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MF2058 Mechatronics, Advanced Course Spring Semester

AKI

Abstract

This project involves further developing the AKI robot, a social tabletop robot for child interaction.

This project's stakeholder is the HONDA Research Institute of Japan, and the work is done in collaboration with the Robot Design Lab of the Mechatronics Unit.

The project is a continuation of a previous project that was part of the Mechatronics Higher course - Högre kurs (HK) in 2022. The goal was to create AKI, a tabletop robot that would be able to express nonverbally six basic emotions: happiness, sadness, surprise, fear, anger, and disgust.

The goal is to revise and expand AKI's mechatronic design, extending its functionalities while ensuring reliability and safety over long-hour operations. The robot shall have extended locomotion capabilities, updated structural design, response to ledges and obstacles, verbal communication with AI, and wireless operation. It should do this while being reliable and safe as part of UNICEF policy guidelines on AI for children.

This report includes the SOTA for each of the AKI functionalities: existing solutions, locomotions, patterns and emotions, obstacle detection, reliability, verbal communication, AI, hardware, and wireless operation. From the SOTA concept design was made. The type of locomotion that was chosen was omni wheels, primarily because of its maneuverability. It also includes locomotion patterns that will be implemented on AKI, corresponding to one of six basic emotions. To track the environment and surrounding obstacles, ToF sensors were chosen to support AKI's movement. The wireless operation also been primarily designed as LiPON battery providing power and Wifi was choosen for communication. For verbal communication, CMU sphinx and ChatGPT API will be used, although actual solution may change depending on the hardware to be used. The report also includes the risk analysis, and future work during the fall.

Acknowledgements

We would like to express our gratitude to Honda Research Institute of Japan and our stakeholder Georgios Andrikopoulos for the opportunity to develop this project. This report would not have been possible without our stakeholder Georgios Andrikopoulos and our supervisor Seshagopalan Thorapalli Muralidharan. We are grateful for their commitment and support during this process. In addition, we would like to thank the previous HK team for their effort in developing the prototype, which provided a solid foundation for our work.

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Acronyms

AI Artificial Intelligence

API Application Programming Interface

ASIC Application Specific Integrated Circuit

ASTM American Society for Testing and Materials

CPU Central Processing Unit

DoF Degrees of Freedom

FMEA Failure Mode Effect Analysis

FPGA Field Programmable Gate Array

GPU Graphical Processing Unit

HK Higher course - Högre kurs

HD High Definition

HRI Human-Robot Interaction

IR Infrared

KTH KTH - Royal Institute of Technology

LiPON Lithium Phosphorus Oxynitride

LLM Large Language Model

NFC Near Field Communication

NiMH Nickel-Metal Hydride

NiOOH Nickel Oxide Hydroxide

NLG Natural Language Generation

NPU Neural Processing Units

OpenCV Open Source Computer Vision Library

SIM Subscriber Identity Module

SOTA State Of The Art

ToF Time of Flight

TPU Tensor Processing Unit

UWB Ultra Wide Band

1 Introduction

This section provides an overview of the project's background, scope, team structure, requirements, and ethical considerations.

1.1 Background

This project is a further development of an existing robot called AKI. The original robot is a social table-top robot from a research project from KTH - Royal Institute of Technology (KTH), Stockholm, Sweden.[10]

The interaction between humans and robots has become more lifelike and sophisticated over the years. Robots designed for different purposes, for example, in service and hospitality, are increasingly capable of assisting humans in their daily lives. One sector where robots are currently being introduced and researched is in schools and classrooms, where they can serve as tools for teachers and aids for students. [11] Social robots have also been shown to help the development of social communication skills in children and adolescents with autism. [12]

To effectively engage children, the robot needs to have a variety of human-like features. Adding and developing functions for robots is costly, so these features need to provide significant added value to the interactions. Choosing the right functions is crucial to balancing the robot's cost efficiency and effectiveness.

The field of Human-Robot Interaction (HRI) is a relatively young field that outlines some key concepts for enhancing the user experience when interacting with a robot. The robot needs to be seen as a living entity with its own goals and achievements, where interactions with humans fulfill the robot's needs. Also, its behavior and manners must be acceptable and comfortable to humans. While its actions and decisions need to be seen as intelligent and intentional. [13] These human-like characteristics must permeate the robot's features and attributes to get a satisfactory user experience.

1.2 Scope

This project aims to add new features to the existing robot, AKI, in order to enhance the user experience during interactions. It is an open-ended project from KTH, where the team is asked to collaborate and develop solutions to fulfill the stakeholder's requirements. The project aims to advance the team's proficiency in mechatronics further and spans over two semesters. During the first one, research and concept development was undertaken. During the second semester, the focus shifts to building and developing new features for the robot.

The team created and developed the project's requirements in compliance with UNICEF policy guidance on AI for children. Stakeholder Georgios Andrikopoulos later verified and confirmed them.

1.3 Team Structure and Management

The team comprises seven members with the same responsibilities to contribute to the project. Before the team started any work, they created a code of conduct that every member contributed to and signed. The contract stated the team's rules and the penalties for breaking them. For instance, one rule stated that every individual is expected to deliver at least 400 working hours in the fall semester, corresponding to the course's 15 credits.

The team will split into smaller sub-teams that will focus on different implementations of AKI. Those teams will be very flexible. This means that the size of those sub-teams will differ depending on the workload of that task. Also, the group members will change tasks and sub-teams regularly during the semester to ensure that every member will have worked on multiple tasks related to the work. That way, we can make sure that all of the members will have worked on the tasks related to software, electronics, mechanics, and control, which are the branches that mechatronics focuses on.

The team has shared responsibilities. Someone takes notes during meetings, and one or two project managers ensure that everyone in the group is involved and that the project deadline is met. During the project, these responsibilities are shared from one team member to another.

1.4 Requirements

Below are the stakeholder requirements:

Must-Have Requirements:

1. Enabling Wheeled Locomotion
   - Enabling wheeled locomotion of the robot platform in at least 2 Degrees of Freedom (DoF).
   - The locomotion shall enhance the expressiveness of the robot's emotions.
2. Ensuring Operational Reliability
   - Implementation of rigid and compliant components to increase functionality and presentation quality.
   - Achieving robust and accurate motion regardless of disturbances and extended periods of operation.
   - Ensure locomotion noise levels within permissible ranges for children-robot interaction.
   - Ensuring the component's temperature level is stable and in an acceptable range under prolonged operation.
   - The program code must be modular, facilitating easy testing, and be validated to ensure seamless operation for extended periods without unexpected behaviors.
3. The robot ensures safe usage for children by complying with UNICEF's requirements 3 & 6.
   - Prioritize fairness and non-discrimination for children.
   - Provide transparency, explainability, and accountability for children.
4. The robot shall be able to operate wirelessly.
5. The robot shall detect obstacles and avoid them.

Nice-to-Have Requirements:

1. Enabling Wheeled Locomotion
   - The robot should be able to take user interactions (e.g., verbal instructions, visual directions) and transfer them into movements.
   - Enabling usage of AI tools for user communication and creating a visual, emotional reaction from the robot based on the user's input.
2. Advancing perception
   - Enabling the robot to sense its surroundings.
   - Sensor data for extracting knowledge and information about the physical environment (users, obstacles).
3. Enabling Wireless Operation and Communication

- Should be able to get data in and out of the robot wirelessly.
- The robot should be able to move away from obstacles.

Technical requirements were made based on the stakeholders requirements. They were made to further specify the needs of the final product. These requirements can be found in Appendix C.

1.5 Ethics and Risks

Social robotics has a significant impact on healthcare and plays an essential role in providing companionship for children. To comply with the UNICEF goals, considerations regarding privacy, the ethical role of robots, and their effects on children are crucial and must be addressed in this project. To deal with that, a limited scope of topics will be implemented, and the emotional expression of the robot will be carefully designed based on current psychological research to prevent any negative impact on children. In addition, the possibility of malfunction must be analyzed and handled.

2 State of The Art

This State Of The Art (SOTA) chapter provides a comprehensive overview of the current advancements and methodologies in robotics. Improving the Honda robot, AKI was divided into individual processes that needed to be completed independently before being combined into the final product. Those processes consisted of a few key concepts. Those concepts were researched and presented below.

2.1 Existing Solutions

In this section, we will analyze two existing interactive robot products.

2.1.1 EMO

EMO is an Artificial Intelligence (AI) desktop robot pet developed by Living.AI. EMO's facial expression is performed by a screen on his head, generally showing his "eyes". For better human-like interaction, it equips various actuators and sensors. With bipedal legs, it can move around the desk. The High Definition (HD) camera can recognize the user. For verbal communication, the mic array and speaker are used for listening and speaking. It also has optical drop sensors to avoid dropping down from the desk. To make it more like a friend rather than just a toy, a built-in development system is applied to allow its skills to increase as it "grows up" [14].

2.1.2 Buddy

Buddy from Blue Frog Robotics is a companion robot that can interact with the user through vision, touch, or voice. Similar to AKI, it can also show facial emotions. However, one big difference is the wheels, which allow Buddy to move by rolling, and it can also avoid some obstacles with the help of multiple obstacle sensors. Other types of sensors it has are cliff sensors, cameras, caress sensors, omnidirectional microphones, a touch screen, and actuators (wheel motors, head motors, arm connectors). The voice interaction is done through pre-learned commands and actions. For instance, if the user says, "Can you dance?" the robot will dance a little bit, and "Go for a walk" will make Buddy go for a random walk. Buddy can move in 4 degrees of freedom and has differential drive as a type of locomotion. It communicates via WiFi wireless networks, a 4G Subscriber Identity Module (SIM) card (optional), and Bluetooth. Recharging is achieved manually through a connector plugged into the charger or autonomously by returning to its charging station (optional) [15].

(a) EMO [14]

(b) Buddy [15]

Figure 1: Existing solutions

2.2 Locomotion

This project's key stakeholder requirement and focal point is to develop a locomotion system for AKI. Additionally, stakeholders have specifically requested a wheeled locomotion system with lowprofile wheels. Therefore, this section of the SOTA analysis delves into research aspects concerning locomotion, including locomotion and human-robot interaction, as well as exploring various types of locomotion.

2.2.1 Locomotion and Human-Robot Interaction

In recent years, locomotion capability has become an essential part of HRI. Many studies demonstrated that interactive robots with locomotion functionality can achieve better HRI effects.

H. Huettenrauch's research [16] drew on some research results on social distance in interpersonal relationships and found that interactive robots should dynamically adjust the positional relationship with users to maintain a good interactive environment. Ono et al. finds that locomotion and other movements of an interactive robot can improve the understanding of utterance by enabling the construction of a triadic relationship among individuals, objects, and the environment, which facilitates communication and comprehension [17]. Research by Elie et al. shows that by combining waving, greeting, and moving toward the target, interactive robots can more effectively attract the target's attention [18].

Therefore, locomotion is introduced into many mainstream experiments of interactive robots. For instance, an experiment conducted by CMU designed a robot receptionist with a moving base and a pan-tilt unit to keep tracking the person to whom it is talking [19]. Another one was Kanda's experiment, which designed a humanoid robot Robovie for socializing with children, which has a two-wheel moving base for locomotion [20]. The third one was in Kishi's research, a humanoid robot KOBIAN is designed for comedy performance. KOBIAN has a bipedal unit to achieve locomotion and perform necessary body language to make the audience laugh [21].

2.2.2 Types of Locomotion

There are multiple ways to design locomotion for a robot, and different types have different benefits and drawbacks. Therefore, when deciding on a type of locomotion, the designer has to consider the robot's application, purpose, and requirements. In this case, the main objective is to add locomotion for movement on a tabletop, which means flat terrain but possibly narrow and small moving areas. Below are various types of locomotion (mostly wheeled) introduced to give the designers different options to choose what best suits them.

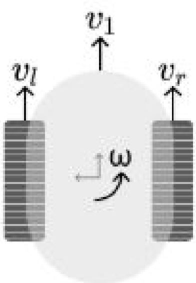
- **Omni Wheels**: Omni wheels enable movement in the direction the wheel is pointing and perpendicular to it. Arranging three wheels in a structure makes various types of movement possible. For example, the structure can move sideways without needing to turn in that direction [22].
- **Mecanum Wheels**: Similar to omni wheels, but with rollers set at an angle to the rotational axis of the wheel. This allows the robot to rotate and move in any direction, offering great agility. This type of locomotion is common for movement in narrow spaces, often used inside warehouses on forklifts [23].

(a) Omni wheel [22]

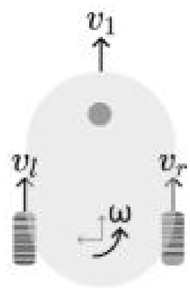
(b) Mecanum wheels [23]

Figure 2: Omni wheels and Mecanum wheels

- **Differential Drive**: Differential drive employs two wheels, each driven by its own motor. By independently adjusting the speed of each wheel, the robot can turn. There are various configurations of differential drive systems. One basic configuration involves using only the two main wheels 3a, necessitating some form of balancing control to prevent the robot from tipping over. The most prevalent setup includes adding a caster wheel or rolling ball, which introduces a third point of contact 3b [1]. Differential drive is a simple concept that does not require excessive calculations and control while still allowing flexible movement on flat terrain.



(a) Differential drive configuration



(b) Caster wheel/rolling ball configuration

Figure 3: Differential drive configurations [1]

- **Swerve Drive**: A system in which each wheel can point in any direction. Since the wheels can point in any direction, the robot can move in any direction. This allows for both translation and rotation without the need for differential steering. Additionally, it can maneuver very well in tight spaces since it can turn its wheels to form a circle and spin 4 [2]. This type of locomotion would, however, require additional motors and power.

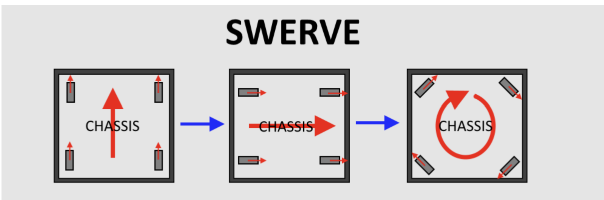
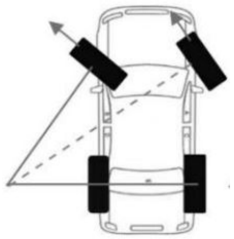


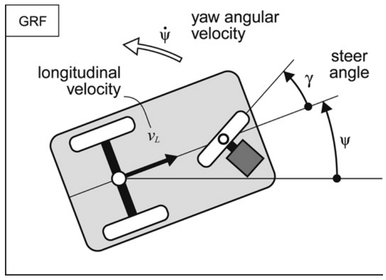
Figure 4: Movement of a robot with a swerve drive [2]

- **Ackerman steering**: Like a car that has 4 wheels. The two front wheels handle the steering while the rear 2 are stable. This is also not very maneuverable in tight spaces [24].
- **Tricycle Drive**: Two driven rear wheels and one steerable front wheel. Not very maneuverable in tight spaces. Even if it looks similar to differential drive, it is more comparable to

Ackerman steering, which is listed above, since the two driven rear wheels will always have the same speed, and the turning will be handled by the front steering.



(a) Ackerman steering [24]



(b) Mobile robot with tricycle kinematics [25]

Figure 5: Ackerman Steering and Tricycle Drive

- **Synchro Drive**: All wheels are steered together and driven simultaneously. That means it is very good for maneuvering in tight spaces, but the bad thing is that it always faces the same direction. However, AKI can rotate its body without any locomotion part, so this would not be a problem.

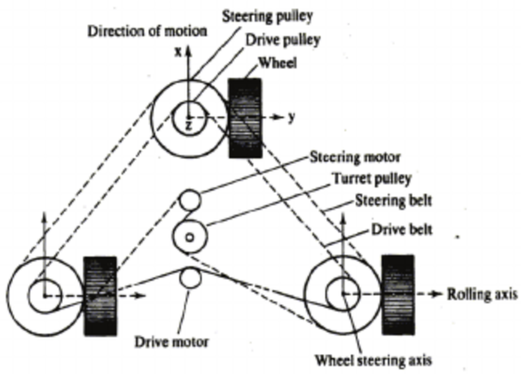


Figure 6: Synchro drive

- **Skid Steering**: The chassis is fixed, so the wheels always look straight ahead. The Wheels on each side are synchronized in movement, so the robot can only make turns if the wheels spin at different speeds on each side. This is good for movement in tight spaces [3].
- **Explicit Steering**: In explicit steering, the chassis is not fixed; the wheels can turn freely. It is accomplished by changing the heading of the wheels to cause a change in the vehicle's heading 7 [3].

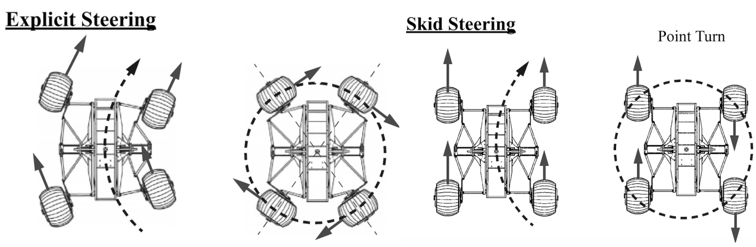


Figure 7: Explicit steering compared to skid steering [3]

- **Statically unstable two wheels**: Uses two coaxial wheels and has the center of the body above the wheel axle. It uses an inverted pendulum model to actively stabilize. It will topple over if it is not actively stabilizing [26].

- **Legs**: Legged robots can step over objects. They involve more complexity, have more degrees of freedom compared to wheeled locomotion, and are less energy efficient [26].

2.3 Patterns and emotions

Body movement is a standout feature that distinguishes robots from other machines. It serves as a powerful medium for expressing emotions and intentions. When humans interact with robots, they tend to be psychologically affected by the robot's movement. That is why the robot has to display the correct emotion and intention, which reflect the condition of its system and the context of its interaction with the human, for example.

Nonverbal communication is a prevalent form of human interaction that involves conveying messages without spoken words. Humans have a strong tendency to sense and be cued by the movements of other people and objects. Also, humans have a tendency to personify non-human machines and objects. As a result, robots working close to humans are strong determinants to produce psychological effects on him or her [27].

Furthermore, displaying motion to complement facial expressions has showed to increase the recognition of the emotion. One study with a robot showed that there was an average increase of +33.5 % compared to simple facial expression recognition, with particularly notable increases observed for Anger (+61.7 %) and Surprise (+68.5 %) [28].

2.3.1 Happiness

There are many parts of the movement that contribute to a happy emotion. The most associated with happiness are jump, spread, rhythmicity, free and light, up and rise, and rotation. The rhythmic movement is distinct but involves moving or dancing in a specific rhythm. The spreading movement is also very characteristic but that involves spreading the arms and reaching out. Those two movements are the ones that increase the ability to recognize happiness the most [29].

2.3.2 Sad

There are also nonverbal communications that contribute to being sad. Some body gestures are lowering the head and keeping eyes open or closed. Another gesture is to have a hunched back, which creates a closed body language position.

The movements that contribute to being sad are slow body movements; for example, a sad person looks like he is dragging their feet when he walks. It also has swallowing movements, which occur in a sad person's neck area, indicating that that person may be about to cry. The last movement related to being sad is because a sad person is so focused inward, making it more likely to be tripping over things [30].

2.3.3 Anger

The components of movement that most notably are connected to anger are strong, sudden, advanced, and direct. Sudden is the component that most increase the recognition of anger, it increases the recognition of anger by over 9 times [29].

2.3.4 Disgusted

The components of movement that contribute to the feeling of disgust are few. The most notable expressions of feeling disgust and contempt are facial expressions, not movements. But still, the movement of disgust is to move to the side, facing away from the things that disgust us [31].

2.3.5 Surprised

The movement of surprise is the quickest of all the other emotions because that feeling only lasts for a couple of seconds. The movement that is connected to surprise is to take one short step back from the surprising element [32].

2.3.6 Fear

The components of movement that express fear include movements such as bind, retreat, condense and enclose, and twist and back, with the most significant expressions being retreat and twist and back [29].

2.4 Obstacle Detection

In this project, AKI is expected to avoid potential obstacles during operation. Considering our application is primarily indoor and involves usage on the table with edges, we will primarily address the ledges and obstacles encountered by the robot during its movement to ensure it can navigate around obstacles along its path and recognize edges to prevent the robot from falling. Thus, we go further into the sensors that can meet our requirements.

- **Infrared (IR) Sensor**: An IR sensor is an electronic device that emits infrared radiation to sense some aspects of the surroundings. It offers simplicity in implementation, reduced power consumption, and excels in detecting objects in low-light conditions. However, their detection angle is limited. Additionally, since IR sensors depend on temperature differentials for detection, detecting objects with similar temperatures to the background would be a challenge [33].

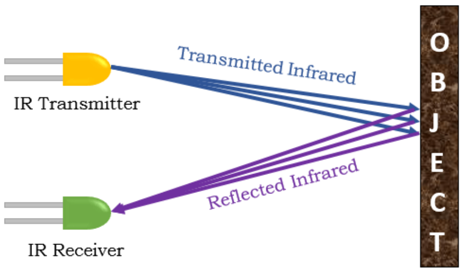


Figure 8: IR sensor [4]

- **Cliff Sensor**: Cliff sensor is mainly used in robotic vacuum cleaners to help prevent them from falling off edges or stairs. These sensors use infrared technology to detect changes in floor height and alert the vacuum cleaner to change its direction or avoid the obstacle altogether. This ensures that the vacuum cleaner operates safely and efficiently without the risk of damage or accidents [34].
- **LiDAR**: LiDAR works by sending out pulses of (usually infrared) light in a tight beam to a distant object, then measuring the time it takes for the reflected light to return, which is widely used in autonomous driving applications. LiDAR has various strengths: a large field of view, power efficiency, speed, and robustness. Despite that, LiDAR is not without limitations. Its performance is easily affected by environmental factors. On the other hand, LiDAR is a complex device with rotating parts, usually expensive and susceptible to mechanical damage [35].
- **Stereo Camera**: Stereo cameras, unaffected by light emission and capable of functioning in various lighting conditions, are suitable for indoor and outdoor use due to their robustness. Compared to other active sensors, it has a simple structure and is far less expensive. Moreover,

it has the inherent ability to extract a high-quality color image well-aligned to the depth map. Overall, a stereo camera is an excellent choice for robot navigation and mapping in diverse, unstructured environments [36].

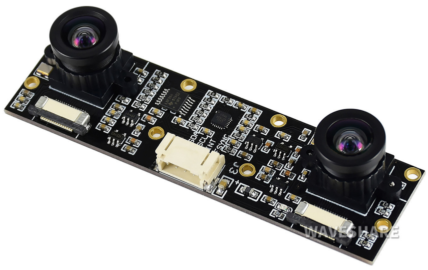


Figure 9: Stereo camera [5]

- **Monocular Camera**: Monocular camera is a versatile imaging device that plays a crucial role in capturing visual information. Its compact size, cost-effectiveness, and ability to capture high-resolution images make it a popular choice in various industries. With advancements in computer vision and machine learning, monocular cameras are becoming even more powerful in their ability to understand and interpret the visual world. Unlike a stereo camera that uses two lenses to create a 3D effect, a monocular camera captures images in 2D [37].
- **Time of Flight (ToF) Camera**: All ToF cameras are compact, lightweight, and relatively inexpensive, making them suitable for embedding in small devices such as cell phones. They operate effectively in low light conditions or darkness due to their own laser illumination. Their accuracy rivals that of Structured Light Cameras, ranging from 1mm to 1cm. Indirect ToF cameras offer high-resolution depth information up to 640×480 pixels. With rapid operation at up to 60 frames per second, ToF cameras are ideal for real-time applications. Moreover, ToF cameras are cost-effective compared to alternatives like Structured Light Cameras and LiDAR sensors [38].

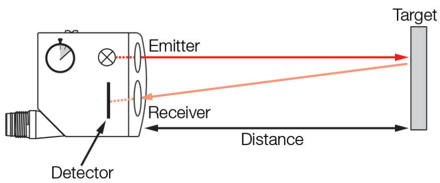


Figure 10: ToF Camera [6]

2.5 Reliability

Currently, AKI has been equipped with a complete system. It has single-degree-of-freedom wheels for movement. It can achieve basic emotional expressions while movable auxiliary arms and head are implemented for communication with users. The robot utilizes Open Source Computer Vision Library (OpenCV) for person-tracking its surroundings and can greet users upon initial interaction. Additionally, the speaker is available but not extensively utilized for user interaction. However, AKI experiences mechanical system friction and motor overloading, leading to noise and temperature concerns. Additionally, Arduino Nano disconnections occur during operation. On another note, the mechanical structure design requires improvement, as disassembling the robot becomes challenging once all parts are screwed in place and when all electronics are connected [7].

In order for the robot to maintain stable and consistent performance for a prolonged period of time, the robustness of it's components is paramount. The robot's robustness criteria can be dissected into four categories involving its mechanical, electrical, and software components, with an additional thermal section to ensure reliable operations over long-hour usage.

2.5.1 Mechanical

Mechanical wear can break or render the robot's components less effective. The American Society for Testing and Materials (ASTM) Committee categorizes mechanical wear into abrasive and non-abrasive. Abrasive wear occurs when a hard surface slides along a softer surface. The result can be compromised or distorted components. Nonabrasive wear typically occurs in sliding systems with materials of similar hardness, for example, roll bearing and gears [39].

Friction between moving surfaces is the primary reason for failure in machines, influenced by factors such as load, speed, hardness, and roughness of the surface of the two sliding pairs [40].

To minimize abrasive and nonabrasive wear, reducing friction can have a significant impact on the robustness of the robot. Additional measures that can be taken is creating smooth surfaces and reduce load.

Regarding the noise issue, the gear rack structures in the neck exhibit higher noise levels. On one hand, despite sanding, the 3D printed materials currently in use remain relatively rough, which is an area for potential improvement. On the other hand, as mentioned in previous test reports, it is better to redesign the slider, even if lubrication resolves it in the short term [7]. A thing to consider is implementing structures with lower friction to address direct friction between materials in the original design, such as by incorporating bearings. Additionally, inspection and maintenance issues for the robot should be considered when redesigning the mechanical structure. This implies that the robot should be designed to assemble and disassemble individual components easily.

2.5.2 Electrical

Wiring optimization is needed because there were periodic disconnections with the Arduino Nano during experiments. Firstly, choose appropriate electrical control components and controllers to ensure the reliability and stability of the system, considering the component's size, load capacity, and working noise. Secondly, design the system layout and wire the electrical system according to the robot's motion trajectory and sensor positions, to avoid electromagnetic interference and power supply noise, as well as the disconnection error that occurs during operation. In addition, meeting fundamental electrical system safety requirements, implement appropriate electrical safety measures such as isolation switches, fuses, and grounding, to ensure the safety of the robot's electrical system. Besides, an emergency switch is significant to ensure safety during robot operation.

2.5.3 Software

The existing software is built on C++, operating with a master from a UP-core and two slaves, Arduino Nano and Teensy 4.0. It is currently compatible with Ubuntu 22.04 and is modularized as a distributed system, with each slave and master responsible for various operations. The programming is structured to execute all operations sequentially from a unified C file. The stakeholder's objective is to redesign the program to improve it and create faster sampling. One approach to achieve this could involve modularization the software using threads, semaphores, etc, possibly adding more Central Processing Unit (CPU)'s to increase speed and computational power.

2.5.4 Thermal

The thermal part can be part of the mechanical, electrical, and software since overheating is mainly caused by overload due to unreasonable mechanical design, unsuitable electrical components, and excessive demands on computation (software). In the current state, thermal is not of concern but needs to be considered when adding electrical components. One way to solve the problem would be heat-dissipating components such as a fan and thermal interface material (silicon thermal pad) for the robot mainboard.

2.6 Verbal Communication and AI

To make AKI more appealing, adding verbal communication skills could be considered. To do that, AKI will be able to communicate using AI, which has seen significant improvements in recent years, facilitating its seamless fusion with robotics.

2.6.1 Natural language generation

There are several types of Natural Language Generation (NLG) systems. Templete-based NLG systems use predefined templates to generate texts, rule-based NLG systems use predefined rules to generate texts. However, these two methods have the similar drawbacks of having limited flexibility while handling unexpected interactions. The most popular NLG system currently is ChatGPT [41], which is developed by OpenAI. ChatGPT is a Neural Network based NLG system, it can generate human-like text and voice naturally, as well as keep a reasonable context while chatting. But it consumes a large amount of computational resources and data.

2.6.2 Speech to text recognition

In order to use a NLG system, spoken language must be able to transform into text. There are several services that offer the ability to transform speech to text. One such service is Google Cloud, which can be used together with a Raspberry Pi and ChatGPT to make a vocal interaction system [42]. Pocketsphinx is a lightweight open-source speech recognition engine developed by Carnegie Mellon University[43]. It is specifically designed for embedded systems that have limited processing power and memory resources. ChatGPT also has the ability to directly transfer speech to text and back via itself [44].

2.6.3 Emotions and speech

The way children, young adults, and adults understand emotions based on what was said and how it was said varies significantly. Young kids mainly focus on what is being said, while adults focus more on the context of what is being said. Even while expressing contradictory emotions, younger kids put a heavier focus on the actual words [45]. The integration of an AI to enable interactive communication with the robot would enhance the emotional perception of the user. Especially between children and robot interaction.

2.7 Hardware

Deploying AI requires a varying degree of computation power. There are different ways to run an AI. They can be run locally on an external server, called edge running, or in a hybrid variation, combining cloud and edge architectures. Running an AI in a cloud puts less processing demand on the local system, which is limited to its size and resources, but it introduces latency and security risks [46]. To more efficiently implement AI, hardware accelerators can be utilized. Hardware accelerators are computer components that are specifically designed to run certain functions more efficiently than software that could run on a general-processing unit alone, such as a CPU.

- Graphical Processing Unit (GPU) can be useful AI hardware accelerators. GPUs can process multiple data pieces in parallel, making it suitable for machine learning. Although some limitations of GPUs are latency, bandwidth, and branch prediction.
- Field Programmable Gate Array (FPGA) is a special architecture and has the programmability to implement any design. The downside is that they can't be optimized for the various

requirements of different applications. They also have less performance and energy efficiency than Application Specific Integrated Circuit (ASIC).

- ASIC is also a spacial architecture. They are designed for a specific application and can't be changed later. These chips are efficient and optimized.
- Tensor Processing Unit (TPU) is based on ASIC and it is used for cloud-based AI. To implement the machine learning, TPU uses TensorFlow. It uses digital processors which have local memory on a network. On the chip is high bandwidth memory, and each core has scalar, vector, and matrix units.
- Neural Processing Units (NPU) are used on mobile application processors and serve as a neural network specialized hardware accelerator. By using data-driven parallel computing, it runs deep neural networks energy efficiently [47].

2.8 Wireless Operation

For tabletop robots, wireless operation provides flexibility and a cleaner look. To enable wireless operation, battery is needed for powering the robot without a power cable, wireless communication achieves controlling the robot and transmitting data wirelessly.

2.8.1 Battery

To enable robust wireless operation, the robot should have an independent power source. Batteries are a way to power a desktop robot. This section studies several commonly used battery technologies.

- Alkaline batteries: A type of primary battery that is usually made of zinc as anode and manganese dioxide as cathode with an alkaline electrolyte. Alkaline batteries offer high energy density and long shelf-life, which makes them very popular in cheap small electrical appliances and toys. However, because of being disposable, alkaline batteries will create harmful waste with hazardous substances, and have higher cost than rechargeable batteries in the long run.
- Nickel-Metal Hydride (NiMH) batteries: A type of rechargeable battery consists of a hydrogen-absorbing alloy for the anode and a Nickel Oxide Hydroxide (NiOOH) for the cathode. The electrolyte used is usually potassium hydroxide. NiMH battery is currently the least expensive rechargeable battery technology [48], and it is environmentally friendly since lacking toxic heavy metals compared with other solutions.
- Lithium-Ion batteries: The most popular type of rechargeable battery used in portable electronic devices commonly consists of a graphite anode and lithium metal oxide. Compared with NiMH batteries, Li-Ion batteries often have higher energy density and more cycle life. At the same time, higher voltage also makes Li-Ion batteries have broader application scenarios [49]. Different cathode materials provide different performances. For small robots, Lithium Phosphorus Oxynitride (LiPON) is the predominant choice [50].

To know more about which type of battery is needed for this robot, the following needs to be analyzed [51].

- The robot can be powered by disposable or rechargeable batteries. Disposable batteries are better at low-power applications, and it takes little time to change them. Rechargeable batteries are better for higher power applications when the application is using more energy under its life.
- The battery must have sufficient energy and power to be able to operate at full speed for a sufficiently long time.
- The battery must have a voltage level that fits with all the electrical components. If multiple voltage levels are needed, multiple batteries or a voltage divider are needed.

- The battery must operate effectively at its ambient temperature.

2.8.2 Wireless Communication

When considering the need for a robot to freely move indoors and communicate wirelessly with a control terminal, selecting a technology suitable for short-range communication is crucial. Based on the application scenario of AKI, we primarily conducted research on the following four short-range wireless communication technologies.

- **Ultra Wide Band (UWB)**: UWB is a wireless technology that uses very low energy pulses of radio waves to transmit data and measure the location and direction of objects with high accuracy [52], which enables high-speed data transfer with low-power, simplified transceivers, while efficiently utilizing spectrum resources without significant interference to other wireless technologies, such as Wi-Fi, Bluetooth, and Near Field Communication (NFC). But as a new technology, UWB has many shortages like low data transmission rate and low spectrum utilization system. So far, it has not been recognized in universal equipment (such as mobile phones and personal computer terminals) as a tag [9].
- **Wi-Fi**: Wi-Fi is a technology that enables electronic devices to connect to local networks through radio waves [9]. Wi-Fi has been widely applied, it boasts stability and supports connectivity with a variety of devices. For wireless communication needs in robotics applications, Wi-Fi effectively meets the demands of wireless communication in robotics, facilitating real-time transmission of extensive data, including sensor data.
- **Bluetooth**: Bluetooth devices send short-range radio signals to connect with each other, replacing the need for cable connections. They consist of transceivers, basebands, and protocol stacks, enabling the formation of small or large networks [52]. Typically, Bluetooth has an effective communication range of around 10 meters, depending on the type and version of the devices. Due to its short range and low power consumption, Bluetooth is commonly used to connect nearby devices like smartphones to headphones, keyboards, mice, and smart home devices.
- **ZigBee**: Zigbee, introduced in 2003, aimed to overcome Bluetooth's limitations like complexity, high power usage, limited range, and small network scalability. Zigbee uses self-organizing network communication and is a leading wireless protocol in sensor networks. In sensor networks, if a message encounters transmission issues, dynamic routers quickly find an alternative channel for reliable data transfer. While not mainstream, Zigbee's benefits of low power usage, affordability, low data rates, high capacity, and long battery life have attracted attention from manufacturers [53].

3 Design Concepts

Based on the research in the SOTA, the design of the new robot implementations could begin. The stakeholder requirements can be fulfilled by implementing different concepts that are presented below.

3.1 Reliability

There are different areas of concern regarding reliability that needs to be addressed. Firstly the noise level from the neck and the rotating base-plate. By implementing locomotion, the noise from the base plate can be disregarded while still enabling the robot to turn in any direction. When it comes to the neck structure a new proposal is to implement a single linear actuator, to minimize noise and optimize space allocation inside the shell.

For the problem with wiring and disconnection, a couple of solutions were proposed. The current Arduino Nano will be replaced to solve the disconnection issues. To further increase the robustness, a custom wire harness will be created for different parts of the robot. This would minimize entanglement and make it more organized. Twisting the cables in the harness will also have a reduction in electromagnetic interference. Another plan is to use cable strain relief to protect wires from tension during the robot's movement while also allocating the path of the cable with an appropriate length according to the robot's motion trajectory.

To mitigate heat, incorporating additional fans and heat sinks can effectively lower the temperature inside the shell. Additionally, introducing holes or gaps in the outer shell will allow for more airflow. The overall structure is going to need some reorganizing. One idea is to mount pockets on the inside of the outer shell to make it easier to disassemble and mount components.

To improve the software design and sampling speed, it will be modularized using threads. To further improve it, the UP-Core will be replaced by another computer with a CPU that has more computational power.

3.2 Locomotion

A potential locomotion design was formulated based on previous research findings in the SOTA. A decision matrix was created for each locomotion category and assessed for its functionality, see Appendix B. The assessment was made based on its compatibility with the stakeholder's requirements. Differential drive and Omni Drive proved to be the optimal choice for AKI.

3.2.1 Omni Drive

The decision to go with the Omni drive was heavily influenced by both the decision matrix and the fact that the group wanted something challenging. The criteria were set and prioritized in the decision matrix based mainly on what the stakeholders needed and what was feasible. For example, because AKI is meant to move around on tabletops, it needs to be highly maneuverable. Also, the desired locomotion type was a space-efficient one since the insides of AKI are already packed. Generally, omni drive is not the most space-efficient choice, however in this case, the shape of the setup with omni-wheels fits AKI:s cylindrical shape well. Additionally, since the omni drive allows for rotation around the z-axis, the whole baseplate (which allows for the current feature of rotation) can be removed and replaced with the omni-wheels' implementation.

3.2.2 Patterns and Movements

The new locomotion features will be combined with the six basic emotions that AKI can already express via its facial expressions and gestures, as seen in figure 11. Below are locomotion concepts for each of the basic emotions. For the purpose of the images, the front of the robot is pointing downwards.

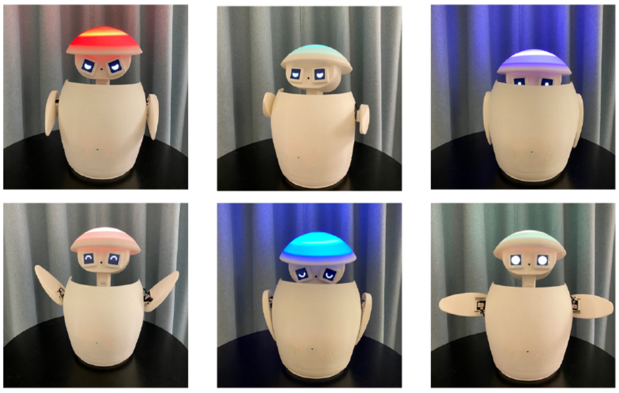


Figure 11: The six expressions of AKI [7], From the top left corner to the right: Anger, Disgust, Fear, Happiness, Sadness and Surprise.

- Happy: Aki will do one of the following: AKI will move forward at medium speed, spinning, dancing, driving in a circle or an 8 shape, or doing rhythmic dancing. Regardless of movement, AKI will open its arms and smile.
- Sadness: AKI will move its arm inwards, lower its head, and look down. AKI will move forward slowly or drive off slowly in a "J" shape, indicating it wants to be alone.
- Anger: AKI will stretch its arm forward and glare ahead. AKI will also suddenly drive fast forward a short distance.
- Disgusted: AKI will put arms in tandem and have a depressed facial expression. AKI will rotate to the side and move away from the thing that disgusted it.
- Surprise: AKI will open its arms, and look forward with its eyes wide open. AKI will move backward a short distance, or it could move forward to indicate a pleasant surprise.
- Fear: AKI will retract his head into his body and tuck his arm at the side of his body. AKI will move straight backward for a long time or in a zigzag pattern, indicating it is shivering out of fear.

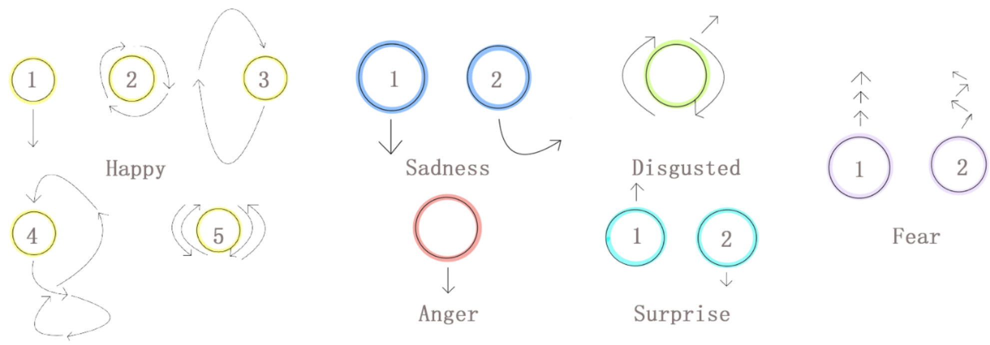
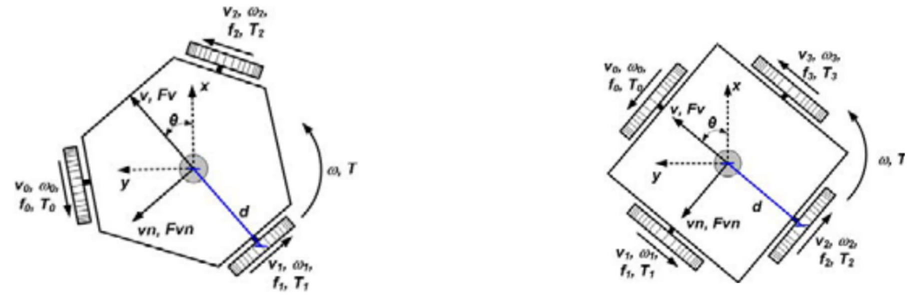


Figure 12: AKI's expressions

3.2.3 Implementation

The implementation of omni drive can be done in two main ways. Firstly, the drive system could be arranged with three wheels set up in a triangular shape as in figure 13a or four wheels as in figure 13b. The exact setup has not been decided, but the pros and cons of each implementation have been discussed. For a 3-wheeled setup, the advantages are its improved maneuverability, making it good for tight spaces and corners, and its lighter weight, which can boost efficiency and performance. It might also be cheaper since fewer parts are required. However, since it only has 3 wheels, it has less stability, especially at higher speeds or with heavy loads. A 4-wheeled setup has better stability and balance, particularly with heavy loads or at higher speeds, enhancing safety and performance. However, a 4-wheeled setup might be less maneuverable [8].

One of these setups will be installed inside and underneath the robot, keeping the wheels hidden. This improves the robot's appearance and enhances safety by making it harder for things like hair to get caught in the wheels. However, this requires us to modify the robot's bottom interior. Currently, it has a base plate that allows rotation around the z-axis. Since the omni drive setup also provides this feature, we can remove the base plate and replace it with the omni drive. Additionally, the wheel configuration for both setups is space-efficient for AKI due to its cylindrical shape.



(a) 3-wheel omnidirectional robot (b) 4-wheel omnidirectional robot

Figure 13: Omni-directional robots with different wheel configurations. [8]

3.3 Obstacle Detection

In this project, the obstacle detection sensor is responsible for identifying obstacles and ledges. When selecting the sensor, our goal is to preserve the AKI's original appearance and avoid adding significant weight, necessitating a compact design. Considering the robot's locomotion function, accurate data is required to detect obstacles and execute avoidance maneuvers, which requires the sensor to have high processing speeds. Here we listed all the factors and utilized a matrix to conduct weighted calculations for the factors we needed to consider, the result of the matrix indicates that ToF can be a good choice for AKI, see Appenix B. Since we want to detect the obstacles around AKI, the sensors are considered to be placed all around AKI.

3.4 Verbal Communication and AI

To enable verbal communication, AKI will get voice input, and convert speech to text, as well as make reasonable responses to it. The responses will be generated by a Large Language Model (LLM). The communication content will comply with the requirements by UNICEF.

3.4.1 Microphone Array

In the existing solution, there is a speaker for audio output, however it is missing a microphone array for audio input. Therefore, a new microphone array will be installed. The microphone should be farther away from the speaker to avoid echo.

3.4.2 Communication Software

As AKI has limited computational resource, and fast response should be achieved, the verbal communication software will be implemented both on cloud and locally. Pocketsphinx will be installed on AKI locally to reduce the delay. ChatGPT will process on cloud to improve AKI's communication performance.

As discussed in SoTA, Pocketsphinx could be suitable to be used as speech to text converter in AKI. With Pocketsphinx, AKI could convert the voice received by the microphone array to text offline efficiently.

To achieve speech response, AKI could send the text converted from voice to ChatGPT Application Programming Interface (API). ChatGPT is a powerful LLM that can chat with user naturally. We will configure the API to strictly comply with the UNICEF's policy guidance on AI for children.

3.5 Wireless Communication

In the existing solution, the wires for power supply and communication are limiting AKI's mobility and flexibility. To remove those wires, AKI will be powered by batteries and communicate wirelessly.

3.5.1 Battery

The rechargeable battery is an environment-friendly and cost-efficient battery solution. For small robots like AKI, LiPON is a predominant choice [50]. With high energy density and long cycle life, LiPON would make it possible to satisfy our operation time and performance requirements.

3.5.2 Connectivity

Items	Working frequency band	Standard of globalization	Communication range	Communication speed	Encryption mode	Application field
UWB	3.1GHz~10.6GHz	null	>100m	>100Mb/s	THSS	Home network
Wi-Fi	2.4GHz	IEEE 802.11b	100m	11Mb/s	WPA/PSK	Connected to the network
ZigBee	2.4GHz	IEEE 802.15.4	10~20m	20K~250Kb/s	AES-128	The sensor network
Bluetooth	2.4GHz	IEEE 802.15.1	1~10m	10Mb/s	PIN code	Mobile devices

Figure 14: Comparison of short-region wireless communication technology [9]

In the design and development of AKI, the choice of wireless communication technology is crucial. Noting that AKI is more likely to move over short distances indoors, considering the distance, Zigbee and Wi-Fi are better suited to the project's needs. Comparing Zigbee and Wi-Fi, using a demo board with a Wi-Fi module may be more suitable for designing a robot for kids and achieving IoT connectivity in this project. While Zigbee offers advantages in low power consumption, cost-effectiveness, and self-organizing networks, Wi-Fi connections provide higher data transfer rates, suitable for transmitting multimedia content or other large datasets, offering more possibilities for interaction and functionality in children's robots. Therefore, for this project, opting for a development board with a Wi-Fi module may offer a more convenient and practical solution.

4 Discussion

This chapter looks into what will be conducted next semester and some risks that could appear.

4.1 Risk Analysis

In this section, we outline the risk analysis conducted for the project. Risk analysis is crucial for engineering purposes as it helps reveal potential hazards and uncertainties that could impact project success. For this project, a Failure Mode Effect Analysis (FMEA) was created to identify and evaluate potential failure modes of the robot's components. This method allowed us to prioritize risks based on their severity, likelihood of occurrence, and detectability. The greatest risk that was found was "Integration hell" and "Software bugs or glitches". To minimize these risks, extensive testing and maintaining a good time schedule is important. Please refer to the FMEA table in Appendix E for more details.

4.2 Future Work

In order to minimize the risk of procuring components, the last thing to be done before the spring semester ends is to order some critical components.

The group will start work in week 35, when the fall semester starts, and continue until the end of the year. The work will begin with the hardware implementation, starting with creating a CAD model of the new robot and implementing different hardware to AKI, such as wheels, batteries, and sensors. Also, the internal structure will be made better, and electrical routing will be done inside AKI. This will be finished by the end of September, and two weeks before then, we will begin working on the software implementation of AKI.

That will begin by implementing edge detection, obstacle detection, and emotion locomotion patterns. Then, by mid-October, the group will implement AKIs' locomotion response to edges and obstacles as well as its verbal communication function.

All of the software implementations of AKI should then be finished by the end of November, meaning the robot should be completely done by then. After that, the group will work on finishing the report, which will be written constantly throughout the semester, and the final presentation and validation of AKI (see Appendix D).

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Appendix

Appendix A: Emotions table

Emotion	Component	Estimate	SE	Wald S.	OR	Lower CL	Upper CL
Happy	Jump	2.73	1.02	7.20**	15.29	2.09	112.09
Happy	Rhythmicity	3.54	1.02	11.95***	34.64	4.64	258.47
Happy	Spread	3.15	1.01	9.63**	23.42	3.20	171.51
Happy	Free and light	2.74	1.02	7.24**	15.48	2.11	113.81
Happy	Up and rise	2.39	1.03	5.43*	10.94	1.46	81.89
Happy	Rotation	2.54	1.02	6.24*	12.68	1.73	92.98
Sad	Passive Weight	0.49	0.17	8.37**	1.64	1.17	2.28
Sad	Arms to upper body	0.18	0.17	1.08	1.19	0.85	1.68
Sad	Sink	0.90	0.18	23.92***	2.47	1.72	3.55
Sad	Head-drop	2.03	0.18	128.48***	7.60	5.35	10.79
Fear	Retreat	0.98	0.13	53.32***	2.65	2.04	3.45
Fear	Condense and enclose	−0.26	0.13	3.92*	0.77	0.60	0.99
Fear	Bind	0.03	0.13	0.04	1.03	0.79	1.33
Fear	Twist and back	1.12	0.13	69.67***	3.06	2.35	3.98
Anger	Strong	1.32	0.15	80.22***	3.74	2.80	4.99
Anger	Sudden	2.24	0.16	205.78***	9.42	6.93	12.80
Anger	Advance	1.16	0.14	66.15***	3.20	2.42	4.23
Anger	Direct	0.44	0.13	11.58***	1.56	1.21	2.02

*Each emotion is colored with a different color: happiness is yellow, sadness is blue, fear is green, and anger is red. As can be seen from the table most components significantly increased the recognition of their associated emotion, and one component significantly decreased the recognition of the associated emotion. SE, Standard error of the estimate; Wald S., Wald Statistic; OR, Odds Ratio; Lower Cl, Lower confidence interval; Upper CL, Upper confidence interval; Significance level was marked: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.*

Appendix B: Decision Matrices

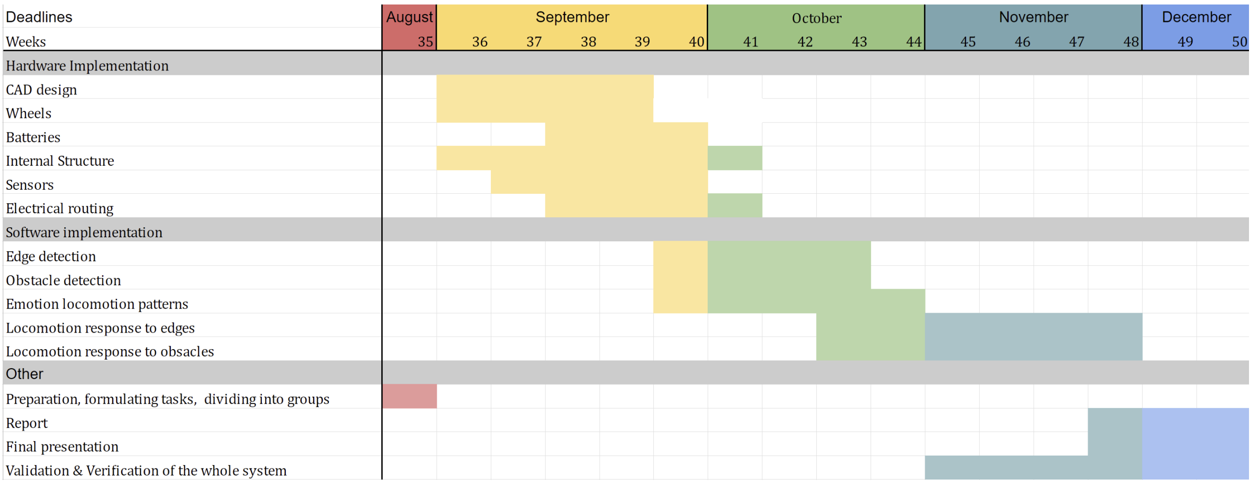
Criteria	Factor (1-5)	Omni Wheels	Mecanum Wheels	Differential Drive	Swerve Drive	Ackerman/ Tricycle	Synchro Drive	Skid Steering	Legs
Accurate maneuverability	2	3	2	3	4	5	5	5	1
Directional maneuverability	5	5	5	2	5	1	4	2	1
Easy implementation	2	4	2	5	1	5	1	4	1
Reliability	5	3	3	5	1	5	1	4	1
Required space	4	3	1	5	1	2	1	2	1
Visual appearance	2	4	1	3	5	1	5	3	5
Sum		74	54	77	54	60	51	62	28

		Edge Detection	Obstacle Detection	Both			
Criteria	**Factor (1-5)**	**Cliff Sensor**	**Lidar**	**Monocular Camera**	**IR Sensor**	**ToF**	**Stereo Camera**
Distance	4	1	5	2	3	5	5
Weight	1	5	1	4	2	4	2
Size	2	5	1	4	5	4	2
Accuracy	5	4	3	1	4	5	4
Easy Implementation	3	5	3	2	2	4	2
Visual Appearance	5	5	1	4	3	4	2
Computer Processing	1	5	5	1	5	4	2
Sum		89	58	56	77	97	66

Appendix C: Technical Requirements

Demands (D) / Wishes (W)	Type	Description
Locomotion		
At least 2 DOF	D	The locomotion shall allow forward and backwards, aswell as rotation along z-axis
Maximum wheelsize 7 cm in diameter	D	To keep current apperance
Speed of minimum of 40-100 cm/s	D	
Rotational speed of minimum 120-240 degrees/s	D	
The robot shall be able to stop from full speed in less than 5 cm	D	
The robot should move to a specific area	W	
The robot shall have one type of locomotion pattern per emotion	D	
Reliability		
The thermal equilibrium of the components in the robot shall not exceed 80 % of their maximum temperature	D	
The outside of the robot shall not exceed 10 degrees above room mean temperature	W	
The arms and head of the robot shall not excert a contact/collision forces above 1 N	D	For safety reason
The robot shall have error reporting features	D	
A manual and a wireless off switch (E-Stop)	D	For safety reason
The robot should be able to be disassembled in less than 60 minutes	W	
The noice level shall not exceed 55 dB(A) one meter from the robot	D	
Wirelessness		
The robot shall have a minimum operating time of 1/2 hour during average operation in a single charge	D	
Charging 0 - 80 % will take less than 40 minutes	W	
The robot should be able to fetch and send data at a minimum 200 samples/s	W	
Obstacle detection		
The robot shall be able to detect an obstacle less than 50cm in front of it	D	
The robot shall be able to detect an edge less than 20cm in front and behind of it	D	
The robot shall be able to detect an obstacle less than 50cm behind it	W	
The robot shall be able to detect an edge less than 20cm behind it	D	
The robot should swivel around an obstacle	W	
The robot shall avoid collision and falling off an edge	D	
The robot should drive away from an edge	D	
Communication		
The robot should be able to respond to movement by user, by moving or speaking	D	
The robot should be able to react to voices by moving	W	
The robot should be able to react to voices by speaking back	W	
The robot should use child friendly language	W	
The robot should not store any personal data after it has been turned off	D	
The robot should have a audio/visual response time of less than 2 seconds	W	
Dimensions		
The addeed weight shall not exceed more than 50% of current weight	W	
The design of proportions of AKI shall not be changed	D	
The center of mass shall be as closed to the bottom as possible	D	
The dimensions of the robot shall not be changed without consultation from stakeholder	D	

Appendix D: Project plan



Appendix E: Failure Mode Effects Analysis

Failure Mode	Effect	Severity (1-10)	Cause	Occurrence (1-10)	RPN	Recommended Action
Wheel mechanism failure	Robot becomes immobile	5	Weak motors, Bad implementation,	6	30	Use higher quality components. Review the implementation
Battery failure	Unexpected shutdown	2	Weak battery, loose cables, battery degradation	7	14	Implement battery redundancy
Wireless communication loss	Loss of control	1	Signal interference	10	10	Use more reliable modules
Obstacle sensor failure	Obstacle sensor failure	10	Sensor malfunction	2	20	Add backup sensors, improve algorithms
Mechanical wear and tear	Performance degradation	7	Lack of lubrication, loose cables material fatigue	6	42	Add more lubrication, Reduce friction
Sensor Malfunction	Inaccurate data	10	Calibration errors, current sensor (cut off fingers) physical damage	1	10	Improve sensor calibration, implement redundant sensors
Environmental Hazards	Component damage	7	exposure to warm temperatures, moisture	1	7	Implement environmental sealing, relocate sensitive components
Software Bugs or Glitches	Unexpected behaviour	7	Programming errors, inadequate testing	8	56	Improve software testing procedures
Integration Hell	Unexpected behaviour	7	System is not collaborating	10	70	Time consuming troubleshooting
Group problem	Disagreements, miscommunication scheduling	4	Complex development process	3	12	Code of conduct, regular meetings
Failure to procure components	The project gets delayed	5	Delay in manufacturing and shipping	3	15	Find other similar components, wait and work on other things