SOTA - State of the Art
Honda HK Project

MF2058 Mechatronics Advanced Course, Spring Semester

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Abstract

This project aims to design and construct Natsu, a new social robot for child interaction. Tasked by the Honda Research Institute, this project builds upon previous development of the social robot Haru (2018). The goal of the project is to realize a tabletop robot that, through nonverbal communication, is able to express the six basic emotions of happiness, sadness, anger, surprise, disgust and fear. It should do this while being reliable and safe, complying with *UNICEFs policy guidelines on AI for children.* To achieve this goal, a state of the art analysis has been performed, where several fields of study as well as existing social robots have been investigated. This report includes the SOTA analysis, Natsu concepts based on the research, and a plan for continued work during the coming fall. The Natsu concept designs are referred to as the *Improved Haru*, the *Egg*, and the *Snowman.* The *Improved Haru* is based upon the design of Haru and and will not be continued upon, while the *Egg* and the *Snowman* are two novel concepts that will be developed further. For the continuation of the project, a final concept will be chosen and realized during the autumn of 2022.

Acknowledgements

We would like to express our gratitude to Honda research institute for getting the opportunity to develop this project and our stakeholder Georgios Andrikopoulos for supporting us during the project. We would also like to thank our supervisor Sesh Thorapalli Muralidharan for supporting us throughout the project and giving us helpful advice leading us in the correct direction.

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Acronyms

AI Artificial Intelligence. 1, 2

AUs action units. 6

DoF Degrees of Freedom. 22

FACS Facial Action Coding System. 6

HRI Human-Robot Interaction. 5, 11, 13

OGIP Office of Global Insight and Policy. 1

pHRI physical Human–Robot Interaction. 13

UNICEF United Nations Children's Fund. 1–4

Chapter 1

Introduction

The idea of interacting with automated machines goes back to the ancient years [1]. However, it took many years of technological development before being able to talk about fully automated machines and Artificial Intelligence (AI) [1],[2].

Nowadays, AI enables the design of intelligent machines and robots with interfaces, which provide two-way interaction with humans. This, in turn, has led to the study of the social capability of a robot. Social robots have no punctual definition but a common characteristic, except the interactivity, is that they have the ability to express thoughts and emotions [3]. Such types of robots have become increasingly popular in recent years, a trend that grew significantly during the Covid-19 pandemic [4].

1.1 Background

Social robots have proven to be usable in several different areas. They are able to handle tasks in society such as receptionists, safeguards [5] and within healthcare. The integrated AI technology contributes to easier decision and diagnoses making [6] but also to the promotion of mental health [7]. In addition, studies have shown a beneficial contribution in the field of education. Studies have been done on the possibility of using these robots as an aid for children with autism [8], or as a complement for teachers in school [9]. These studies originated in an initiative from United Nations Children's Fund (UNICEF) that aimed to understand how AI can protect, provide for, and empower children [10].

This project has been inspired and is based on a previous study of a social robot developed by the Honda Research Institute, named Haru. An example of Haru expressing emotions can be seen in figure 1.1 According to the Office of Global Insight and Policy (OGIP) "Haru is a prototype robot that aims to stimulate children's cognitive development, creativity, problem-solving and collaborative skills" [11]. Haru has been developed in accordance with UNICEF's guidelines and aims to meet at least two of them; namely to "Prioritize fairness and non-discrimination for children" and "Provide transparency, explainability, and accountability for children" [10]. In collaboration with UNICEF and universities from around the world, including KTH Royal Institute of Technology, Honda Research Institute is now looking for potential improvements in the Haru robot and new designs. The initiative aims to develop a new robot called Natsu.

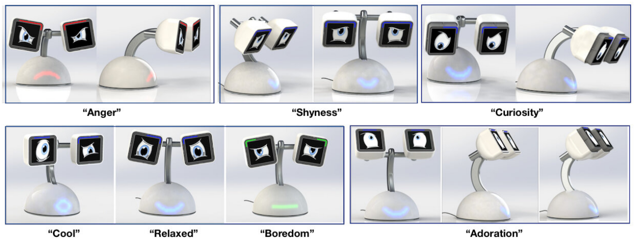


Figure 1.1. The Haru robot expressing emotions [12].

1.2 Scope

The scope of this "open ended" project is to develop a platform for a social and emotionally expressive robot. The robot will be developed in accordance with UNICEF's global insight policy on AI for children, and some requirements predefined by the team and confirmed by the stakeholder.

This takes the form of a project that extends over two semesters and two different courses. During the spring semester, a prestudy and research was carried out on relevant articles, existing solutions and the ethical aspects of this project. The team's task is to develop a concept on a social robot and define requirements in order to enable the design process of a potential prototype. During the autumn semester, the process of building the robot as a physical prototype begins. The students are then asked to collaborate and use their knowledge within the field of mechatronics.

1.3 Team structure and management

The team consists of eight members and an internal structure was needed in order to achieve a more formal organizational structure. Initially, each member was given a role in the group and a group contract was written. Furthermore, communication channels and file hosting services were selected for a clear information sharing.

For the research process, the team was divided into smaller groups where each member had to look into two selected areas. The group had regular meetings during the whole period to keep each other updated and to work together on the development of potential solutions. A mindmap has been made to summarize and the team's brainstorming process and the investigated areas. The results can be found in appendix C.

1.4 Requirements

This project was initialized with very general requirements, which means that the group had to set its own requirements. A list including all the defined requirements that were presented and confirmed by the stakeholder can be seen below. The list is divided into Stakeholder requirements, soft requirements and some basic technical requirements.

Stakeholder Requirements

- The robot should comply with requirements from UNICEF [10].
  - Prioritize fairness and non-discrimination for children.
  - Provide transparency, explainability, and accountability for children.
- The robot should be understandable by people of all ages, but specifically designed for children between the ages of 5 to 16 years.
- The robot should be able to express emotions through body movement and/or facial features.
- The robot should be able to express the 6 basic emotions of: happiness, sadness, anger, fear, surprise, and disgust.
- The robot should provide safe interaction with its user, this in terms of both physical and psychological safety.
- The robot should be reliable and be able to run for several hours without issues requiring service.
- The robot should have multiple Degrees-of-Freedom. Motors and sensors should enable required localization and perception.
- In addition to the hardware design Motion control, planning algorithms and software for enabling reliable and safe operation should be developed.

Soft Requirements

- The robot should be able to track a person in its surroundings.
- The Robot should be able to greet the user upon first interaction.
- The Robot should be able to express itself using additional nonverbal channels such as sound, colour, haptics and graphics.

Technical Requirements (First Draft)

- The robot should not produce noise levels above 45 dB from a distance of one meter.

- Height: 10-40 cm.
- Base: 5-30 cm box.

1.5 Ethics and risks

Ethical and safety aspects must be kept in mind during the development of Natsu. The results of the group's research within the field showed that some of the main ethical concerns about this project are the privacy and integrity, data collection, discrimination and social exclusion [13],[14]. Therefore, the presented concepts are taking these aspects into consideration with hardware and software carefully used. Furthermore the concepts have been designed to be neutral and in accordance with the UNICEF's requirements mentioned above. Other identified risks are the physical safety due to the interaction between robot and children. The non-physical safety because of the robots ability to express negative emotions. In addition the robot must be reliable and the team must ensure that the robot design is not similar to any existing patent.

Chapter 2

State of the art

This section goes through the results of the research done, summarizing the most important takeaways from existing areas of research, and highlighting ideas, principles and concepts relevant to the continuation of the project. Before going into the different topics researched, here is a quick mention of our research methodology.

The project was quickly determined to be one that would require information from several different fields of research. The following research questions were formulated as the basis for our research.

- Emotional modeling, what emotions are there, and how can they be modeled?
- Expression of emotions. How can a human or other actor successfully express emotions to a human observer?
- Human-Robot Interaction (HRI), how can a robot interact with people in a natural and trusting manner, while not compromising safety?
- Existing products, what similar robots have been created and why are they designed the way they are?

Answers to these questions, provide a basis on which to design Natsu.

2.1 Emotional Models and Universality

To implement successful expression of emotions in a robot. A topic as abstract as emotions need to be discretized, or in the very least translated into some form of tangible model, that can be used to determine the actions of the robot.

Trying to explain and categorize different emotions is a long studied field, with Darwin's *"The Expression of the Emotions in Man and Animals"* often considered as one of the pioneering studies [15]. Particularly important for this project is the notion about universality, that there exists universal emotions with expressions that are understandable for all humans independent of culture. Since then, there has been many studies and articles debating this topic with results being both supportive [16][17] and critical [18][19][20]. Although the theory of universal emotions is challenged, the six basic emotions proposed by Paul Ekman have been used in many characterization studies and therefore have an abundance of data available. In addition, they are also a well defined set of distinct emotional expressions, lending themselves very well to implementation on a robotic platform. We have therefore chosen to focus on expression of the six basic emotions throughout this project, the emotions being happiness, sadness, anger, surprise, fear and disgust. This discrete set is sufficient for a proof of concept, but could be further developed to facilitate more complex emotional expression, for example using the circumplex model of emotions [21]. Note however that in interaction with children, the negative emotions should be used very carefully to maintain a psychologically safe interaction. Expressing negative emotions towards a child, outside of a storytelling context, could have negative consequences.

2.2 Expression of emotions

In this section, studies on how humans best express emotions through different mediums is presented. This is a well researched area and the information found was summarized in a table seen in appendix A. This is to be applied when designing the Natsu robot.

2.2.1 Facial Expressions

A facial expression is a shape one's face can take for example a smile. While an emotion is a feeling in your body, like happiness. In other words, different facial expressions can be used to reflect different emotions.

With 43 muscles in the face, humans can create thousands of different expressions. To simplify things, Paul Ekman have divided these to seven universal facial expressions of emotions: happiness, sadness, anger, fear, surprise, contempt and disgust[22]. To describe these emotions, the Facial Action Coding System (FACS) was introduced. Each facial movement is categorized into action units (AUs) and these units can then in combination be mapped to specific facial expressions and emotions[22]. For instance, a cheek raiser (AU=6) + a lip corner puller (AU=12) is interpreted as joy or happiness[23]. For this project we have chosen to focus on the six basic emotions mentioned in section 2.1.

Another facial expression technique is Kismet. The expressions are generated using an interpolation-based technique over a three dimensional space. The three dimensions are stance, valence and arousal, see 2.1. Depending on the amount of each dimension, an emotion can be generated. Kismet is created considering both believability and readability. Believeability refers to how believable or life-like it actually looks and readability refers to how well it can be interpreted. [24]

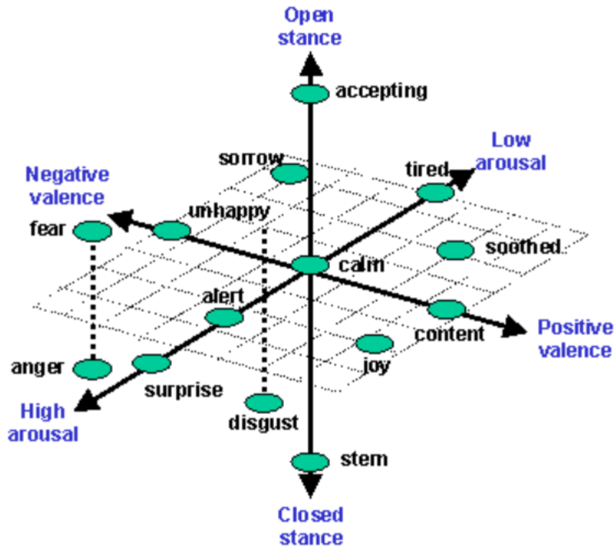


Figure 2.1. The three dimensional space of the kismet technique.[24].

Facial expressions can be connected to different emotions. Different areas of the face say more or less depending on what emotion is being interpreted. Both the eyes, mouth and the brows are features that have a big role in most of the six basic emotions [22].

2.2.2 Body Language

Body language is an important part of nonverbal communication between humans and could therefore be a vital part of the robot design [25]. Compared to facial expressions, body language is a less researched topic but there are still many studies performed.

For the design of Natsu we needed to know if there exists any archetypal body language expressions for different emotions. If there is, what movements are the most important for expression and which ones do not matter as much for an observer? Studies performed by Walbott [26], Coulson [27] and De Meijer [28] try to answer this question with differing methodology. In his study, Wallbott had 12 actors perform according to different scenarios corresponding to different types and intensities of emotion. Their movements were filmed and could thereafter be judged according to several factors such as head position relative to body, arm position, hand motion, body weight balance, and several others. From the classification of the labeled video clips, the distinctive posture and motion for each of the studied emotions could be decided. Similar methodology was used by De Meijer in his study where three actors were videotaped and the tapes were reviewed. The focus of this study was however the classification of emotions based on the ”gross body movement”, not the static posture. In his study from 2004, Coulson used a different methodology. Computer generated images of a mannequin were generated, where the pose of the mannequin was varied through it's seven degrees of freedom. The 176 poses were rendered from three viewpoints each and presented and individually judged by a group of 61 students (age 18-50). For each image, the students were asked to pick which of the six basic emotions best described the pose. The most fitting pose for each emotion was thereafter calculated as the one with the highest concordance between all participants.

The studies mentioned above all give some perspective of the archetypal body language related to each basic emotion. This was used to determine the most important degrees of freedom for expression through body language, and what degrees of freedom that were to be included in the design. A table summarizing this can be found in appendix A.

One important note is that all studies mentioned above researched emotional expression and interpretation of adults, whereas the robot to be designed is meant for younger children, and that the findings of the studies do not necessarily transfer between the two groups. Studies performed by Beck et al. [29] and Ross et al. [30] show that children do in fact react to the same cues as adults, albeit with less precision. In the study, Ross and his colleges found that children above the age of 8,5 performed almost at the same level as adults, while younger children were rapidly improving in from lowest studied age group of 4-5 years of age. This implies that the findings regarding adult's body language are applicable to the robots target group of 5-16 year old's, although recognition performance is expected to be lower for the younger children.

2.2.3 Combination of body language and facial expression

To correctly understand nonverbal cues in others is a very important aspect of social interaction. As stated above both facial expressions and body language are crucial when it comes to displaying emotions. Many studies have been made about how emotions are perceived by facial expressions alone, as well for body language. But in real-life, humans' perceptions of emotions are a combination of both facial expression and body language. One study investigated the relative contributions of the face and the body to the accurate perception of basic emotions [31]. They chose to use dynamic stimuli (video clips) instead of static stimuli (pictures), since the static stimuli don't capture all the necessary dynamic patterns which then may influence the emotion recognition. In addition to that, extensive dynamic facial, and body movement, like rotating, vertical movement, or tilting, may also serve as an important aspect of perceiving emotions [32].

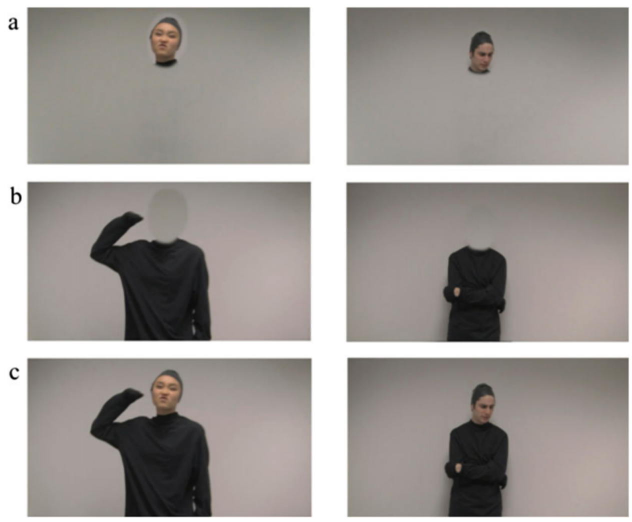


Figure 2.2. Still frames from video clips displaying anger and sadness, (a) face only, (b) body only and (c) face + body [31].

These dynamic stimuli were made with actors portraying the six basic emotions. In the study they conducted 2 experiments, experiment 1 and experiment 2. In the later, they showed sixty participants in the age between 18-28, 3 dynamic stimuli, face, body and one with both face and body see figure 2.2. The participants were then asked to identify which of the 6 basic emotions that was displayed. The conclusion that could be drawn from the results, were that clips with face and body alone would provide enough information to identify the right emotion. But the participants were most accurate at identifying the emotion of the face + body video clips and least accurate at the body alone clips, which can be seen in figure 2.3. They also found that isolated facial expressions had minimal confusability between positive and negative emotions, but isolated body on the other hand were misrecognized nearly at the same rate as they were correctly recognized.

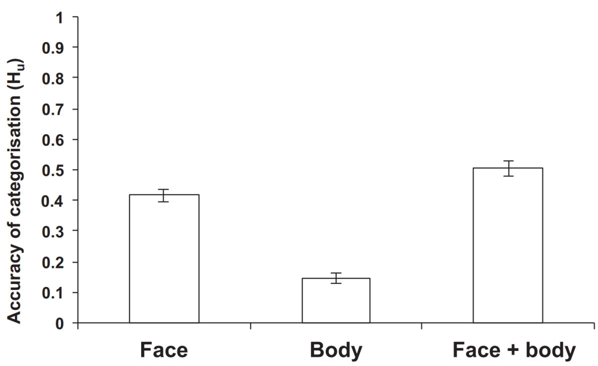


Figure 2.3. Accuracy of rating the 3 dynamic stimuli [31].

However, there are also studies that had the opposite findings. A recent work compared the recognition of affective faces and bodies [25]. The participants were asked to rate the affective valence of some static images portraying tennis players. Either the tennis player was winning a critical score, or they were losing one. The static images were presented as: face, body, face and body. The results revealed that participants, when rating the facial expression alone, failed in differentiating the winners from the losers, but when faces were presented with the right context body, the participants easily differentiated the winners from the losers. They noticed that body context basically changed the processing of the face. But during a peak intensity moment, like in the images in the study, the face expression would become non diagnostic for the affective valence of the situation. This may influence the results of the study. As for another study the results were similar to the first study [33]. There they found that participants made much more accurate decisions when the face was accompanied with the right contextualized body, than with a wrong body. From the above findings, the conclusion is that a combinations of both facial expressions and body language may leads to a better recognition of emotions.

2.2.4 Colours

To create sensory enriched environments for children, colours are often used [34]. It is an easy way to stimulate a child's mind and is therefore present in most toys, educational material, décor, and media that children interact with [35]. To play into this stimulation, as well as create familiarity with something children already know, it was thought to incorporate a specific colour for each of the six emotions.

To adhere to the *UNICEFs policy guidelines on AI for children*, the robot should be understandable by all, and that includes the colour-emotion association. An investigation into the cultural differences of this relationship was therefore made. In a study done by Jonauskaite et al., it was found that there are somewhat of a global homogeneity but differences can be found on a national basis (and individual as well) [36]. In the study, 711 participants' answers on the association between 12 colours terms and 20 emotion terms were analysed. Participants were adults from four countries, the UK, Greece, Germany, and China. In terms of cultural differences related to this report, white was associated at a higher frequency with negative emotions in China compared to any other examined nation. The same can be said for yellow in Greece. However, similarities could also be found. In the same study, it was observed that strong colour-emotion associations were present for red, black, and pink regardless of participants' country of origin. Red and pink were associated with love and black with sadness. Red also had strong emotional connection, but in a lesser extent, to anger. It was also concluded that, although the rest of the colour terms could not be linked to a specific colour term, they were associated with either positive or negative emotions. Positive associations were made for blue, green, orange, purple, turquoise and white. Negative associations were made for brown and grey [36]. However, blue being a happy colour can be contradicted by Löffler et al, who states that the colour is a metaphor for sadness in the saying "feeling blue" and therefore suitable to express the same emotion in a social robot [37].

A study by Boyatzis and Varghese further states that children have a mostly positive reaction to bright colours and a dislike for darker colours, which is in line with Jonauskaite et al. findings [38]. It will therefore be presumed that children and adults have roughly the same colour-emotion association.

By examining the stated research above, a colour was selected for each of the six universal emotions. Out of all the non-verbal ways of expression, besides facial expressions and body language, colour is the most important one. However, using multiple modalities when conveying emotions from a robot to its user are preferred. It will increase the level of understanding further [39].

2.2.5 Vibrations

To further help express emotions, the use of vibrations in robots was examined. Vibrations were generally found to convey negative emotions and vibrations with a high intensity were perceived as an expression of angry emotions. The study by Song and Yamada therefore strongly advised against using vibrations when trying to express positive emotions. The study further observed that using vibrations as the only modality was ineffective and confusing to the user [39].

2.2.6 Sound

The last modality to be investigated was sound. The same study as above stated that rising sounds were found to be strongly connected to angry emotions while falling sounds were strongly associated with sadness. Flat sounds were hard to link to any emotion. It was also found that when the robot used sounds in an attempt to express relaxation, it was hard for the user to categorise the emotion [39].

Furthermore, another study found that the musical parameters of pitch, intonation and timbre are important when expressing intentions and emotions in socially interactive robots. The pitch should range between 100 and 1,500 Hz to simulate the range used in normal human communication. Intonation is used to show different intentions of its producer. For example, a rising intonation is used when people ask something. Lastly, timbre is the quality of sound and a way to convey characteristics, such as age, gender, personality etc., of the robot [40].

2.3 Human-Robot Interaction

When creating a social robot, Human-Robot Interaction (HRI) is an important research topic to take into account. The goal is to create a trusting and safe robot that a user can interact with.

Just as people, it is assumed that it only takes as little as 100ms to form impressions of robots [41]. Because of this, how we perceive a robot is very important. A robot larger than a human, with a highly authoritative, machine-like appearance creates a very different appearance than a small, friendly looking robot. This shows that the form factor of the robot plays a big role in how it will be perceived. Another important aspect when designing a robot is the embodiment of it. Both the trust and engagement rises if it is physically embodied opposed to it only being displayed on a screen [42][43]. This also leads into the aspect of anthropomorphism, which is defined as the tendency to attribute human characteristics to inanimate objects, animals and others with a view to helping us rationalize a situation [44]. In a study to show the role of trust in child-robot interaction made by Zguda et al, they introduced a semi-humanoid robot to Polish kindergarten kids to study their first encounter with it [45]. From this, it was concurred that the level of anthropomorphization incurs some risks, such that human like features also come with expectations that the robot would interact the same way a human would. This was seen as they tried to get its attention by raising their hands and waiving to it. Moreover, they sympathised with the robot as it was only two years old and asked if it had any parents to take care of it. With these risks of the robot not being understood and doing as it was expected the level of anthropomorphization still is a useful tool to help engage interactions. Further research on how children trust robots has been done by Geiskkovitch et al [46]. They conducted an experiment to examine how robot errors affect young children's (3-5 years old) trust in robots. The results suggest that besides the importance of first impressions, a child will side with a robot that has previously proven to be trustworthy. This in terms of it not repeating errors when providing information. In addition to this, Theories like the Uncanny Valley [47] imply that the more human-like robots become, the more natural the interaction; nevertheless, what is natural between humans is not necessarily natural with a robot. This project needs to find a balance so that the robot is both approachable using some human-like features but not too many so that it will become frightening and end up in the uncanny valley, see figure 2.4.

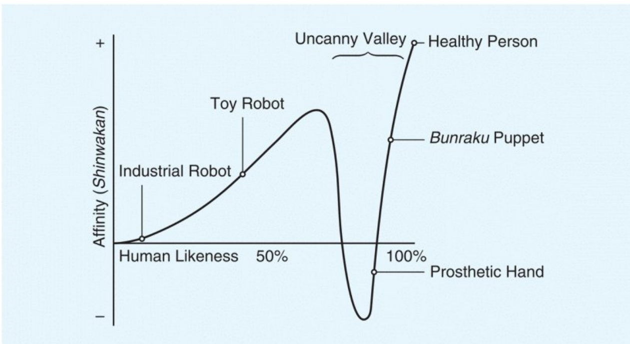


Figure 2.4. The uncanny valley, the proposed relation between the human likeness of an entity, and the perceiver's affinity for it [47].

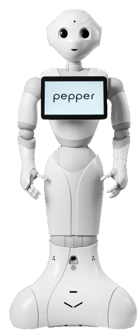
As previously mentioned, the non-verbal communication plays an important role in showing emotional expressions. In this includes also the part of affective touch which has a fundamental role in human development, social bonding, and for providing emotional support in interpersonal relationships. This is something that Andreasson et al. has done a study on and how to express emotions to a small humanoid robot via touch [48]. During the study, participants acted more negatively when they were prohibited from touching the physically embodied robot than when they were allowed to interact with the robot via touch.

A final note on HRI is the safety aspect, both physical and non-physical safety needs to be taken into account. physical Human–Robot Interaction (pHRI) consists of risks of collisions, avoid sharp edges, lightweight and or soft materials, compliant actuators, reacting to collisions through sensors and software and how the control architecture along with the dependability of a robot needs to be taken into account [49].

2.4 Existing solutions

Driven by science fictions epos, such as Star Wars, people became familiar with the idea of having a faithful and entertaining robot companion. In 2015 the market for social and entertainment robots stood at 1 billion USD [50]. It is forecasted to grow to 1,38 billion USD by 2025. Sparked by this huge market potential, industry and science have enforced research in the field of social robotics. Today there exists a great variety of models. Various authors have created helpful overviews of existing social robots [51]. For the purpose of this study three different categories are examined: Human-like robots, animal-like robots and smaller tabletop robots. Starting with human- like robots, two examples are the Furhat (developed by former KTH students) [52] and the Pepper robot [53]. Both are shown in figure 2.5. While the Furhat robot only consist of a face the Pepper robot has a whole body with arms, legs, trunk and head. The face of the Pepper robot is reduced to two eyes and a mouth. The mouth is rigid and represented by a black dot or line. By showing familiar features, human-like robots help to establish a social relationship. On the other hand, there is a risk of with creating too many expectations. If a robot has legs and/or arms, one expects that the robot can walk and/or grab an object.

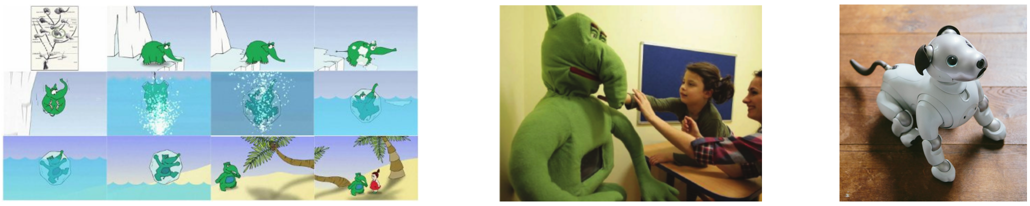
(a) The Furhat robot [52].



(b) The Pepper robot [53].

Figure 2.5. Two examples of human-like social robots.

Just as the anthropomorphism debate, there is also a zoomorphism debate. Zoomorphism describes the recognition of familiar animal body features and behaviors. Two examples of animal-like robots are the Probo (elefant) [54] and the Sony Aibo (dog) [55]. They are presented in figure 2.6. Probo is based on a comic design. However, translating the comic design into a mechanical design takes away some of its appeal (compare figure 2.6b). The Sony Aibo robot takes the role of a faithful companion. It strongly builds on the attributes connected to dogs (a human's best friend). Nonetheless, it should be pointed out that animals are not associated the same characteristics all around the world.



(a) Comic design of the Probo robot [54]. *(b) Physical design of the Probo robot [56].* *(c) The Aiboo robot [55].*

Figure 2.6. Two examples of animal-like social robots.

Four examples of smaller table top robots are the Kuri, Jibo, Vector and Emo robot [57] [58] [59] (see figure 2.7. Usually these robots are designed to look cute. Surprisingly, many of them include the ability to dance (e.g. Jibo, Vector and Emo). However so far small social robots are waiting for their commercial breakthrough. In 2019 Jibo and Kuri failed in the market and in 2020 they were followed by Vector [60]. So what are the barriers? A big challenge is to deliver what people expect. Communication and movement of small table top robots are often neither flawless nor natural. Communication for example usually follows the scheme of one after another thereby ignoring spontaneous interruptions. While motion is used to express emotions it is not designed to help with physical tasks. These limited capabilities meet advanced prices. The prices for the basic Vector models start at 249 USD [59]. So people question if they really need the robot. Nonetheless, the story for Jibo and Vector continues. After their respective companies closed down, design and patents were acquired by other companies (Anki by Digital Dream Labs and Jibo by NTT Inc).

(a) Kuri robot [57]. *(b) Jibo robot [58].* *(c) Vector robot [59].* *(d) Emo robot [61].*

Figure 2.7. Four examples of smaller table-top social robots.

Two more examples of table top robots are presented in figure 2.8. These are the Keepon robot and a companion robot by Panasonic (without name). The Keepon is made of two balls which sit on top of a platform. It looks like a chick. Compared to other robots the Keeko robot consists of soft materials. The companion robot by Panasonic is an egg shaped robot. Its comes with the novelty that the upper part of the egg can be lifted. When doing so a moveable arm is exposed.

(a) The Keepon robot [62]. *(b) Panasonic companion robot [63].*

Figure 2.8. Two inspiring table top robots.

Going back the requirements, in section 1.4 it is stated that children will be the primary target group for the Natsu robot. So how do children image a robot? Rincon et al. asked 19 children the question, what would be a robot they would like to play with [64]. The children described a robot with anthropomorphic features. Moreover, the children wanted the robot to be able to move, grab and speak as well as play popular children games. They also imagined the robot as being tough and strong. Some children drew a sketch. The robots sketched showed quadratic shapes and grey colour (metal resemblance). All robots also had arms and legs.

Moving on from the physical designs, further takeaways from existing solution have been found in the field of body language. McGoll et al. describe the development of an emotional body language for the human like social robot Brian [65]. Their findings stress the importance of viewing angle on the perceived emotional state. Furthermore, they provide body language descriptors for different emotions (e.g. Sadness: Bowing trunk, head forward, hanging arms and low movement dynamic). Another study on the expression of emotions is conducted by Takashi et al. [66]. The team developed a teddy bear robot that is able to express the six basic emotions. The respective motion design is based on the Laban movement analysis. One takeaway from this study is that emotions are not expressed as a static posture but rather as a dynamic movement. Further inspiration for the expression of emotions can be taken from animations and cartoons. Ribeiro et al. study different animations techniques and relate them to the design of an emotional body language for the EMYS robot [67]. Techniques include the ideas of exaggerations (e.g. eyes popping out, separating body parts) and follow-through movement (actions should not stop abruptly). A helpful point of reference are Disney's 12 design principles [68]. Instead of emotions Chatterjee et al. explore the question whether a robot arm can convey certain messages using only body language [69]. The messages examined in the study were: The robot saying hi, not disturb, act in a friendly manner, and act in a machine-like manner. The idea of conveying messages additional to emotions will be considered in the design.

Chapter 3

Concept Design

Based on all the research, a design of the robot could be explored. This has been an iterative process where research, sketches and 3D-models have been done in parallel. Sketches have been refined with increasing knowledge in different research areas. The stakeholder requirements were also taken into account when the design ideas were being developed. From all the design ideas, three concepts were formulated. The three concepts can be referred to as the egg, the improved Haru and the snowman. When developing the Haru concept it became clear that the improvements from the earlier model were not enough. In addition, when the concepts were being presented to the stakeholder, we got the information that these improvements were already being done by another team. What he wanted from us instead was a whole different concept. It was therefore decided to not move forward with this concept. Instead, focus was on improving the egg and the snowman concept. A more comprehensive description about the concepts, the technical challenges and the expression capabilities are presented below.

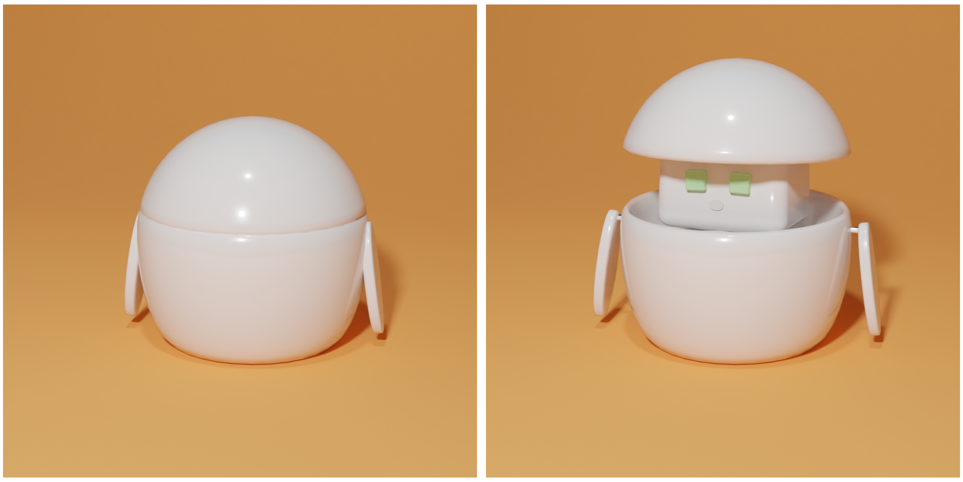
3.1 General technical aspects

General technical aspects that needed to be considered for both projects are sensors and how to process sensor data. In order to fulfill the requirement of tracking a person it is required to have sensors in all designs. These can vary from radar sensors to high definition cameras. Only one of the following will need to be implemented but both have been considered. In terms of radars, the Soli radar sensor developed by Google has been considered very relevant to this project. To quote Google, "Soli is a miniature radar that understands human motions at various scales" [70]. In terms of cameras it was considered that a high framerate camera with low resolution would be optimal. This is because kids very often move at high speed and the high framerate would provide better tracking of that speed. Increasing the resolution would provide little benefit as it would take more computational power to process the data and tracking facial expressions is out of the scope of this project. Microphones were also considered to be used for tracking, but it is often used in combination with another sensor. Furthermore, it was considered how the sensory data would be processed. This is crucial to the integrity of the robot. If for example, the data from the camera does not get stored or sent online it provides a higher level of integrity and safety which is required in this case. Something that also have been investigated is which physical devices that could be used in order to process the data and act as the robot's brain. It was found that the Arduino Portenta H7 was the most relevant to this project [71]. This, as it provides a good balance between performance and price. It also has a dual processor setup which allows for true hardware parallelism.

3.2 Egg

The egg concept was based around the idea that the robot would look like an egg when closed. This can be seen in figure 3.1. When in a closed state the robot clearly indicates that it is not in use, therefore fulfilling the requirement of providing transparency to the user. It is also structurally a very strong shape with no sharp edges. This protects both the robot and the child using it, ensuring safe operation. When active and in the "open" position the robot can:

1. Move head up and down
2. Tilt head back and fourth (within a limited range)
3. Rotate head
4. Extend/retract arms
5. Rotate arms up and down
6. Rotate eyes



(a) Closed *(b) Open*

Figure 3.1. Concept renders of the egg. Made with Blender [72]

3.2.1 Patent infringement

To ensure that the concept designs do not infringe on any existing patents or designs, a patent infringement check was made. Since the Egg robot was inspired by Panasonic's Desktop "Companion" Robot [63], this was checked first. Here it was concluded that Egg concept were not infringing on any existing patents that would be of risk for future work. Further design patents were checked and none were found to be a risk of the Egg design.

3.2.2 Technical challenges and simplifications

The main challenge with the egg robot is to fit everything inside the "egg" (body of the robot). This has been researched and found that motors with sufficiently good size/strength ratio are available to fit the need of this project. For the above motions the following solutions have been proposed followed by figure 3.2 to further demonstrate:

1. **Move head up and down**: Using a threaded rod mounted at the bottom, driven by a DC-motor.
2. **Tilt head back and fourth** (within a limited range): DC motor mounted at the neck of the robot
3. **Rotate head**: DC motor mounted in between threaded rod and tilt motor
4. **Extend/retract arms**: Using rack and pinion mechanism

5. **Rotate arms up and down**: DC motor mounted on the rack on pinion mechanism

6. **Rotate eyes**: DC motor inside head

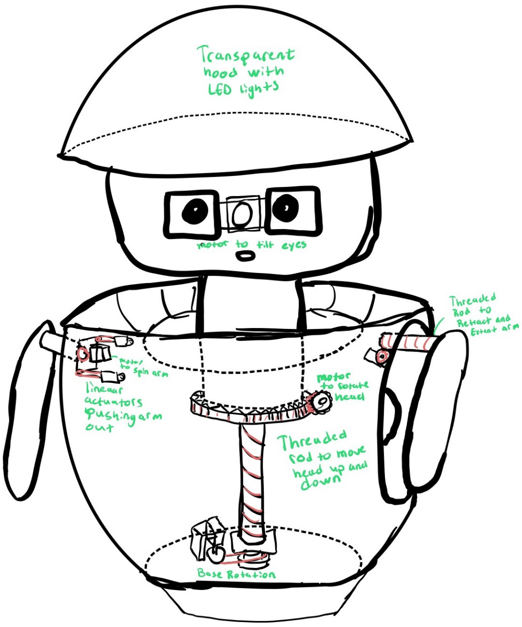


Figure 3.2. Sketch to illustrate technical aspects of the Egg concept.

Another challenge is to make sure the robot is not able to cause any harm to a child. This can be achieved by using compliant motors. Therefore if the robot closes but a child's hand is in between it would comply and not hurt the child. The arms could use the same mechanism but could also be made from a soft material, increasing safety even further.

3.2.3 Expression capability

Using the six movements described above the robot can express emotion as seen in figure 3.3. Other possibilities include graphics or colours on the eyes which would further improve the capabilities of this concept. Sound is also being explored in addition to the movement.

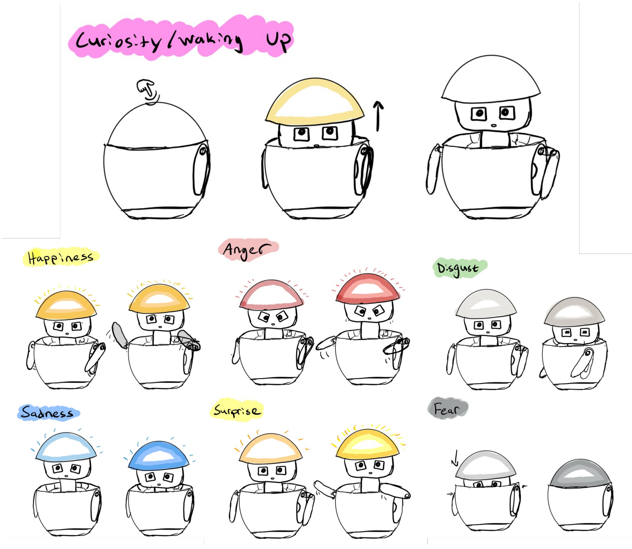
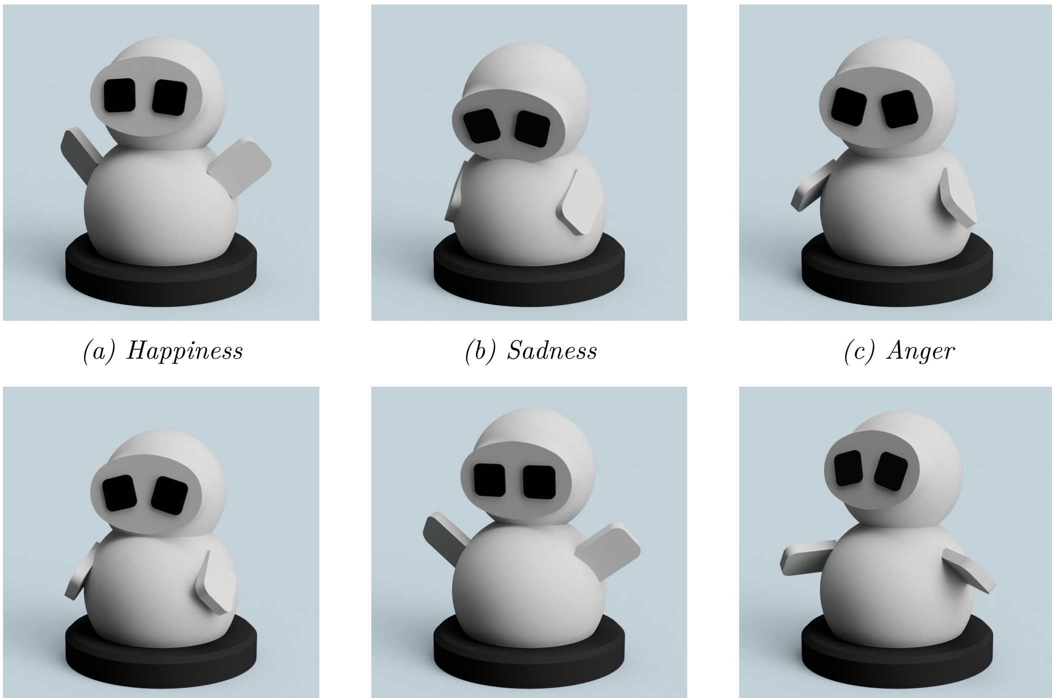


Figure 3.3. Sketches on how the Egg concept expresses emotions..

3.3 Snowman



(a) Happiness *(b) Sadness* *(c) Anger*

(d) Fear *(e) Surprise* *(f) Disgust*

Figure 3.4. Concept renders of the snowman expressing the six basic emotions. Made with Autodesk Fusion 360. [73].

Named after its appearance, the Snowman concept consists of a spherical head mounted on a larger spherical body with two simple arms. Being a simple and non threatening design, the Keepon robot served as the main design inspiration [74][62]. While being similar in appearance, the snowman is mechanically quite different. To effectively express emotions, the four Degrees of Freedom present in Keepon were not deemed enough. Instead the snowman was envisioned with eight or nine DoF, depending on if the two arms are controlled individually or not. The possible movements are full positional control of the head in three dimensions (6 DoF), rotation of the eyes (1 DoF), and finally raising and lowering of the arms (1 or 2 DoF).

The design process started by primarily looking at body language instead of focusing on facial expressions, since detailed facial motions could pose a large challenge to fit into a smaller robot. Creating an expressive mouth would for example be challenging if more detail than opened/closed was desired. Drawing inspiration from the passive body of Keepon, only the head of the snowman is actuated actively, with a soft body following passively. To improve the expression capability as compared to Keepon, the concept uses a stewart platform inside the body to freely position the head within it's range of motion [75]. This allows for the illusion of separate spine and neck joints, while having all the actuators seated on the base.

Since having only the head and body was still not deemed sufficiently expressive, the arms and eyes were added. While the head could be shifted and rotated to express some emotions such as sadness, others such as surprise and happiness were hard to distinguish for us in the team. The arms add an easy way to express directionality and can also exaggerate the motion of the head. The eyes enable the robot to show facial cues that can help a viewer distinguish between emotions such as happiness and surprise (see figure 3.4).

The actuation of the arms is a challenge with the arms being mounted on a soft body, with the joints following the body movement. The simplest solution could also be to mount the actuator to the body and to have a rigid assembly of arm and motor moving together. This could add a significant amount of weight to the body, potentially deforming it, and more importantly might interfere with the stewart platform linkage inside. The more complex and more promising option is to cable actuate the arms, this way the motor could be situated in the base with only a flexible cable attached to the arm joint, not hindering it from moving with the body. Specifically, a bowden tube and cable would be used to actuate the arm, enabling actuation without exerting a force on the body itself. Construction was imagined similar to that of a classic bicycle brake caliper, with a mount taking the reaction force of the actuation (see figure 3.5 below).

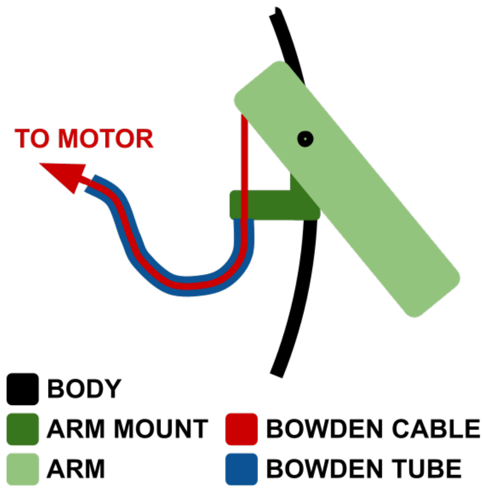


Figure 3.5. Proposed construction of the arm mechanism for the snowman concept.

3.3.1 Patent infringement

Since the design of the snowman concept was heavily inspired by the *Keepon* robot [74][62], possible patent infringement was checked carefully and no related patents could be found.

3.3.2 Technical challenges and simplifications

As envisioned, the snowman concept uses a steward platform to position the head, with a soft body that deforms and follows the head motion. This way, you can achieve the illusion of separate body and head joints, while having all the motors stationary in the base. In addition, the two arms are fastened to the soft body and must be actuated. The concept therefore faces three major technical challenges.

1. Can the linkages required for the stewart platform fit inside the body while providing adequate range of motion?

2. Are there actuators with sufficient power to both fit inside the body and drive the head motion properly?

3. How can one actuate arms that are attached to a soft body without interfering with the body motion?

Chapter 4

Conclusion

This chapter presents a brief summary of the work that has been done and includes a discussion of the developed concepts. In addition, the last section goes through some of the team's plans and the work to be done in the future.

4.1 SOTA

Based on the research done and what is already existing on the market the group have taken and summarized some of the most important areas, ideas and concepts relevant to this project, which have been stated in *Chapter 2*. From these points we, together with our stakeholder and supervisor were able to draw some conclusion. Since the task is to develop a platform for a social robot to show different emotions towards children, a starting point was to research how humans perceive and express emotions. As stated in *Chapter 2.1*, we have chosen to focus on what are called the 6 basic emotions. The 6 basic emotions include happiness, sadness, anger, fear, surprise, and disgust. Expressing negative emotions towards children should be used very carefully to maintain a psychologically safe interaction. To express these 6 emotions, a human uses both the face and the body. The research showed that one can get enough information from either the face alone or the body alone. Nonetheless, both together deliver a more accurate result. Therefore we decided to include both facial features as well as body language in our concepts. Furthermore, to enhance the emotions, we have investigated the concepts of colour, vibrations, and sound. Different colours are connected to different emotions, but it may depend on which culture and which country. The robot must also be safe and trustworthy to interact with. Therefore HRI was an important research topic. How we perceive the robot is a major aspect, since a large robot may be intimidating, and a small robot more approachable. Consequently, it was decided that the robot should not exceed 40cm of height. Another aspect tackles the question whether the robot should be be human like/animal like, as mentioned in *Chapter 2.3*. This can create expectations on the robot. The team came to the conclusion that the robot should have a head and a body including arms. Furthermore, including eyes and familiar features can make the robot more expressive and trustworthy. However hands are going to be excluded from this design in order to avoid over-expectations. To get a trustworthy nonverbal interaction, affective touch was taken into considerations as well, since it is a fundamental role in human development, social bonding and for providing emotional support. Also, there are a lot of existing solutions already on the market see *Chapter 2.4*, which have given inspiration to this project.

4.2 Concept Design

The sketching process started almost immediately with the project kick-off. The team was aware that innovative designs can take a long time and therefore it was important to be efficient. We tried not to limit our imagination hence technical realization was not considered in the early sketches. Furthermore, we tried to come up with as many ideas as possible, some of which can be found in appendix B. During our meetings, the main discussion except the research topics, was how each design could be further developed and what technical solutions could be used to implement the design in reality. Finally, we landed on two concepts which are the egg, inspired by Panasonic's desktop robot, and the snowman that was inspired by the Keepon robot. To choose one final concept, an evaluation method has been developed, where the concepts will be graded according to a template. The template is based on how well they correspond to the requirements mentioned in *Chapter 1.4*.

4.3 Future work

To begin with, we will conduct a concept evaluation. With a set concept we then need to formulate technical requirements and confirm them with the stakeholder. Based on the technical requirements we can then move forward to design development and component ordering. After the summer, a more extensive CAD model will be made, software and hardware will be implemented and the design will be evaluated.

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Appendix A

Basic Emotion Characteristics

Here we present the tables used to summarize our findings from the different research fields regarding emotional expression. These tables were used as references in the concept design phase to decide on what features and degrees of freedom was most important.

Table A.1. BODY LANGUAGE

	Head	**Spine**	**Arms**	**Movement**	**Weight**
HAPPINESS	Looking Up, Forward	Arched Backward, stretched	Raised Up (straight), hanging	High, low movement dynamics	Normal
SADNESS	Looking Down, forward	Arched Forward	Hanging Down, hanging	Low	Normal
ANGER	Looking Forward	Arched Forward, bowing	Close Frontal	High	Forward
SURPRISE	Looking Forward	Straight	Raised Up	High, overall backward movement	Backward
DISGUST	Looking Up/Side	Straight w. Side-twist	Outstreched Frontal	Low, Arms opposite to head	Backward
FEAR	Looking Forward	Arched Forward	Hanging Down/Frontal, closing	Medium/High	Backward

Table A.2. FACIAL EXPRESSION

	Mouth	**Brows**	**Cheek**	**Eyes**	**Nose**
HAPPINESS	Lip corner puller	Outer and inner brow raiser	Cheek raises	Lid high	
SADNESS	Lip corner depressor	Brows lowers overall but inner brow raises	Check lowers	Lid low	
ANGER	Lip tighten	Brow lower, outer brow raises		Lid tightens	
SURPRISE	Jaw drop and lips apart	Outer and inner brow raises		Big eyes, lid high	
DISGUST	Lip corner depressor and lips apart	Brows lowers		Lid low	Nose wrinkles
FEAR	Lip stretches and apart	Outer and Inner brow raises		Upper lid raises	

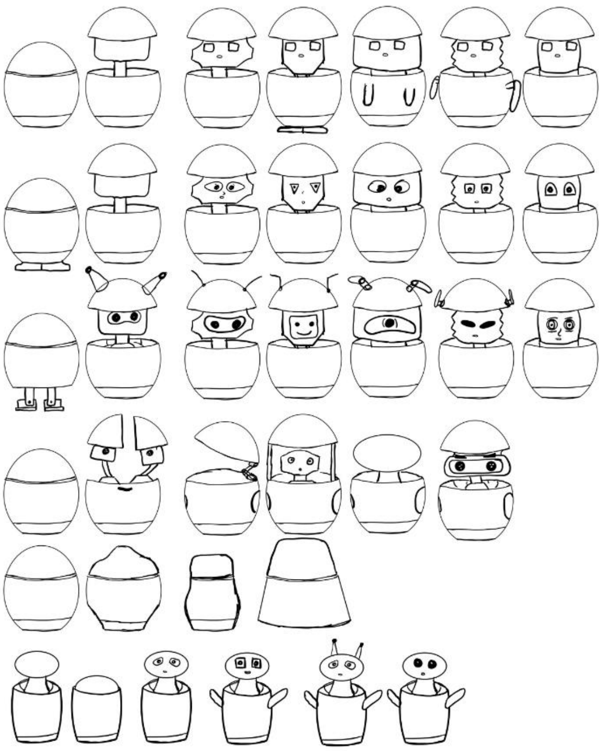
Table A.3. COLOURS, VIBRATIONS AND SOUND

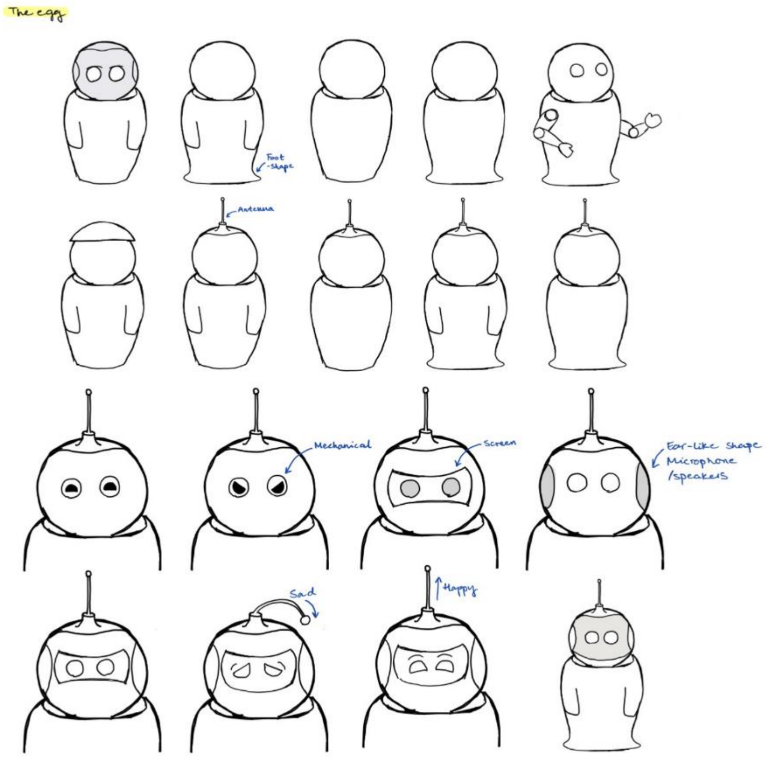
	Colour (HSB)	**Comment**	**Vibrations**	**Sound**
HAPPINESS	45/100/100	Less saturated red	Non	
SADNESS	230/40/40			Falling
ANGER	0/100/100	Fully saturated red	Highly intense	Rising
SURPRISE	60/100/100		Non	
DISGUST	30/67/40	Low brightness		
FEAR	0/0/20			

Appendix B

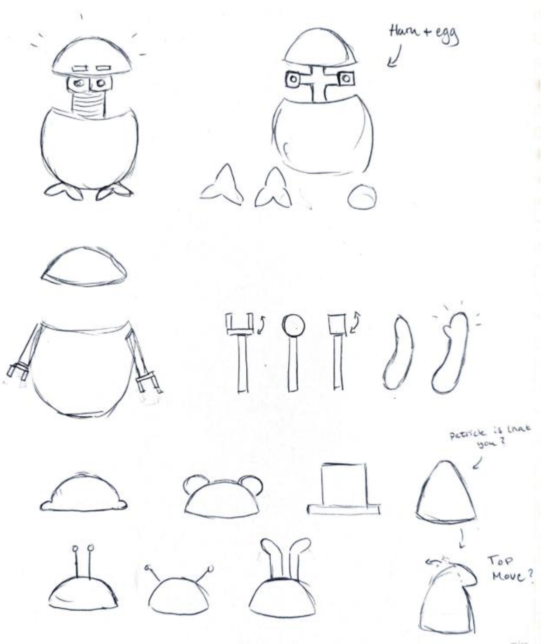
Sketches

B.1 Egg sketches



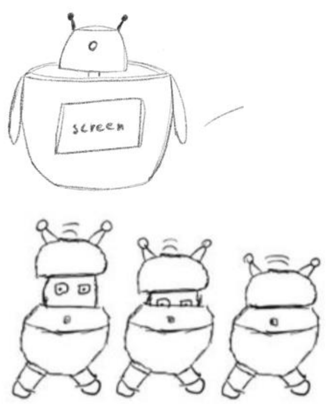


The egg
Foot -shape
Antenna
Mechanical
Screen
Ear-like shape
Microphone
/speakers
Sad
Happy

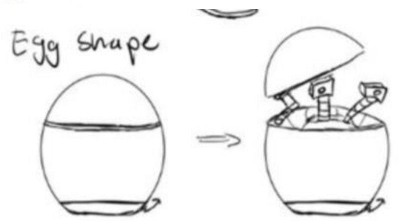


Harn + egg
Patrick is that you?
Top
Move?

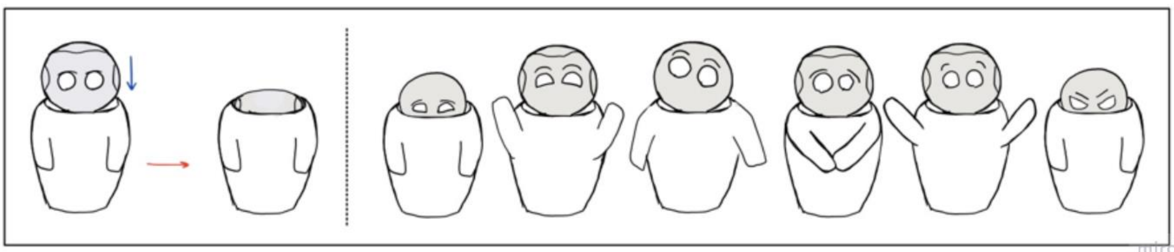
The mushroom
The hat can move
up and down
forward & backwards
Arms?



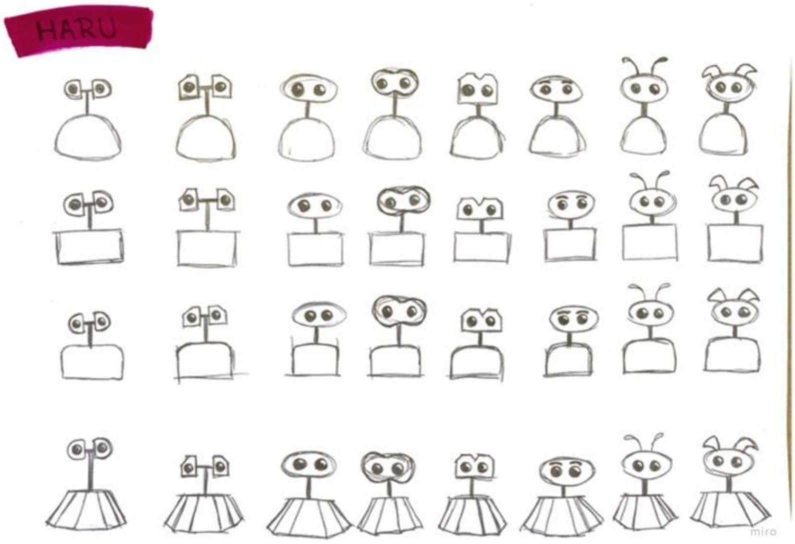
screen

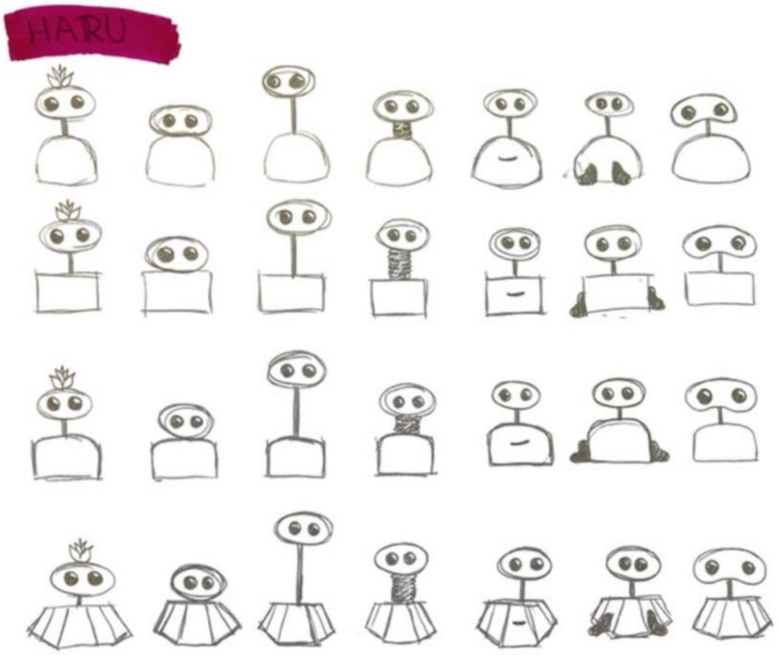


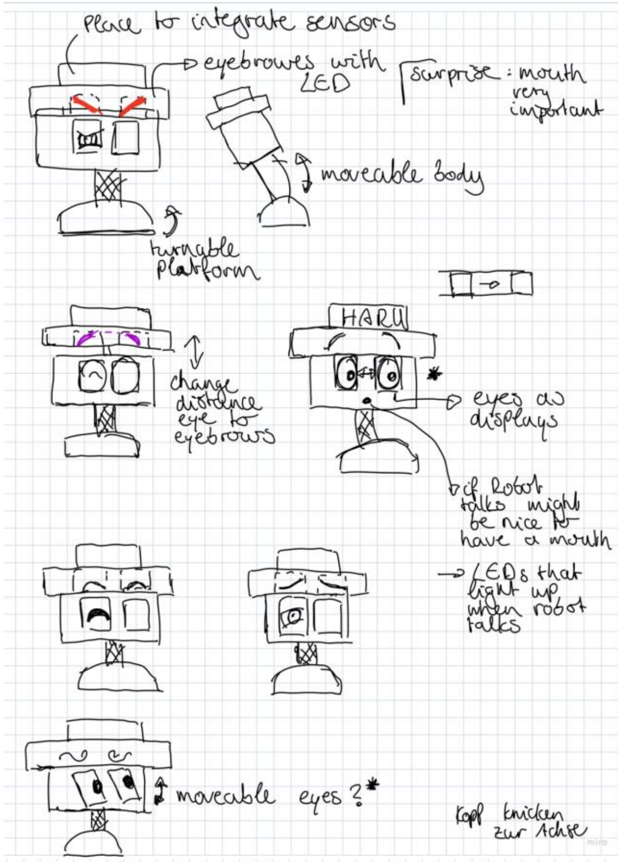
Egg shape

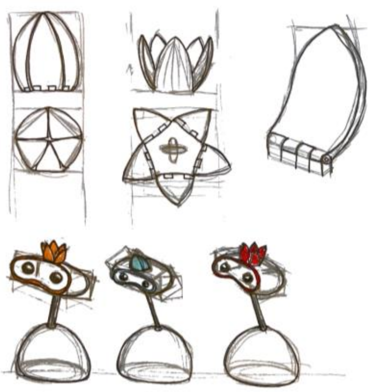


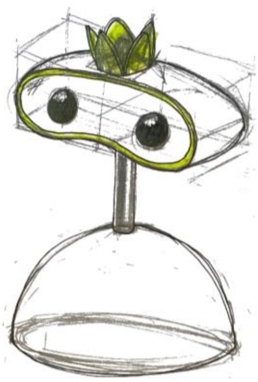
B.2 Haru sketches

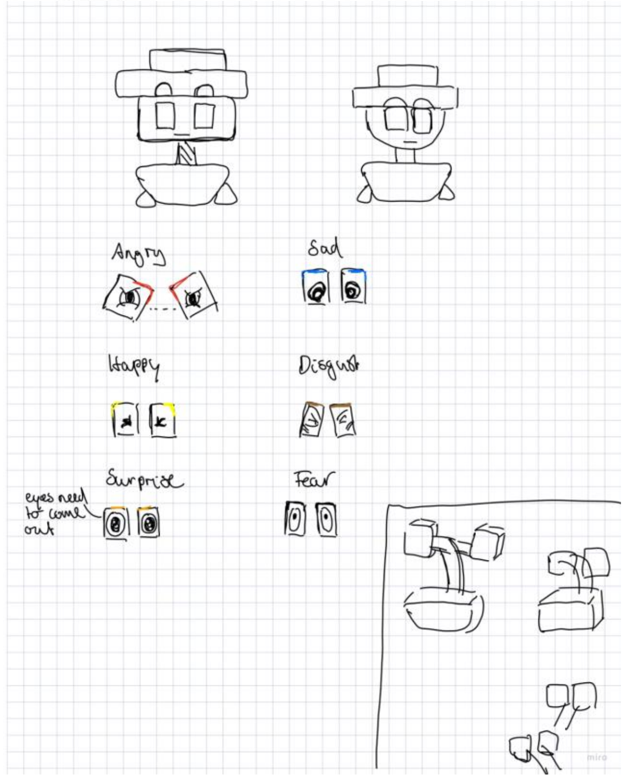

HARU

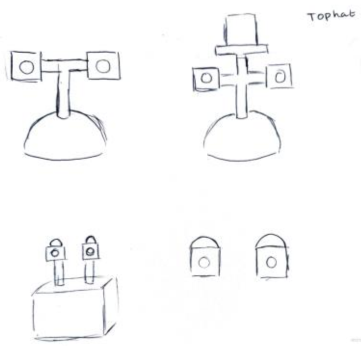

HARU

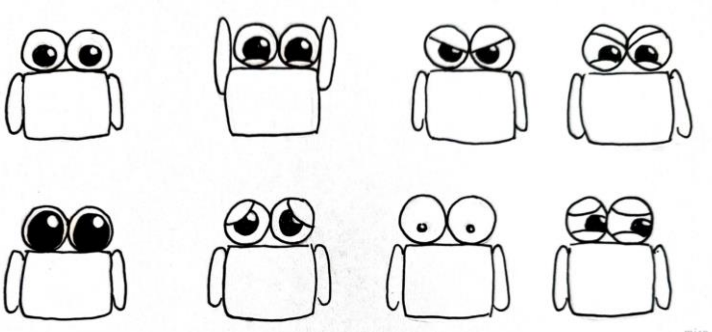

Place to integrate sensors
eyebrowes with LED
surprise: mouth very important
moveable body
turnable platform
change distance eye to eyebrows
HARU
eyes as displays
if Robot talks might be nice to have a mouth
LEDs that light up when robot talks
moveable eyes ?*
Kopf knicken zur Achse



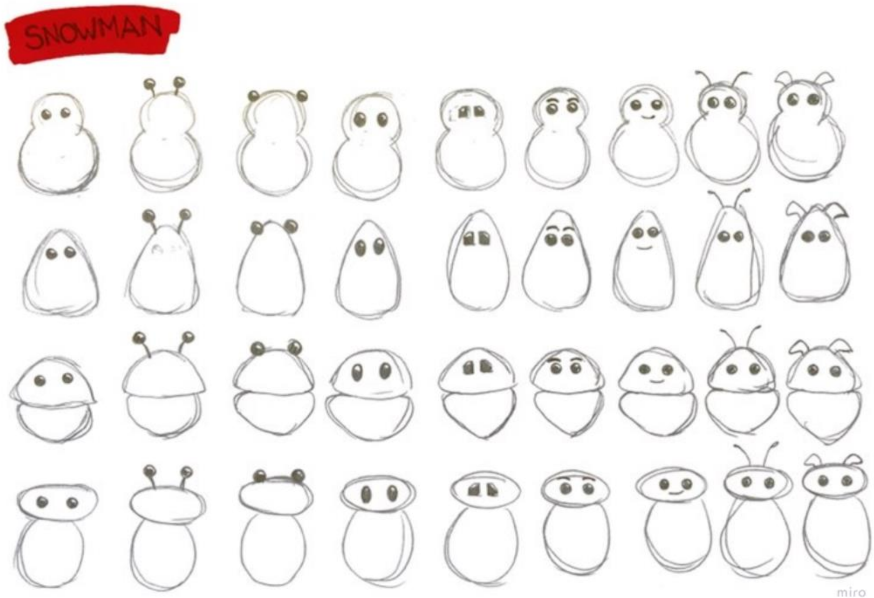


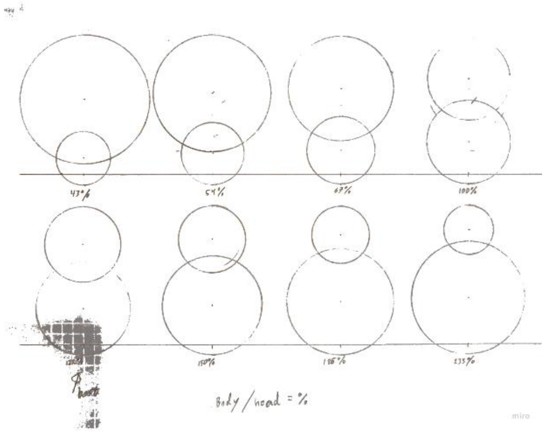

Angry
Sad
Happy
Disgust
Surprise
Fear
eyes need to come out

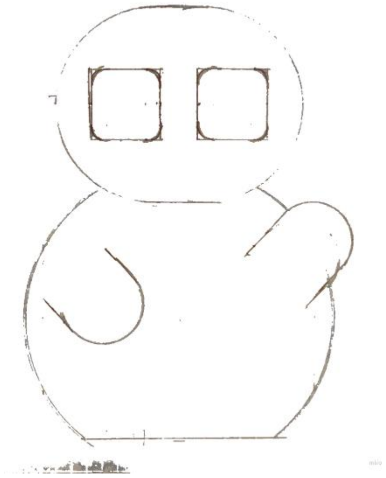

Tophat



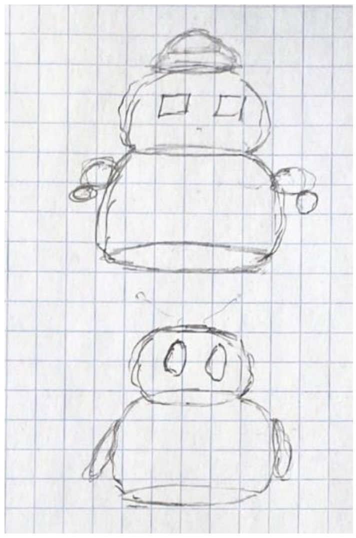
B.3 Snowman sketches

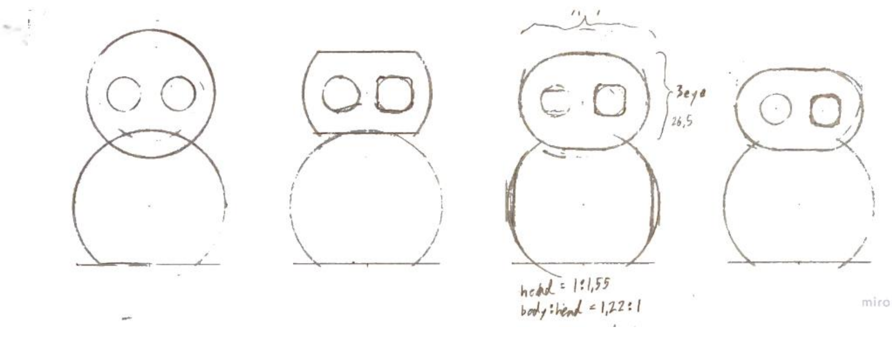

SNOWMAN
miro

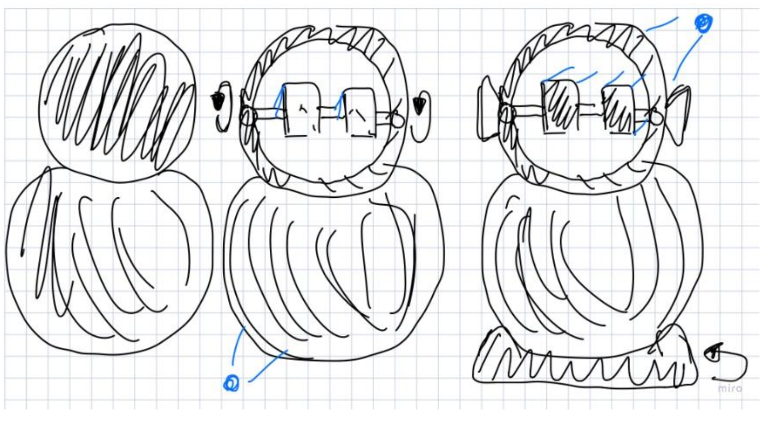

43%
54%
67%
100%
150%
185%
233%
Body / head = %
miro




SNOWMAN
from the back
miro

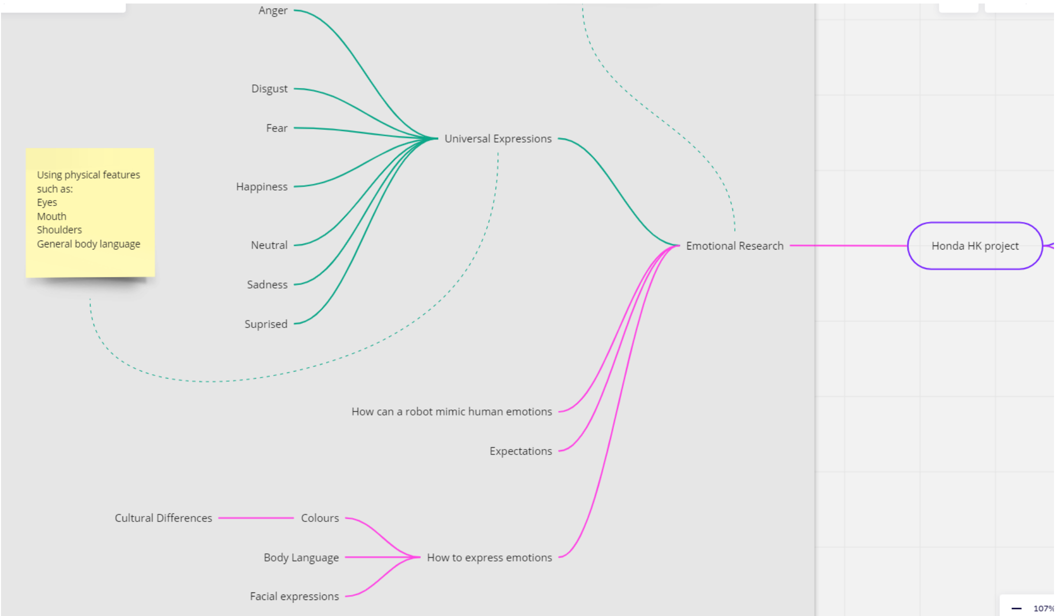



3eye
26,5
head = 1:1,55
body:head = 1,22:1
miro

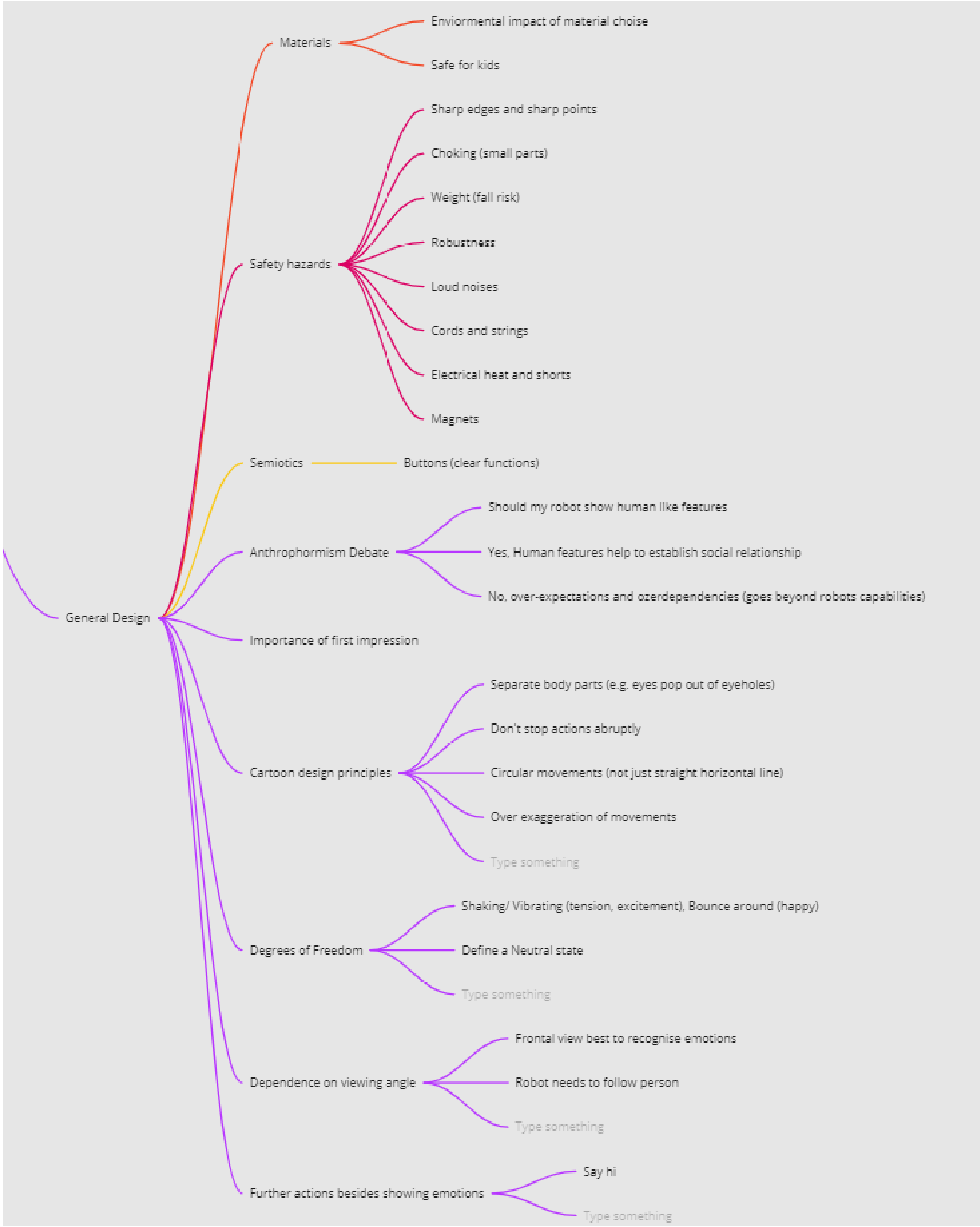

miro

Appendix C

Mindmap




Requirements
Unicef requirements
Prioritizing fairness and non discrimination
Including age, ethnicity, race, gender identities, disability, rural or urban contexts, socioeconomic status or location.
Interaction should understandable for all.
Any prejudicial bias against children, or certain groups of children, that leads to discrimination and exclusion should be reduced.
Provide transperacy, explainability and accountability
Important to explain why a robot acted the way it did.
Everything should be directed so that a child could understand it.
Use age-appropriate language to describe AI, descibing how it uses and maintains data.
children should be notified when being interacting with it
The development of AI systems cannot ignore or exploit any child's lack of understanding or vulnerability.
Lack of long - term studies
Type something
Abstract requirements
Physical features
Have a head
Multicolored curved
Monochromatic zigzag
hat/ antenna
2 eyes
Movement of eyes
Eyebrows
Arms
Without giving too many expectations
Body
Actions
Lean Forward/ backward
Turn left and right
Body language
Spin around


General Design
Materials
Enviormental impact of material choise
Safe for kids
Safety hazards
Sharp edges and sharp points
Choking (small parts)
Weight (fall risk)
Robustness
Loud noises
Cords and strings
Electrical heat and shorts
Magnets
Semiotics
Buttons (clear functions)
Anthrophormism Debate
Should my robot show human like features
Yes, Human features help to establish social relationship
No, over-expectations and ozerdependencies (goes beyond robots capabilities)
Importance of first impression
Cartoon design principles
Separate body parts (e.g. eyes pop out of eyeholes)
Don't stop actions abruptly
Circular movements (not just straight horizontal line)
Over exaggeration of movements
Type something
Degrees of Freedom
Shaking/ Vibrating (tension, excitement), Bounce around (happy)
Define a Neutral state
Type something
Dependence on viewing angle
Frontal view best to recognise emotions
Robot needs to follow person
Type something
Further actions besides showing emotions
Say hi
Type something