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On the Design and Development of a Tabletop Robot for Interaction with Children

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Abstract— **This article presents a novel emotionally expressive robot platform targeting social engagement with children. This platform was implemented in accordance with UNICEF's policy guidance on artificial intelligence (AI) for children, focusing on factors such as safety, transparency, reliability and explainability. The robot prototype is presented from a design and development perspective, outlining all utilized electromechanical components that enable its 11 degrees-of-freedom and sensing functions. Preliminary evaluation results are provided in terms of dependability and expressiveness of basic emotions, thus demonstrating the robot's potential to facilitate trustworthy and secure interactions with children.**

I. INTRODUCTION

Robots are becoming increasingly sophisticated and integrated into human life, not only as industrial robots but also as social companion robots. Nowadays, Artificial Intelligence (AI) facilitates the design of intelligent machines and robots with interfaces that provide two-way interaction with humans, which has led to the investigation of robots' social capabilities. Social robots lack a precise definition, but in addition to their interactivity, they share the ability to replicate and communicate emotions [1]. Such robots have grown in popularity over the past decade, a tendency that accelerated during the Covid-19 pandemic [2].

Social robots have proven useful in a variety of contexts [3]. They have been able to assist in various societal roles, ranging from security, transportation [4], customer service, healthcare [5], to education and entertainment for children [6], [7]. The integrated AI technology contributes not only to the simplification of decisions and diagnostics, but also to the improvement of mental health. In addition, research has demonstrated a positive impact in the field of education, as there have been investigations on the possibilities of utilizing these robots as a help for autistic children [8] or as a support tool for teachers in the classroom [9].

For this transition to a robot-assisted society to be successful, robots must be made to be trustworthy. When discussing users, all prospective stakeholders must be taken into account but children are the most vulnerable population. UNICEF sought to investigate how AI can protect, provide for, and empower children. Its resulting policy guidelines [10] assessed the effects of AI systems on children and provide industries and governments with actionable suggestions.

This work aims at implementing a novel emotionally expressive robot platform for social interaction with children. The presented prototype was designed, developed and preliminarily evaluated in compliance with UNICEF's policy guidance on AI for children, focusing on the requirements for "prioritization of fairness and non-discrimination for children" and "provision of transparency, explainability, and accountability for children" [10].

Through an iterative design process, the goal was to create a tabletop robot that, through nonverbal communication, would be able to express the six basic emotions: happiness, sadness, surprise, fear, anger, and disgust [11], [12], [13]. Emphasis was given on the factors of safety, transparency, reliability and explainability, for producing a design output with the potential for enabling a trustworthy and secure interaction. In addition and as the Uncanny Valley theory [14] suggests, this work sought to strike a balance between human-inspired traits that make the robot friendly and expressive, and those that could potentially scare children, prevent meaningful interaction, or create overexpectations.

The selected concept follows an egg-shaped design approach for promoting interaction safety and simplicity, with expandable structure revealing a total of 11 Degrees of Freedom (DoF), in the form of a head, two arms and a rotating base, all actuated via motors. Various sensors including thermal and optical cameras, joint position and temperature sensors etc., as well as interfaces including screens, LED lighting, speakers etc. are incorporated inside the robot structure to enable its localization, perception, and expression capabilities. The developed prototype is evaluated in terms of structural dependability and expressiveness of basic emotions through non-verbal communication, demonstrating its potential to facilitate trustworthy and secure interactions with children.

The rest of the article is structured as follows. Section II provides information on the design process from the initial concept to the mechanical design of the robot's subsystems. Section III presents the developed robot prototype and all its structural and electromechanical components. Section IV provides the preliminary evaluation results of the robot's capability for emotion expressiveness and durability during operation. Finally, conclusions are drawn in Section V.

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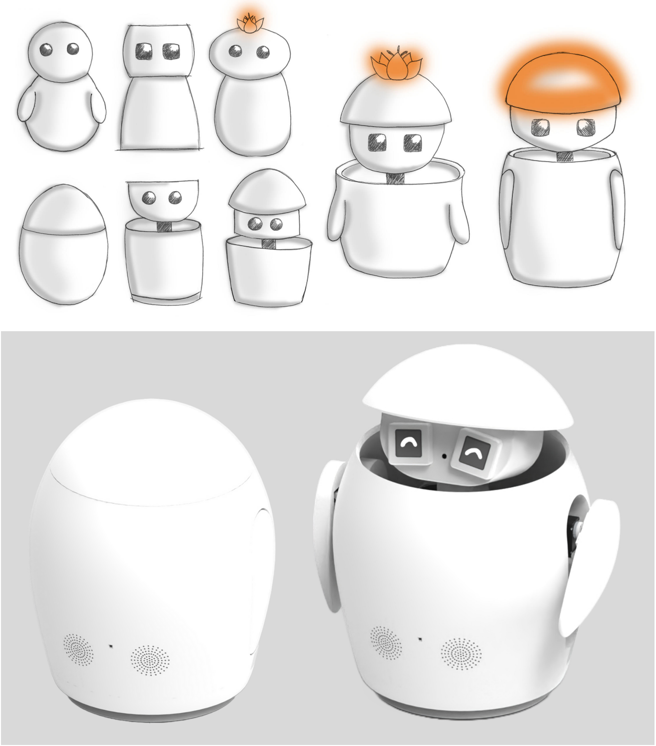


Fig. 1. Conceptual design process (top) and renders of the final robot concept during idle (bottom-left), and activated (bottom-right) state.

II. DESIGN SPECIFICS

A. General Concept

The conceptual design process followed UNICEF's policy guidance on AI for children and emphasis was given on four factors for producing a design output with the potential for enabling a trustworthy and secure interaction:

- Safety– In terms of both physical and non-physical.
- Transparency– Addressing user questions like: ”When am I recorded?”, ”Is any of my data stored?”, ”Is the robot connected to the internet?”.
- Reliability– Ability to operate for several hours without failure.
- Explainability– Addressing user questions like: ”What can the robot do?”, ”Why did a robot act the way it did?”.

Based on the related literature, potential designs of the robot were explored. This was an iterative process where previous research findings, sketches and mock-up 3D-models were made in parallel succession (Fig. 1 (top)). From the accumulated concepts, an egg-inspired design was formulated as the most fitting for use with children.

The egg concept was based on the notion that, in its closed state, the robot would resemble an egg (Fig. 1(left)). In this state, the robot would plainly indicate that it is not in use, thereby satisfying the criteria to provide the user with transparency. This shape would trigger the excitement and curiosity about what's inside and how a user will be able to interact with the robot. In addition, it is a robust design with no sharp edges, which protects both the child and the robot during use and promotes safe operation.

When interacted with, it opens up with the arms extending out and the head popping up. The robot is then able to track a person in its environment and express different basic emotions. When active and in this ”open” state (Fig. 1(right)) the robot's head, arms and base are able to perform the following motions: a) Head extension/contraction, b) Head tilt forward/backward, c) Arm extension/retraction, d) Arm rotation inside/out, e) Arm rotation forward/backward, f) Eye rotation, and g) Base rotation. Using these motions the robot could express emotive patterns, while other capabilities would include graphics or colours on the eyes, which would further improve the capabilities of this concept, with sound also being explored in addition to the movement. Using compliant actuation to safeguard the child in the event that the robot closes while the child's fingers are near the robot's moving segments is a further method of enhancing operation safety.

B. Robot Design

Following the egg concept, the mechanical design of the robot was divided into four subsystems; the base, the neck, the arms and the head. For the robot to work as described, it incorporates 11 DoF as shown in Fig. 2, which enables it to express emotions through both body language and facial expressions based upon findings from the state of the art.

Required torque calculations were done on critical moving parts such as the neck lifting mechanism. Based on the calculations, space limitations and the desired visual design, a 3D-model of each subsystem was developed in CAD software. In this subsection, the mechanical implementation of each subsystem is presented. In addition to the subsystems, a shell was made to fit all the mechanical and electrical components and to provide the desired egg-inspired appearance.

1) Base: To enable the robot's body to rotate, an internal gear was installed in the robot's base (Fig. 3), along with a tapered roller bearing for low-friction motion. To prevent this mechanism from disassembling when the robot is lifted, a locking plate was added in its center to secure the base. A hole through the center of the base and bearing was then designed for routing power cables to the electrical components that are to be installed within the body.

2) Neck: The process of designing the robot neck started from the setting the requirements of the neck extension actuator. With space being limited inside the robot, the neck sub-assembly motor was required to i) lift the head weight, estimated to be 1kg, ii) have force sensing capability to detect potential collision with the user and enable emergency stop functionality, iii) produce a linear travel, and iv) have sufficient vertical space available underneath the head when the robot is closed.

To satisfy these requirements, a rack and pinion mechanism was chosen for easier back-driveability, which is deemed safer in a unintentional obstruction scenario, and also due to smaller space coverage relative to other solutions e.g. lead-screw design. In the final design seen in Fig. 4, a

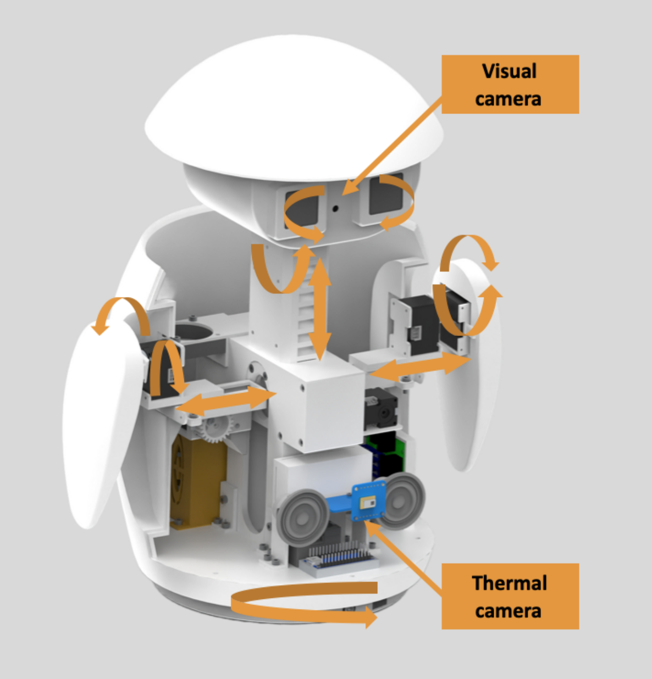


Fig. 2. Visual representation of the robot's internal structure and components. Highlighted are the 11 DoFs of its arms, head and base, as well as the visual and thermal cameras enabling perception of the robot's environment.

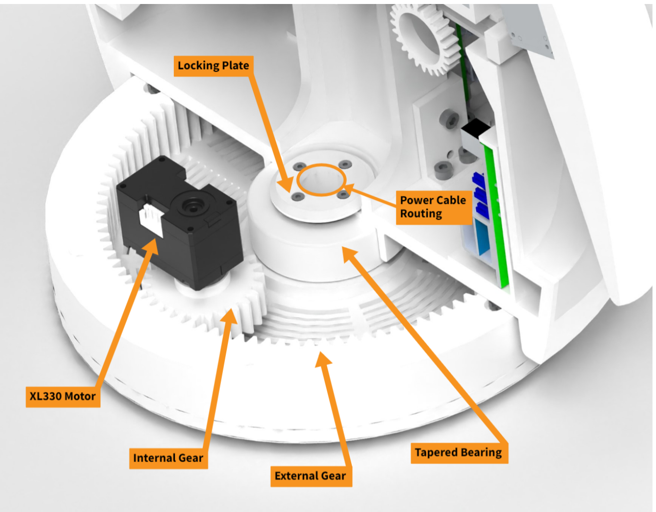


Fig. 3. Component details of the base rotation mechanism.

servomotor is used to drive the neck extension. Torque is transferred through a module three pinion, with a passive pinion and rack supporting the neck on the opposite side of the slider. The free ends of the gear axles (all ends except the one mounted to the motor) are mounted in bearings to reduce friction and noise. For the chosen gearing, the selected motor should be capable of generating 20N of dynamic lifting force.

Lastly, to allow cable routing to the head, the neck was designed hollow with cable access from both sides and downwards. At the top of the neck, the motor enabling head nodding motions is also mounted with its' wires routed down through the neck.

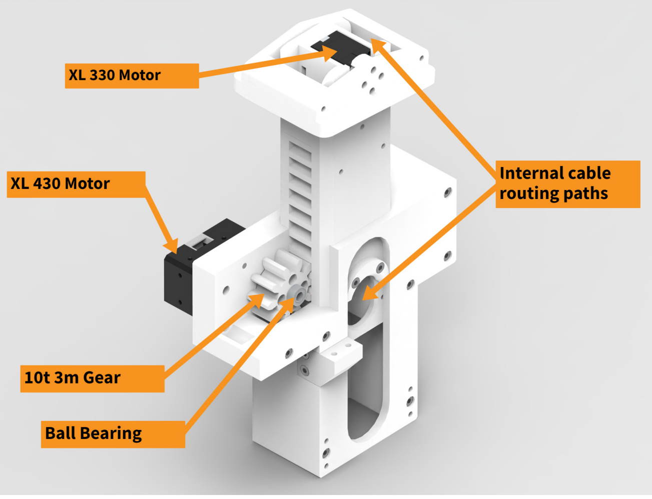


Fig. 4. Overview of the neck mechanism, with a partial section view showing the internal gear enabling the neck's extension.

3) Head: From the relevant State of the art (SOTA), it becomes clear that the eyes play a major part in expressing emotions [15]. It is therefore important for the robot to be able to express the six basic emotions (happiness, sadness, surprise, fear, anger, disgust) with help of eyes that are mounted on the head. To achieve this, a quadratic shape for two cases was chosen, to easier enhance the different states of the eyes. Small displays were incorporated inside the cases, each of them connected to a motor that was placed on the inside of the head, see Fig. 5, whose function is to rotate the case to the desired position connected to a specific emotion. Small-sized servomotors were selected for this motion, due to the small load. The head also contains a camera that is used for user tracking, which is placed between the eyes. The placement of the camera was done so that it provides transparency and safety for the user: when the robot is closed it is also made clear to the user that they are not being recorded.

The head was divided into two components, allowing the hat to be detached from the head for quicker assembly and upgradeability through the use of interchangeable hat designs. A force-sensitive resistor was placed inside the head, while the hat has a pillar structure leading to the force-sensitive resistor (see Fig. 5), which is related to the robot's waking up action. When the robot is closed and someone presses down on the hat, the force sensitive resistor senses the user action and the robot turns itself on. Colours could also be used to enhance the emotion [16], [17], [18], therefore a Light Emitting Diode (LED)-ring was designed and placed inside the head hat-like structure. The LED-ring would light up in different colours depending on the emotion the robot expresses.

4) Arms: The mechanical design of the arm can be seen in Fig. 6. The shoulder-like mechanism consists of three servomotors giving the arms three DoF. The motor highlighted in Fig. 6 as '1' pushes the arm out of the body with help of a rack and pinion mechanism. Motor '2' enables a 360 degrees flexion-extension of the arm, while motor '3'

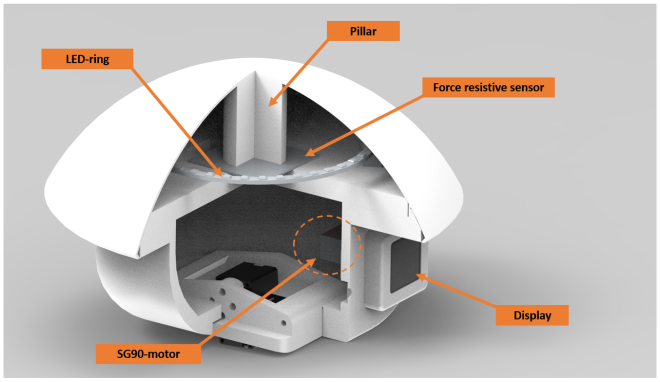


Fig. 5. Section-view of the robot head with internal structure details.

Fig. 6. An overview of the 3 DoF arm mechanism, with highlighted motors and resulting motions.

enables the arm's abduction-adduction motions.

5) Shell: The body shell was designed to realize the egg-shaped exterior of the robot, which brings intended functionality as it protects all the internal electromechanical components and also reduces the sound level of the robot. The base is mounted from the bottom side of the body shell, while the arms are mounted from the top (Fig. 2). Additional mountings were designed for attaching all sensors and interfaces, such as the speakers mounted at the front side of the robot and a thermal camera mounted between the two speakers.

III. PROTOTYPE DEVELOPMENT

For developing the robot prototype, all structural parts were realized using Fused Filament Fabrication (FDM) 3D-printing with PLA materials. The robot's electromechanical components selected for the prototype version are displayed in Fig. 7, while the developed prototype is shown in Fig. 8 during its idle and activated state. The prototype's base diameter is 20 cm, with its height ranging from 28 cm when idle to 35 cm when activated with the head extended to its maximal height.

Hardware-wise, a Teensy 4.0 microcontroller is used to control the LED-ring with the colours, the motion and graphics of the two LCD screens, as well as the pressure sensor (force sensitive resistor) used to activate the robot. Furthermore, an Arduino Nano is used to control the two speakers and the thermal camera located in the body (see Fig. 2). The robot's hands and base movements are controlled by eight XL330 Dynamixel servo motors and one XL430 is used to drive the neck extension mechanism, all of which are controlled via a U2D2 motor board (Fig. 7). The ability to receive current, voltage, position, and temperature feedback signals from each motor, reduces the complexity of the system due to the smaller amount of external sensors needed for monitoring the robot's operating condition. In parallel, current feedback enables safety features for identifying mechanical failures and enable fast reactions during unintentional contact with the user or obstruction. Finally, SG90 servomotors were selected for the screen movements, which play the role of eyebrows.

These components, along with the camera in the head, are connected to a single board computer (UP Core), which controls the different subsystems. All subsystems are communi-

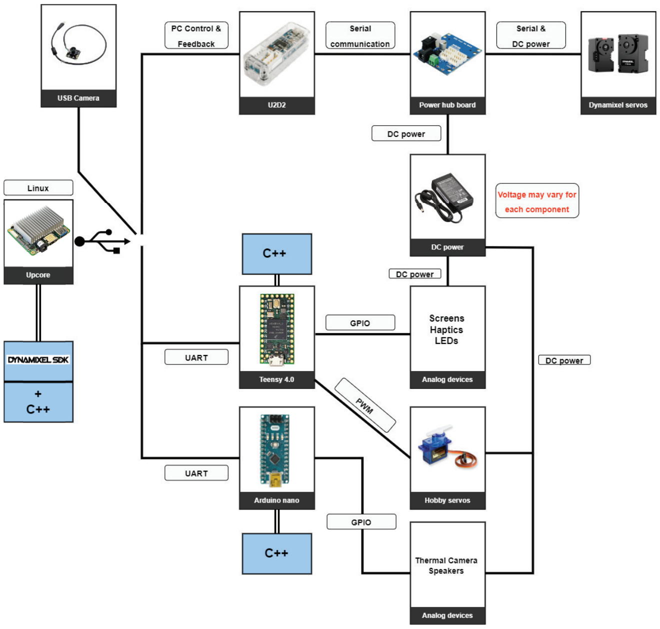


Fig. 7. Software and hardware component diagram for the robot prototype

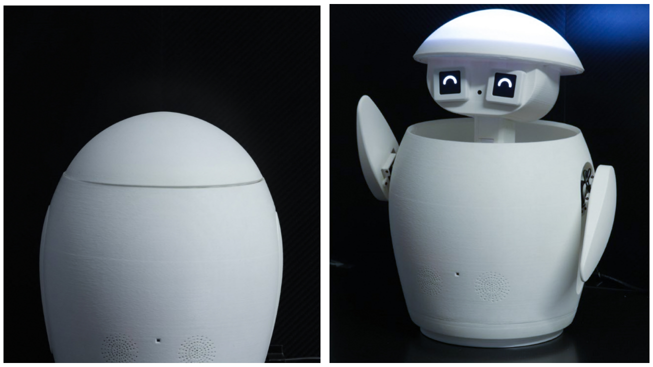


Fig. 8. The prototype robot platform in its (left) closed and (right) activated state.

cating with the UP Core through serial communication using Universal Serial Bus (USB) protocol, except the Dynamixel servos using Transistor-Transistor Logic (TTL) protocol. In addition to the parts mentioned above, there are also two fans, a stereo amplifier for the speakers, boost converters and bi-directional logic level converters for handling the different voltage levels used to power all electronics. As previously mentioned, the system incorporates additional components for sensing and interacting, including a vision and a thermal camera connected to the UP Core and an Arduino Nano, respectively, as well as the LED ring placed inside the robot head and connected to the Teensy board (Fig. 7).

The software for the robot is written in C++ and utilizes many different libraries and packages to fulfill different functions. The software is distributed and running on the three microcontroller boards (UP Core, Teensy 4.0, Arduino Nano) to coordinate different tasks and achieve overall robot function (Fig. 7). Vital for robot functionality is the communication between the main processor (UP Core) and its slave micro-controllers. For the needs of this work a custom serial protocol was implemented, which sends packets of data along with a tag signaling the type of message.

The mechanical constraints in terms of motion range create the need for software-limits applied on the motors' angles. Such limits were therefore implemented for each motor in order to avoid failures and damages during operation. The selected keyframes for showing the six basic emotions contain information to control all motors, the LED-ring and commands to control the screens. For the LED-ring, a predefined colour is set based on the emotion, while for the screens, different images were designed and are shown, depending on the keyframe.

To enable the robot's ability to track a person in its surroundings, the computer vision library Open Source Computer Vision Library (OpenCV) was used, while face detection using Haar feature-based cascade classifiers was implemented for the prototype evaluation [19]. Finally, for the robot prototype evaluation, a simplified version of a Finite-state machine (FSM) was implemented. All emotions were generalised into the ”Playing emotion” state. Other states included: Closed and Awake (idle). This provided a framework for the FSM targeting future implementations.

IV. RESULTS

The results related to the developed robot prototype's ability to express the six basic emotions (happiness, sadness, surprise, fear, anger, and disgust) can be viewed in Fig. 9. It has to be noted that the figure displays static representations of the emotions and specifically their respective end-pose, taken as a snapshot during execution of the predefined motion patterns. As it can be seen in the same figure, some of the LED colors were chosen differently from related literature to better match the robot's properties. For example, the grey of fear was changed to purple due to the practical challenge of displaying grey light. As a result of this, blue was chosen for sadness instead of purple. Finally, disgust was changed from brown to green to create a greater distinction between this and the three emotions already in the red-orange-yellow hue family. Body language, facial expressions and graphics were modeled after the findings in the SOTA.

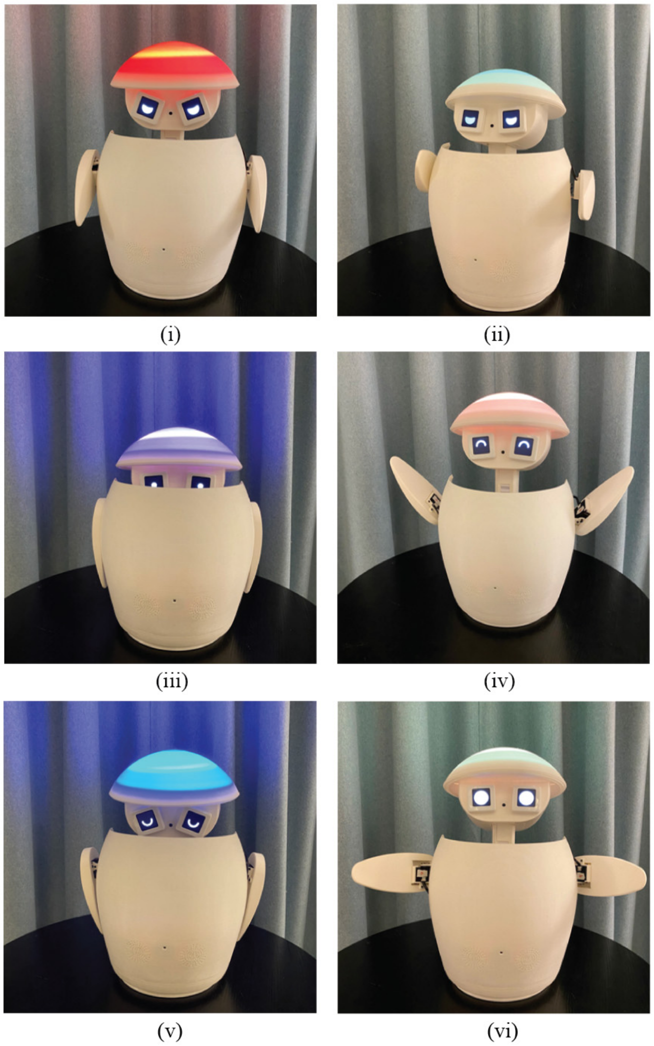
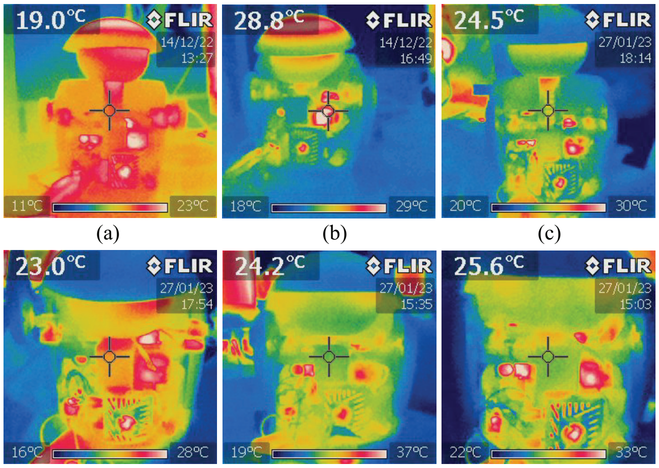

(i) (ii) (iii) (iv) (v) (vi)

Fig. 9. Snapshots taken while the robot prototype displays the six basic emotions: (i) Anger, (ii) Disgust, (iii) Fear, (iv) Happiness, (v) Sadness and (vi) Surprise.

To test long-term reliability, motion loops were created in which the robot would wake up from the closed state, perform pre-programmed motion patterns and utilize all motors, the eye displays and the head LED color. These motion loops were then executed non-stop for several hours, starting operation at room temperature and until thermal saturation was reached. In the presented results recorded via a FLIR thermal camera (Fig. 10(a),(b)), the robot component's external temperature was measured at the beginning and after 4.5 hours of continuous operation.

The goal for later tests was to have the robot perform periodic motions of each DOF to get a result showing all motor temperatures stabilizing at some steady state. Indicative thermal images taken at the end of these tests are shown in Fig. 10(c)–(f). From the acquired results, all components' temperatures stayed beneath permissible levels that ensure unaffected operation, as well as safety if they



(a) (b) (c)

(d) (e) (f)

Fig. 10. Indicative thermal images taken during the robot's operation at the (a) beginning and (b) after 4.5 hours of continuous operation operating all DOFs simultaneously, accompanied by images taken until thermal stabilization of specific DOFs: (c) neck extension, (d) arm roll, (e) base rotation and (f) both head pitch and arm flexion-extension.

were to come in contact with the user. Among the hottest components identified during these tests, was the motor handling the neck extension, whose case temperature was stabilized at 41 degrees Celsius. For all performed tests, no motion deterioration and no structural damages were identified during the tests.

For assessing the prototype's noise levels during operation, additional tests were performed, where the robot executed pre-programmed motion patterns and the sound levels were measured via a microphone placed at the same height as the robot and at one meter distance. The first test involved the execution of the six basic emotions, while the second test was performed during the execution of the robot's full range of motions. All recorded levels fell under "quiet" and "normal conversation" in Centers for Disease Control (CDC) noise meter charts [20], ranging between 37 dBA and 57 dBA.

V. CONCLUSIONS

This work aimed at implementing a novel emotionally expressive robot platform for social interaction with children. The presented prototype was designed, developed and preliminarily evaluated in compliance with UNICEF's policy guidance on AI for children [10], focusing on the requirements for "prioritization of fairness and non-discrimination for children" and "provision of transparency, explainability, and accountability for children". Emphasis was given on the factors of safety, transparency, reliability and explainability, for producing a design output with the potential for enabling a trustworthy and secure interaction. Through an iterative design process, an egg-shaped design approach was selected, with expandable structure revealing a total of 11 Degrees of Freedom (DoF) in its head, arms and base. The robot is equipped with various sensors and interfaces for enabling its localization and perception, as well as supporting different communication strategies. The developed prototype was successfully evaluated in terms of structural dependability and expressiveness of the six basic emotions (happiness, sadness, surprise, fear, anger, and disgust) through non-verbal communication, thus showcasing its potential to facilitate trustworthy and safe interactions with children.

REFERENCES

[1] F. Hegel, C. Muhl, B. Wrede, M. Hielscher-Fastabend, and G. Sagerer, "Understanding social robots," in *2009 Second International Conferences on Advances in Computer-Human Interactions*, no. 169-171, 2009, pp. 169–174.

[2] L. Aymerich-Franch and I. Ferrer, "The implementation of social robots during the COVID-19 pandemic," *CoRR*, vol. abs/2007.03941, 2020. [Online]. Available: https://arxiv.org/abs/2007.03941

[3] G. A. Zachiotis, G. Andrikopoulos, R. Gornez, K. Nakamura, and G. Nikolakopoulos, "A survey on the application trends of home service robotics," in *2018 IEEE International Conference on Robotics and Biomimetics (ROBIO)*, 2018, pp. 1999–2006.

[4] Furhat. Furhat robotics. [Online]. Available: https://furhatrobotics.com/

[5] S. Robotics. Pepper. [Online]. Available: https://www.softbankrobotics.com/emea/en/pepper

[6] Sony. Pepper. [Online]. Available: https://us.aibo.com/

[7] R. Consumer. "haru: An experimental social robot from honda research". [Online]. Available: http://robotconsumer.com/haru-an-experimental-social-robot-from-honda-research/2/

[8] L. Dickstein-Fischer and G. S. Fischer, "Combining psychological and engineering approaches to utilizing social robots with children with autism," in *2014 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, 2014, pp. 792–795.

[9] J. R. C. Honda Research Institute, Japan / European Commission. (2021. [Online], Oct) "case study about hri-jp's social robot haru". [Online]. Available: https://www.honda-ri.de/case-study-about-hri-jps-social-robot-haru/

[10] K. P. Virginia Dignum, Melanie Penagos and S. Vosloo. (2021. [Online], Nov) "policy guidance on ai for children". [Online]. Available: https://www.unicef.org/globalinsight/reports/policy-guidance-ai-children

[11] P. Ekman, "An argument for basic emotions," *Cognition & Emotion*, vol. 6, pp. 169–200, 1992.

[12] L. Martinez, V. B. Falvello, H. Aviezer, and A. Todorov, "Contributions of facial expressions and body language to the rapid perception of dynamic emotions," *Tanfondline*, vol. 30, no. 5, pp. 939–952, 2016.

[13] N. Dael, M. Mortillaro, and S. R. Klaus, "Emotion expression in body action and posture," *Emotion*, vol. 12, no. 5, pp. 1085–1101, 2012.

[14] M. Mori, K. F. MacDorman, and N. Kageki, "The uncanny valley [from the field]," *IEEE Robotics Automation Magazine*, vol. 19, no. 2, pp. 98–100, 2012.

[15] Jordan Lansley. "facial expressions". [Online]. Available: https://www.eiagroup.com/knowledge/facial-expressions/

[16] A. V. Fisher, K. E. Godwin, and H. Seltman, "Visual environment, attention allocation, and learning in young children: When too much of a good thing may be bad," *Psychological science*, vol. 25, no. 7, pp. 1362–1370, 2014.

[17] D. Löffler, N. Schmidt, and R. Tscharn, "Multimodal expression of artificial emotion in social robots using color, motion and sound," in *2018 13th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*. IEEE, 2018, pp. 334–343.

[18] D. Jonauskaite, J. Wicker, C. Mohr, N. Dael, J. Havelka, M. Papadatou-Pastou, M. Zhang, and D. Oberfeld, "A machine learning approach to quantify the specificity of colour–emotion associations and their cultural differences," *Royal Society open science*, vol. 6, no. 9, p. 190741, 2019.

[19] P. Viola and M. Jones, "Rapid object detection using a boosted cascade of simple features," *Comput. Vis. Pattern Recog*, vol. 1, 01 2001.

[20] CDC. Noise and hearing loss prevention. [Online]. Available: https://www.cdc.gov/niosh/topics/noise/noisemeter_html/old/hp60.html