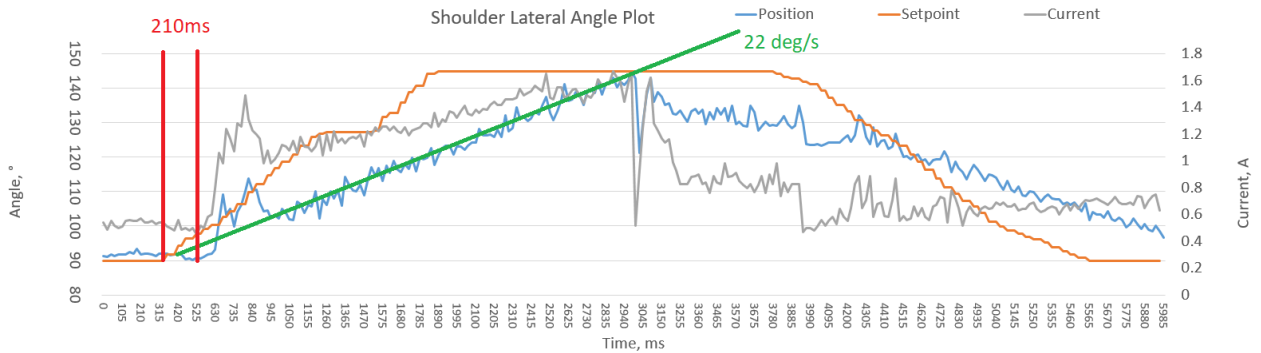


Figure 5.25: Graph showing position, setpoint and current of the lateral shoulder motion.

Shoulder Vertical Joint

Vertical shoulder movement or so-called shoulder flexion (Figure 5.26) and shoulder extension (Figure 5.27) is the slowest joint as it can be seen from the graph in Figure 5.25. Even though response rate is the same as in other joints (around 170ms), the time it takes to complete a full motion spectrum is more than 9 seconds. First of all, this is caused by a low angular velocity of 18 deg/s. Secondly, the range of motion is 160 degrees which is similar to human anatomy. The lack of speed is explained by the use of a worm gear at the shoulder joint which is not as backdrivable as piston gear and can lock in place even when driving servo is switched off. However, it has higher reduction ratio resulting in a lower angular speed requiring either different servos or completely different design. This joint similarly to lateral shoulder joint experiences the highest stress due to the weight of the hand and needs to be redesign to mimic human motion.

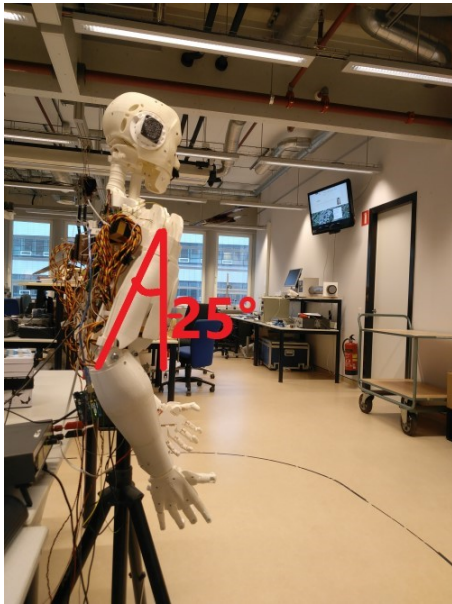


Figure 5.26: Full shoulder extension.

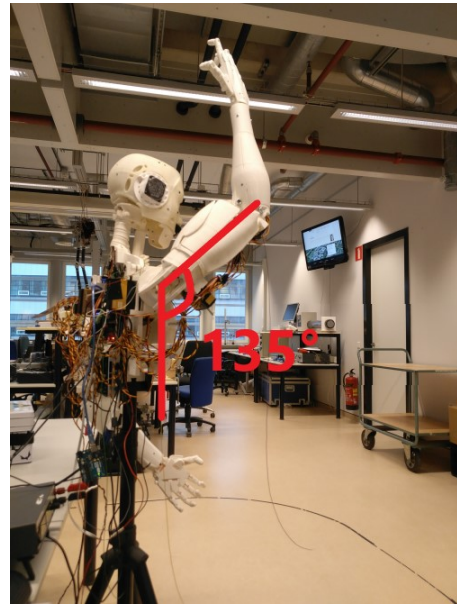


Figure 5.27: Full shoulder flexion.

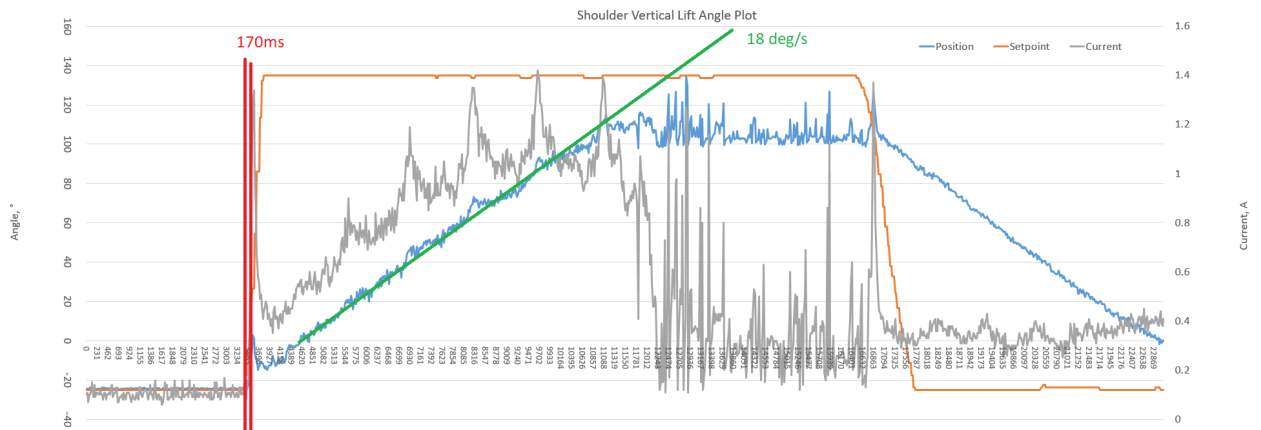


Figure 5.28: Graph showing position, setpoint and current of the vertical shoulder motion.

Jaw motion and voice fluency

Figure 5.29 illustrates the code, which is used to calculate the amount of time necessary to convert a string of 70 characters into speech. The total delay caused by the conversion is 1938ms or about 2 seconds which is well within the required maximum delay of 3-5 seconds. Moreover, the duration of converted text is 5 seconds, meaning that it can be split into parts to minimize the delay even more. However, this was not necessary in this project but should be used in case of longer text blocks.

```

468 print('Starting Timer')
469 millis = int(round(time.time() * 1000))
470 print('Converting text to speech')
471 say_it('Hello! My name is Astrobot and I am robot astrologist! How can I help You?')
472 print('Conversion finished')
473 print('Time elapsed')
474 print(int(round(time.time() * 1000))-millis)

```

Shell ✕

```

Starting Timer
Converting text to speech
Conversion finished
Time elapsed
1938

```

Figure 5.29: Code snippet with time calculation of the speech processing duration.

Next figure (5.30) is a combination of two graphs. The lower part of the graph is the representation of the audio signal fed to the speakers of the robot. The upper graph indicates the current consumption of the jaw servo. Both graphs are synchronized in time to show the delay between audio in the speakers and actual jaw motion of the robot. The average delay is 190ms, which is the same as all other servos in the system.

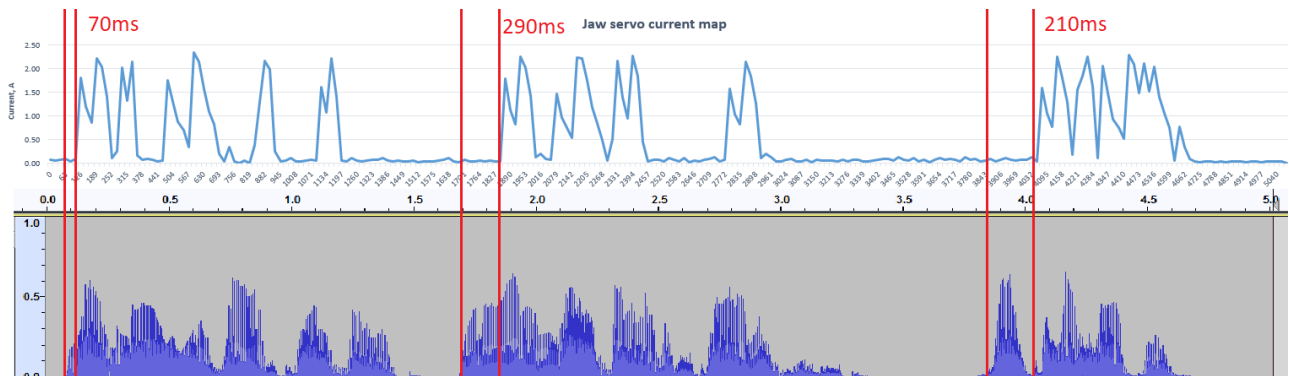


Figure 5.30: Visual representation of current consumed by jaw servo.

Fluency of Image processing

Use of OpenCV Haarcascade algorithms resulted in a good performance on the Intel Core i5-5250U processor. The average frame rates are shown in figure 5.31 with according CPU load. In order to achieve smooth performance, image was scaled down from 640x480 to 320x240 pixels. Reducing the image size increased the framerate from 15 to about 25 FPS. The processor load was reduced from 99% to 45% allowing smooth operation of other parallel processes.

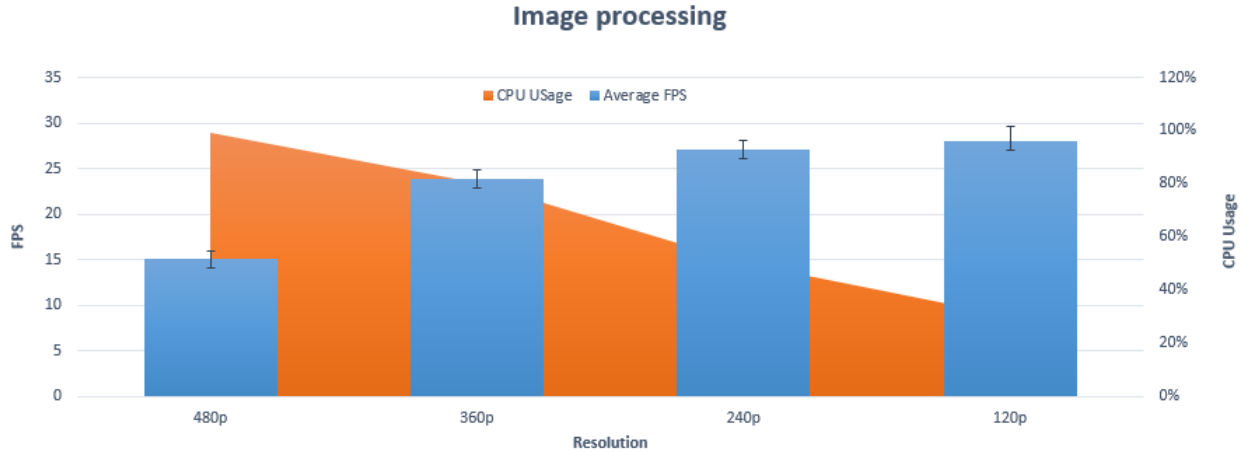


Figure 5.31: Visual representation of FPS and CPU load depending on the resolution of image.

5.2 First experiment

The first experiment was conducted during the RobotLove exposition in Eindhoven organized by Ine Gevers. Figure 5.32 illustrated the advertisement of Astrobot at the official RobotLove Facebook page. The theme of the exposition was *“Human and Robot Relationships”* and Astrobot was a perfect fit for this festival. According to Ine, *there was always a need for such a robot where people jump into interaction without them knowing about the begging of human-robot relations. Astrobot triggers this interaction with ease. In her opinion there should be more dialogue options to extend the interaction even more.*

5.2.1 Setup

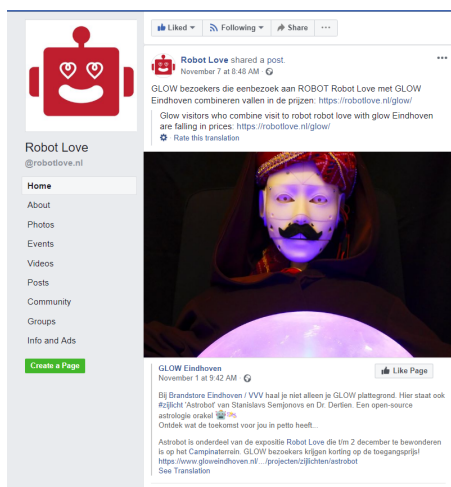


Figure 5.32: Post about Astrobot on official RotoLove Facebook page.



Figure 5.33: Setup of the first experiment conducted during Dutch Design Week festival called Robot Love.

Figures 5.33 shows the setup of the experiment during the Robot Love festival in Eindhoven. It was perfectly suited for the sort of experiment due to the fact that the topic of the festival matched the theme of an Astrobot. As can be seen from pictures, the robot attracted a lot of attention. People were interested in the robot and there was always a queue of people waiting to interact with it. The procedure went according to the described

sequence in the previous chapter. The user started by signing the form of informed consent and agreeing to participate in the experiment. Afterwards, the user stood up in front of Astrobot and put on headphones. The interaction took about one minute after which the user took on a questionnaire shown in A.1.

5.2.2 Questionnaire data analysis

Figure B.1 combines all data collected from 47 participants. The results are grouped into three categories in order to answer research questions mentioned in the first chapter.

Attitude to Astrology vs Robot Astrologist

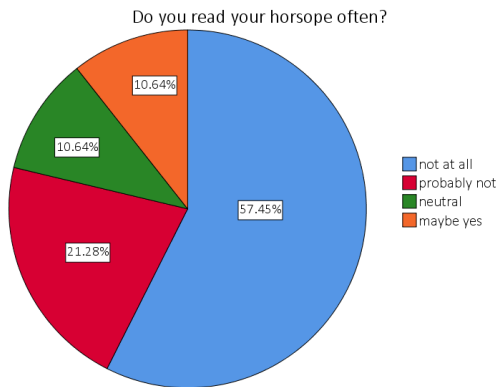


Figure 5.34: Pie chart of the first question about astrology.

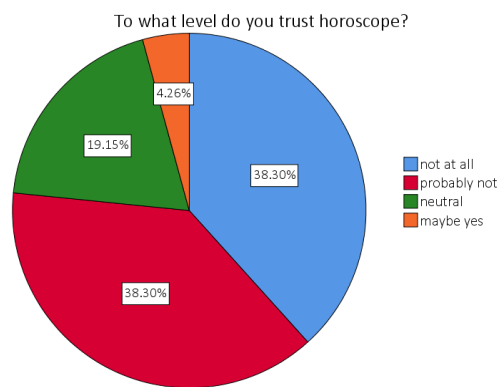


Figure 5.35: Pie chart of the second question about astrology.

As it can be seen from the pie charts 5.34 and 5.35, participant’s attitude towards the use and trust of astrology is low. Moreover, none of the users had indicated the highest answer on the scale for both questions. The answers towards the trust to the robot, on the other hand, received much higher overall rating. The difference in questions indicates that users would rather accept wisdom 5.36 than judgement 5.37 from a robot. Graph in Figure 5.44 shows that regardless of trust to the astrological predictions averaging at 1.7 and 1.9 out of 5, the trust towards the robot is significantly higher averaging at 2.8 and 2.7 respectively.

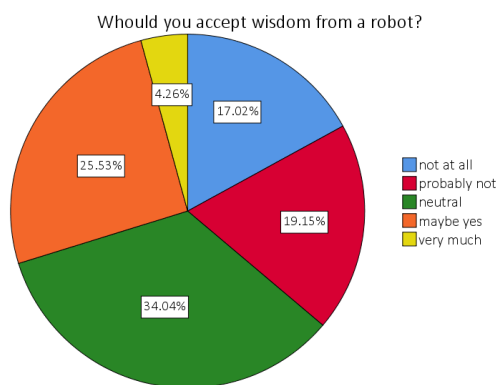


Figure 5.36: Pie chart of the question regarding the trust to Astrobot.

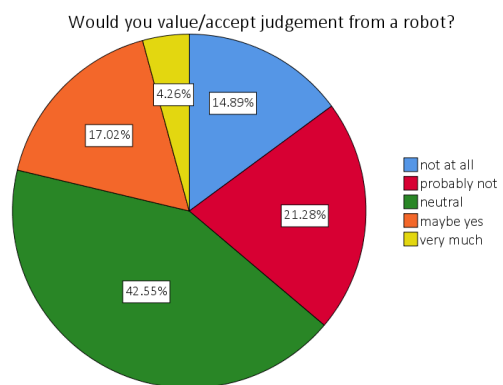


Figure 5.37: Pie chart of the question regarding judgement of the robot.

Persuasion and believability

Another important evaluation criteria is the persuasive ability of the designed robot. In order to evaluate this participants were asked whether or not they found the robot persuasive and believable. Figure 5.40 illustrates summary of all answers with an average score 2.7 out of 5.

Fluency and performance.

In order to evaluate performance, three key parameters were asked to the participants. The main element in the first revision of Astrobot was the dialogue. Therefore, besides asking a question about the fluency and

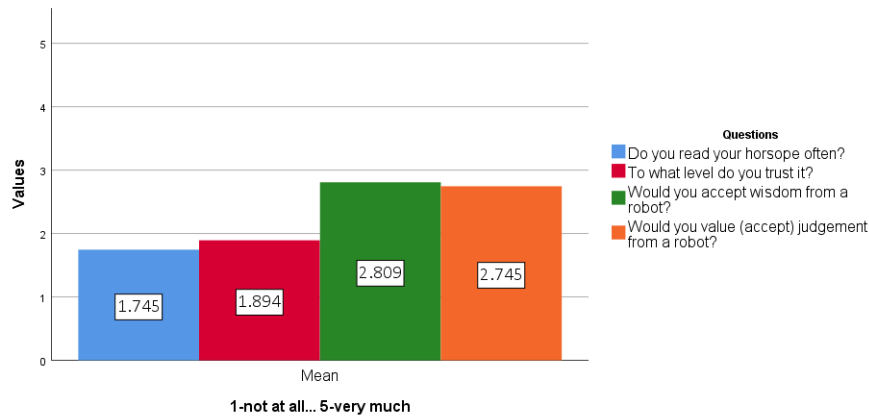


Figure 5.38: Bar graph summarizing means of four questions.

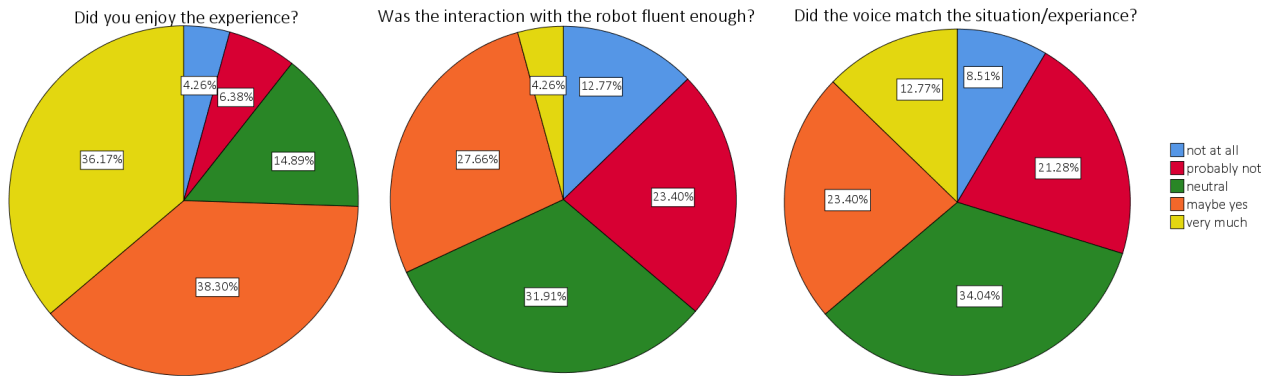


Figure 5.39: Pie charts of the three questions regarding the fluency of Astrobot.

enjoyment of interaction, participants were asked to evaluate robots voice as well. Figure 5.39 illustrates the answers of participants in the pie chart and Figure 5.41 shows the summary in terms of mean values of all three questions. As can be seen, enjoyment is at 4 out 5, stating that the user did enjoy the interaction. However, fluency and voice showing a mean score of 2.9 and 3.1 can be improved significantly.

5.2.3 Comments

During the experiment, one of the questions asked to participants was about the main weakness or most important improvement to be done to the robot. Majority of the comments suggested that the robot's appearance should be closer to human-like, as well as that speech should be clearer and the dialogue deeper. All comments are summarized below:

- *“Improve Dialogue: Wait for a human response before answering.”*
- *“Like the look! And voice and ”wisdom” in comment more dialogue/interaction to make it more believable”*
- *“It is not looking like a thing that is designed by a stereotyping orientalist”*
- *“I liked It! But the voice of the robot was hard to understand”*
- *“Better voice, More clear, Story was unclear.”*
- *“Give it skin. More interaction”*
- *“Clearer Sound”*
- *“Clearer Speech.”*

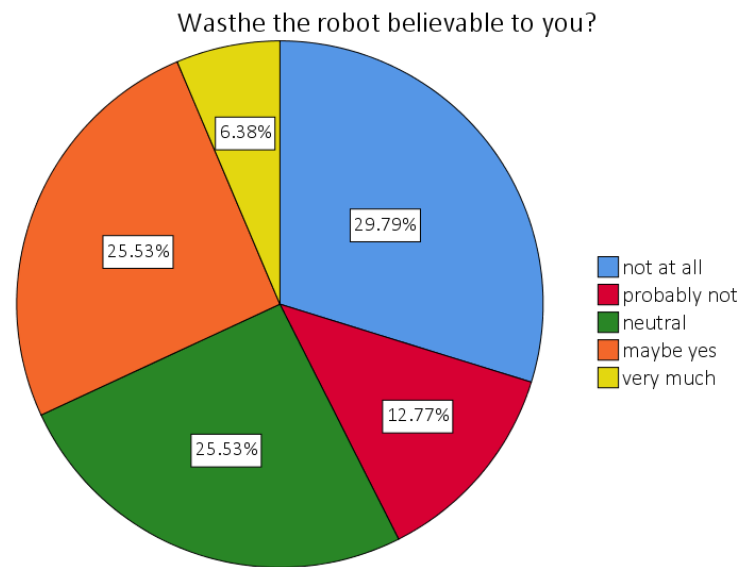


Figure 5.40: Summary of answers to the question about believably.

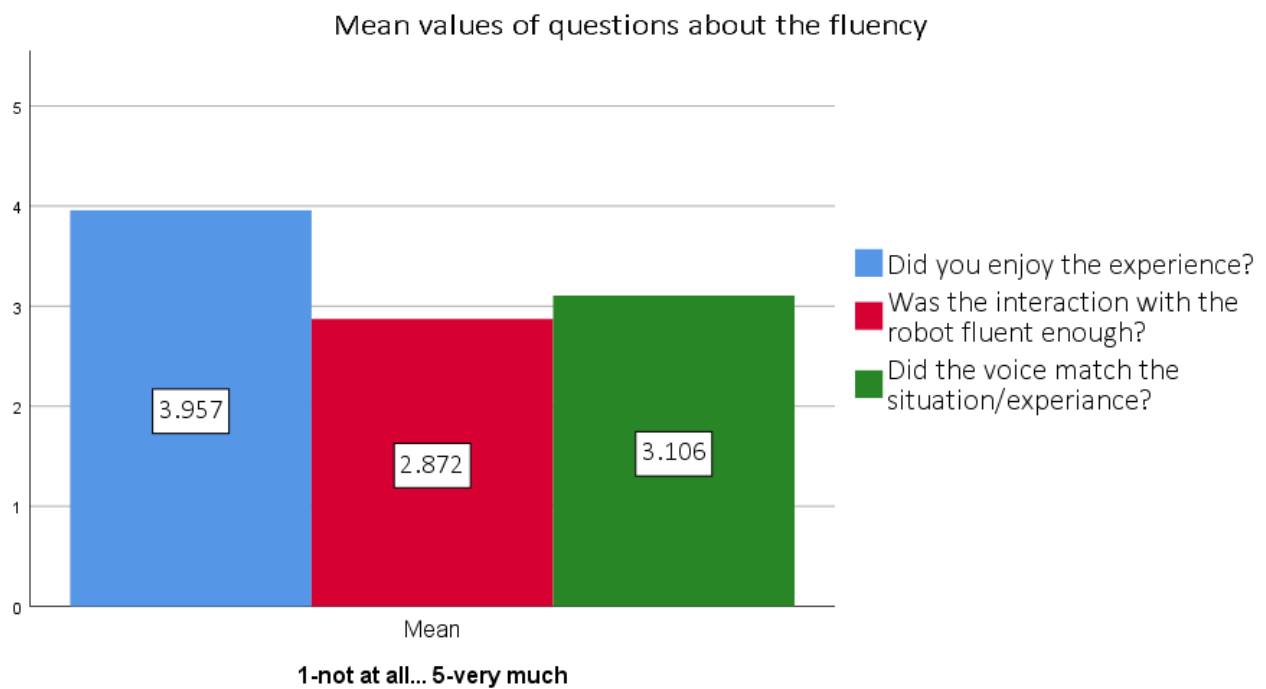


Figure 5.41: Mean values of the three questions regarding the fluency of the robot.

5.3 Second experiment

The second experiment was implemented as a video¹ showcasing the possible dialogue between Astrobot and a client. It lasts for 1.32 minutes and after watching it, participants fill in the questionnaire(shown in Figure C.1) similar to one in the first experiment. The main difference between two questionnaires is a presence of more open questions in the latter one.

5.3.1 Questionnaire data analysis

Same as in the first experiment, the data collected from the users is divided into three categories allowing to evaluate critical, interaction and system design. Summary is shown in Figure D.1.

Attitude to Astrology vs Robot Astrologist

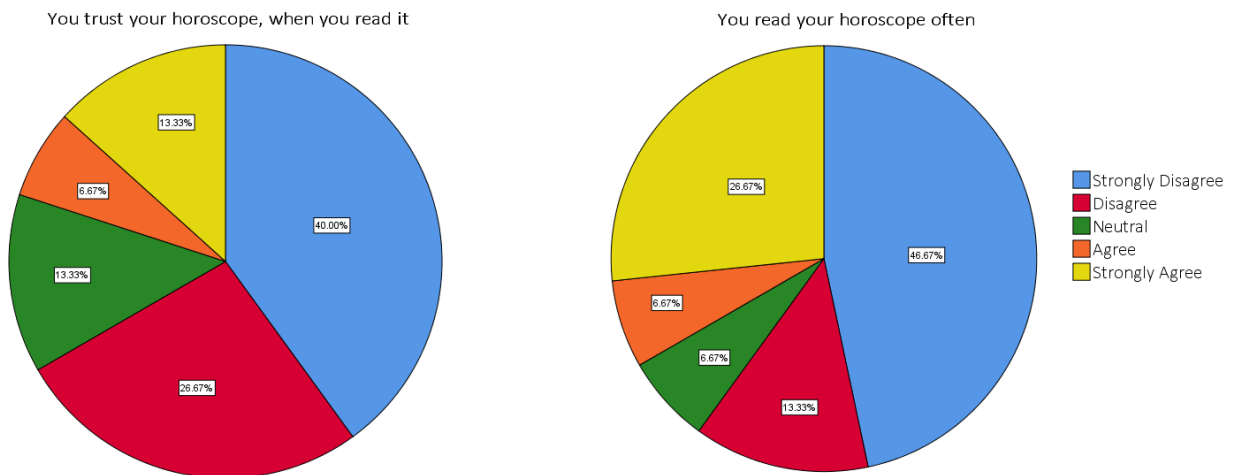


Figure 5.42: Pie chart of the questions about astrology.

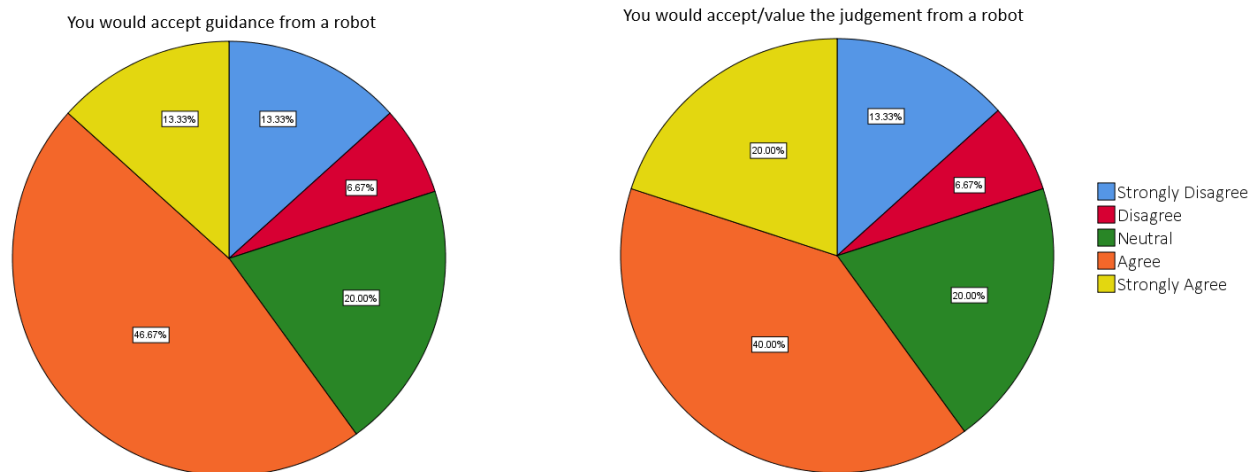


Figure 5.43: Pie chart of the questions regarding the trust to Astrobot.

As it can be seen from the pie charts 5.42 participant's attitude towards the use and trust of astrology is higher than in the first experiment. Moreover, some of the participants had indicated the highest answer score on the scale for both questions 13% and 20%. This could be caused by the fact that if a person follows the link in the video titled *"The Astrobot"* he or she might already be biased towards astrology. The answers about the trust of the robot also received a much higher overall score. The difference between answers 5.43 is insignificant. The graph in Figure 5.44 shows yet again that regardless of trust to the astrological predictions averaging at 2.5 and 2.3 out of 5. The trust towards the robot is significantly higher averaging at 3.4 and 3.5 respectively.

¹https://youtu.be/5CJh7iew_a4

Persuasion and believability

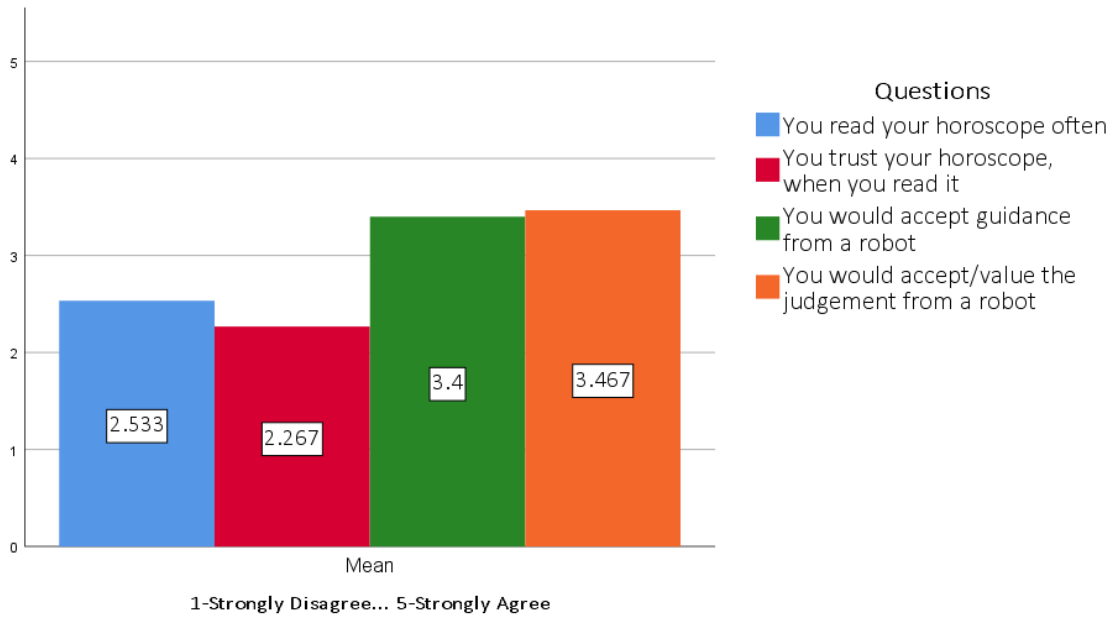


Figure 5.44: Bar graph summarizing means of four questions about the difference in trust to astrology and robot astrologist.

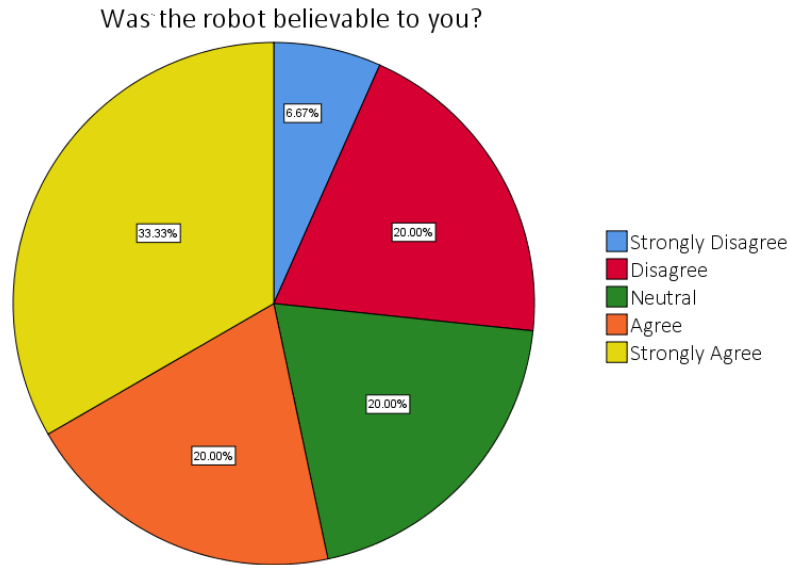


Figure 5.45: Summary of answers to the question about believably.

Figure 5.45 illustrates a summary of all answers regarding the believably of the robot. The average score is 3.5 out of 5. In addition to that, participants were asked to mention the most important categories which in their opinion influence believability. 75% of the participants indicated that the fluency of the dialogue is most relevant. Only 4% indicated that it is important for the robot to look like a human.

Fluency and performance.

Regarding fluency, previous Figure 5.46 also indicates that both fluency of dialogue and motion play a key role in the believability of the robot. Figure 5.47 illustrates the answers of participants regarding fluency and voice of the robot averaging at a score of 3.6 and 2.9 respectively. The increase of fluency and decrease of voice matching between the first and second experiment could be explained by the different voice engine used, which was more clear, however still not matching the expectation of users.

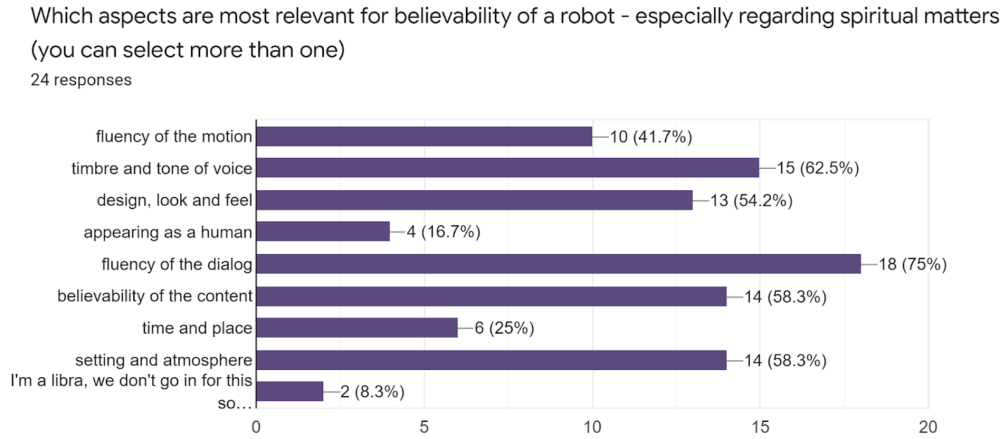


Figure 5.46: Summary of answers about most important criteria of believability according to participants.

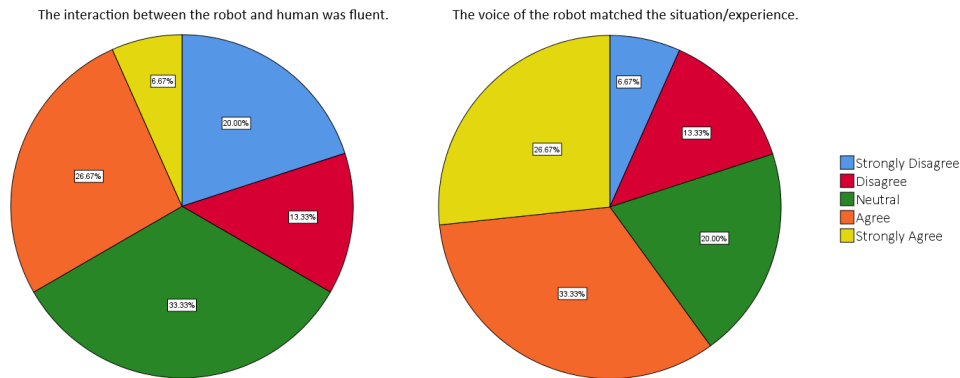


Figure 5.47: Summary of answers regarding fluency and voice of the robot.

Comments and open questions.

The second questionnaire had 7 open questions and in order to limit the amount of text in this chapter most crucial parts are summarized below.

- Understanding the concept:** Most of the participants could understand the message commenting that the interaction was: “About a fortune-telling robot”, “About people using technology to find confidence for their decisions” and “About a robot that can predict the future, or acts as it can”. However, some comments could be placed in a “highly emotional” category, e.g. “Rise of the machines” and “Skynet is coming” since they indicate that people realize how far can robots go in the near future, or at least they think about that.
- Improving believability:** Another open question was formulated to point out weaknesses of the designed interaction. Many users indicate that expanding dialogue would be the desired improvement, e.g. “If I could ask a specific question”, “More dialogue, personalised”, “Ask additional questions about peoples life” or “Make it more elaborate”. However, few participants indicated low impact of dialogue on the interaction: “What the robot says about the person’s astrology can be anything as long as he’s not predicting a terrible disaster” and “I think the biggest part of the experience is: what is said and how it is said it. I personally believe that this needs to be perfected before anything else can take place effectively”.
- Most unrealistic part:** Lastly, participants were asked to point out unrealistic parts of the design and two of the answers were “I guess nothing, it might be 100% real! Maybe that can be the scary part...” and “The absence of a reaction of surprise towards the robot by the visitor”.

5.4 Interview

Jonne Hoek specialist in theoretical philosophy was interviewed to have additional insight. The questions and answers are summarized below.

Which questions is this design raising? What it makes you think about?

Can a robot be a spiritual entity or a medium? Would/Could people believe such an artefact in a similar or different way as when they consult a normal person for spiritual guidance? How does the robot decide on the advice it will be giving?

Can a robot become a spiritual guide?

A Robot is a spiritual guide already when people relate to it in a spiritual manner. Whether people will do so is largely an empirical question: this remains to be seen. However, as the video shows, it is not a stretch of the imagination to believe that people can indeed consult a robot.

What are the key problems which robot will face in the role of a spiritual guide?

The robot must surround itself with an aura that makes it easier to relate to it with life-questions. I think this aura should not only be made explicit in material terms (which the video displays very well), but also in digital terms. For when giving guidance, the robot should have a particular signature, making it different from other mediums of spiritual guidance. The internet (of things) is this signature. For instance: I have searched the entire hyperspace for traces of your destiny (Im no an expert on this type of spirituality, but there needs to be a connection to the technological dimension of our lives making the consult extra believe-worthy.

Are there any ethical issues which may occur ?

If the consult stays very general, and follows only the zodiac as a guideline (I am making up this instance) the ethical issue is not that interesting. Like a fortune kooky, the recipient can do with the message whatever they wish. When using, for instance, online information to make a consult more specific, the privacy issue is both crucial for making the advice, as well as ethically precarious: the more specific information is used, the more likely people will be helped, but also might take offence.

To what extend this project raises awareness in the future role of robots ?

That robots are already shaping our future destinies (in the form of algorithms displaying products for me to buy, deciding on my mortgage, tracking my movements) could be made explicit in this video. The Astrobot is in touch with the many digital avatars that accompany us, and which provide us with guidance or can hinder us. These extremely important problematics can well be exemplified by the astrobot.

Can you see this robot as the bridge between Cosmos and Human?

This robot displays a particular bridge to a particular zone in our cosmos: the technicity of our fate.

Chapter 6

Conclusion and Further Work

6.1 Conclusions

First of all, the project was aimed at exploring the future role of the robots and how people would react to it. It was partially also responsible for answering the question if and how well can such a social robot be built using an open-source and fast prototyping technology. In order to achieve this goal, the research was conducted on the topics regarding the persuasion ability of social robots and how to maximize it to its highest potential. As it was shown in the analysis, the general trend of the design of social robots often incorporates human-like or anthropomorphic behaviour. In addition, it is also a common sense since humans understand complex intent much better if they communicate with their own species in normal situations.

Except for few cases, the research conducted during this project proved that there is lack of knowledge and practical realizations of robots who are or might be playing a key role in spirituality or present themselves as guides and mediators. In fact, there were no cases where a robot could be perceived as a helping hand and a guide in complex life situations, which can be explained by limited intelligence. However, considering the rapid evolution of technology and big data analysis, as well as the presence of robots who already take small scale operations in temples such as chanting mantras and conducting funeral sermons, one can assume that soon this type of robots will emerge. It is the job of the researchers and scientists to predict and evaluate what kind of implications this will bring into society and what limits such robots should have to avoid any unwanted outcomes.

The outcome of this project is Astrobot. Astrobot is an extreme case of the social robot who acts as a medium between human and *Cosmos, Universe, Stars, Noosphere* etc. He has human-like body and shape, human-like eyes and he behaves as if he is a live entity by simulating breathing, gazing, blinking and human-like gestures drawn from cultural references. He is also intentionally surrounded by attributes, which help to support the image of a fortuneteller and in this way give a more fulfilling experience. He also has a speech engine which allows him to communicate with people and understand them.

Two experiments were conducted using Astrobot to have an insight on his ability to attract attention, impress and provoke for a discussion, as well as evaluate his persuasive ability. The first test conducted during the “RobotLove” exhibition, showed that people were very interested in this technology and very a few people could go past him without trying to interact. They also showed a great sense of enjoyment during and after the interaction which was not the main goal but a good side effect of the design. The second experiment was conducted remotely by posting a video about the robot and collecting the data using the questionnaire. The responses were often elaborate and showed great interest as well as, approving this concept and suggesting which improvements to implement in the following versions.

Within the scope of this project the following, research questions are answered.

Can critical design methodology be used as a tool to explore and evaluate persuasiveness and what is the applicability of this method?

The short answer is yes. However, the evaluation of this method might be imprecise and subjective. Astrobot definitely made an impression to the users and some indicated highly emotional responses. Most participants understood well the concept and the message of the design. Moreover, the majority enjoyed the interaction and perceived the attitude of the robot as positive. Despite the positive feedback some people were concerned about their privacy and refused to interact with the robot at all. This is also mentioned in the interview with expert in philosophy of robotics, however, privacy issue is triggered before even interaction with the robot. Some people that assume robot is a potential privacy threat without even interacting with it. Another aspect of this design proves that people tend to create a bond with the robot resembling a spiritual figure, where its signature suggests a cultural reference. This coincides both with the opinion of the expert and previous research on human attachment to robots and object despite the lack of full functionality range present in normal human-human interactions. [41].

Which characteristics and performance criteria of a social robot have the highest impact on persuasion and believability?

As it was expected, the main parameters indicating persuasion are anthropomorphic behaviours. It was hard to distinguish whether persuasion was failing due to the design of the robot or just a limited dialogue because many indicated that absence of deeper discussion and the unrealistic prediction was the main unrealistic factor. The main argument present in both experiments proving the success of the design was the presence of high trust and believability score regardless of faith in astrology. Moreover, the majority of users indicated the desire to have a deeper and more personalized discussion with the robot. Another salient element in the interaction was ambience and looks of the robot, which received very high ranking in first experiment and even higher in the second one. It shows clearly that environment plays an important role during the design of social robots in context of spirituality.

To what extent is it possible to use open source tools and rapid prototyping to realize the software and hardware of the social robot?

In the given time framework it was possible to fabricate from scratch a full-size humanoid robot and make a social actor from it. It does require a set of skills involving 3D printing, electrical and mechanical engineering as well as programming in various languages. However, these types of open source robots are full of pitfalls and have a rather steep learning curve, to begin with. Besides that, a lot of parts are prone to wear out or break which should be taken into account. On the other hand, anything that breaks can be printed and installed within a day and at a low cost. Considering the performance of the robot it can be seen from the results chapter that it is possible to establish soft-real-time control with an average delay of 200ms between the setpoint and start of the motion. However, some joints such as vertical shoulder joint are rather slow due to the gearing design and should be improved to match the human speeds. Similarly, other joints, e.g. elbow joint and wrist joint are lacking range motion limiting the variety of gestures which can be performed by the robot.

6.2 Further work

The field of amalgamation of robotics and spirituality still remains unexplored. There are other roles which robots could and might take in the future. This project was only focused on a robot astrologist, therefore exploring only a small subspace in this domain. Considering the number of tools that persuasive social agent theory allows to use, it was impossible to implement them all perfectly. The robot would benefit greatly from a more in-depth dialogue and a greater gesture set. Another point of attention is the source of information which now is just limited to a daily horoscope citation but could be expended to a big data analysis using face recognition and search of information on the Internet about the user. InMoov as a platform is good for learning, however, it is limited in motion and cannot enact many gestures and those which he can are very robotic and unnatural. A substantial upgrade would be using brushless actuators instead of high power servos, which would decrease volume and increase control over the robot. Having access to PID control would allow implementing silent and fluent motion at the same time avoiding problems with reaching joint limits.

Appendices

Appendix A

Questionnaire test 1

UNIVERSITY
OF TWENTE.

Questionnaire AstroBot RobotLove October 2018

Personal information *(it helps our research, but the results are also valuable to us without it)*

Age	
Profession / workfield	
Male / Female / Both / Neither / Robot	

<i>Please rank the following questions (1) not at all -- (3) neutral -- (5) very much.</i>	1	2	3	4	5
Do you read your horoscope often?					
To what level do you trust it when you read it?					
Would you accept wisdom from a robot?					
Would you value (or accept) the judgement from a robot?					
Did you perceive the attitude of the robot as positive?					
Did you enjoy the experience?					
Was the robot believable to you?					
Would you have liked to have a more detailed/deeper discussion?					
Was the interaction with the robot fluent enough?					
Did the voice of the robot match the situation/experience?					
Is the Ambience important for the credibility of the experience?					
Are the robot's looks important for the credibility of the experience?					

What would in your opinion help us most to build a believable ASTROBOT?

--

If you would like to have a personal copy of this (signed) consent form, please take a picture or make sure to fill in two forms - as we will need a copy to make sure we do research compliant with AVG legislation

Figure A.1: Questionnaire for experiment 1

Appendix B

Data summary test 1

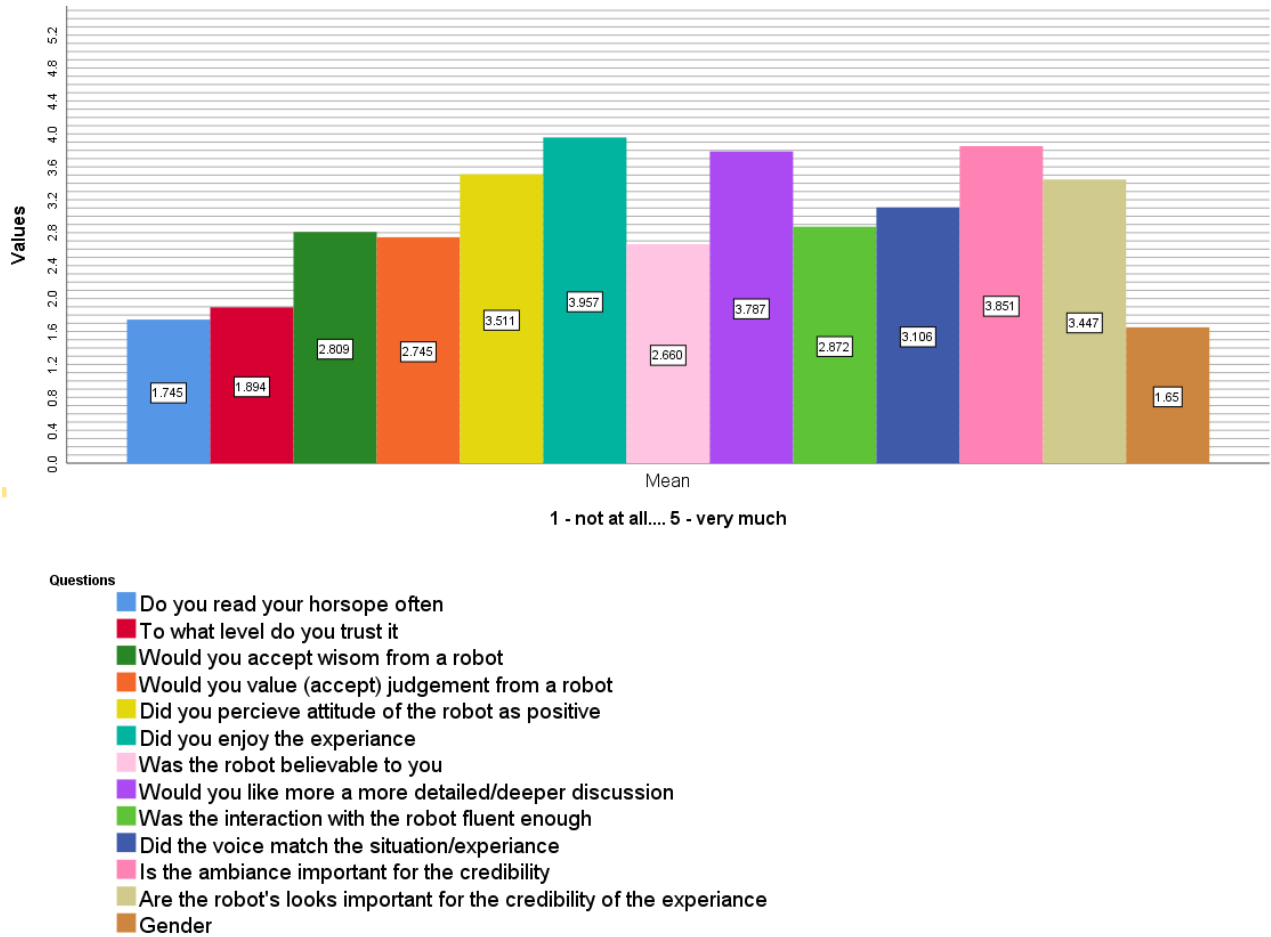


Figure B.1: Data summary collected during the first experiment.

Appendix C

Questionnaire test 2

Astrobot questionnaire
Please submit your feedback regarding the short movie you have just seen.

Can you describe quickly what you think this movie was about?
Your answer _____

What caught your attention the most?
Your answer _____

How realistic was this scenario to you?
1 2 3 4 5
Very unrealistic ○ ○ ○ ○ ○ Completely real

What was the most unrealistic bit according to you?
Your answer _____

Please rank the following questions

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
You read your horoscope often	○	○	○	○	○
You trust your horoscope, when you read it	○	○	○	○	○
You would accept guidance from a robot	○	○	○	○	○
You would accept/ value the judgement from a robot	○	○	○	○	○
You would accept spiritual guidance from this robot	○	○	○	○	○
You perceive the attitude of this robot as positive	○	○	○	○	○
Robot was believable	○	○	○	○	○
You would like to have a discussion with the robot	○	○	○	○	○
You would like more detailed discussion	○	○	○	○	○
The interaction with between robot and human was fluent enough	○	○	○	○	○
The voice of the robot matched the situation/experience	○	○	○	○	○
The ambience is important for the credibility of the experience	○	○	○	○	○
The robots visual look is important for experience	○	○	○	○	○

If you would encounter this robot (for example at a festival as we have been showcasing astrobot) - what would be reason(s) or a trigger for you to have a visit / short session with the robot?
Your answer _____

which aspects are most relevant for believability of a robot - especially regarding spiritual matters (you can select more than one)

- fluency of the motion
- timbre and tone of voice
- design, look and feel
- appearing as a human
- fluency of the dialog
- believability of the content
- time and place
- setting and atmosphere
- I'm a libra, we don't go in for this sort of stuff.

Astrology works, astrologers don't. Most of the people who visit astrologers or read their horoscopes regularly, end up with a sensation of fulfillment and satisfaction. This does not mean that the astrologers have accurately predicted the individuals future or present based on their horoscope dates, but it means that having a horoscope cast can be actually a very fulfilling experience. How could the experience with this robot be improved?
Your answer _____

What would you improve in the robot to make it more believable?
Your answer _____

Personal information
To conclude, this research is of course anonymous and we will not (we are not interested) in linking answers to persons. However, we are interested in seeing differences in responses for different ages etc. Would you like to be sharing some personal information with us? This information helps our project, but the results are also valuable without to us without it.

Age
Your answer _____

Profession/Workfield
Your answer _____

Gender

- Female
- Male
- Prefer not to say
- Other: _____

Figure C.1: Google Form questionnaire for experiment 2

Appendix D

Data summary test 2

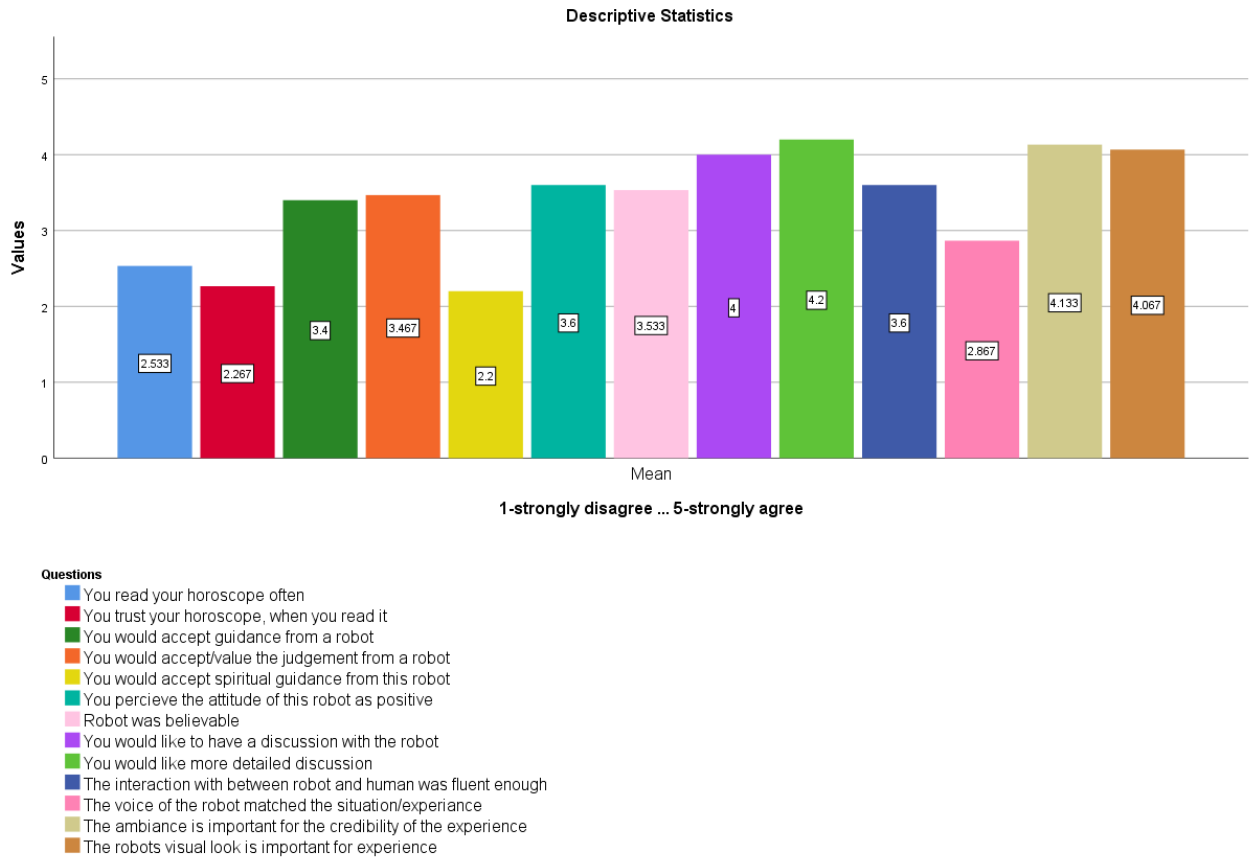


Figure D.1: Data summary collected during the second experiment.

Appendix E

Bill of Materials

Part	Qty	Price per one	Total
Intel NUCi5RYB Mini PC	1		
USB 1 to 6 splitter	1		
Variable Power Supply	1		
Arduino Mega	1	42.65	42.65
Arduino Nano	1	-	-
Arduino Mega Sensor Shield	1	-	-
Fisheye Lense	1	-	-
USB 2.0 MP webcam	1	-	-
1 Kg ABS filament	5	30.99	154.95
ARduino cable	1	5.5	5.5
Screws 2.5x25-30	1	14.47	14.47
6MM Bearing balls	2	6.57	13.14
Extension spring set of 10	1	8.28	8.28
Servos Fingers 11KG	10	6.31	63.1
Servos Wrist 11KG	2	6.31	12.62
Servos Biceps 60Kg	2	49.9	99.8
Servos Shoulders 60Kg	6	49.9	299.4
Fishing line	1	15.68	15.68
Servo 22AWg Cords 45cm (10)	2	1.66	3.32
Servo 22AWg Cords 60cm (10)	2	2.99	5.98
Servo 22AWg Cords 100cm (5)	1	3.31	3.31
8 ohm speakers x2	1	8.98	8.98
M3x20mm Screws (100pcs)	1	0	0
M4x20mm Screws (100pcs)	1	0	0
M8x100mm Screws (5pcs)	1	0	0
M3x12MM	1	0	0
M4x20MM	1	0	0

Appendix F

Movie Scenario

Opening

1. Eye opening scene: To catch the attention scene starts with robot breathing slowly with closed eyes, for 2-3 breaths then sharply opens the eyes.



2. Silhouette:
Shot of robots silhouette with through the curtains.
He moves slightly as if preparing for a visit.



3. Symbolism:
Show what is on the table
 - Tarot cards
 - Glowing incense
 - Candles
 - Astrological Map
 - LED Orb
 -



Midway

4. Girl appearance.
Girl comes in through beaded curtains:
Girl:(worried) **"Hello?"**
AstrRobot lifts up his head slightly than lowers his head back. (Short delay of 1-2 sec)
Then points to the seat and says:
Astrobot: **"Hello! I was waiting for you."**
Astrobot: **"Please, take a seat!"**
Girls obeys.



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