ISR-RobotHead: Robotic Head with LCD-based Emotional Expressiveness

Ricardo Loureiro[1], André Lopes[1], Carlos Carona[2], Daniel Almeida[1], Fernanda Faria[1], Luís Garrote[1], Cristiano Premebida[1] and Urbano J. Nunes[1]

***Abstract*—Worldwide, several research works have been devoted to the development of humanoid robots for human-robot interaction (HRI). Particular attention has been paid to the concept, design and applications of robotic heads and facial-expressions. Together, head and its facial expressions, they compose a fundamental, and "familiar", interface to end-users; which is particularly true in child-robot interaction (CRI). This paper contributes with a functional prototype of a robotic head using LCDs for eyes-eyebrows and mouth animations. The prototype also incorporates vision cameras, microphones, speakers and pan and tilt control on the vertical and horizontal axis. Experiments and validation of the robotic head were carried out at the Cerebral Palsy Association of Coimbra with children (6 – 10 years old). Preliminary observations show that the proposed robotic head, motivated mainly as an interface for children, can accurately convey some of the most basic emotions, whose were recognised by children. The study carried out helped to identify issues for future developments, such as specific or complex emotional states that need to be refined.**

I. Introduction

HRI has grown at a very high rate, with applications in industrial and social environments across the globe. Much of the research in the field of HRI is devoted in designing robots as assistants, companions, or pets, in addition to the more traditional role of servants, with interactive features to augment its functionality and interest in the end-user's perspective [1]. Accordingly, in order for the human-robot interaction to be as natural as possible, the robot's head should act as a "familiar" interface by employing human-like social cues and communication modalities, by means of facial expressions, sounds, movements and artificial intelligence [2].

In this paper, we present a robot head solution, the ISR-RobotHead, whose purpose is to serve as a research platform in the area of CRI.

The effectiveness of multimodal CRI significantly depends on the robots ability to perform meaningful social interactions, which in turn requires accurate emotional expression and detection [3]. Therefore, this exploratory study was aimed at validating the robot head ability to convey six basic emotional states to children with special healthcare needs, thus attesting the robot's capability of expressing human emotions.

[1] Authors are with Institute of Systems and Robotics, Electrical and Computer Engineering Department, University of Coimbra, Coimbra, Portugal.

[2] Author is with Cerebral Palsy Association of Coimbra; Cognitive and Behavioral Center for Research and Intervention-University of Coimbra, Coimbra, Portugal.

This work has been supported by FCT under projects AMS-HMI2012-RECI/EEIAUT/0181/2012 and UID/EEA/00048/2013, with FEDER funding, programs QREN and COMPETE. Luís Garrote is also supported by FCT Grant SFRH/BD/88459/2012.

Email: rgloureiro1121@gmail.com, ccarona@fpce.uc.pt, {cpremebida, garrote,fernanda, urbano}@isr.uc.pt

A. Related work

This work falls within the field of social robotics, or social-interactive robots, a multidisciplinary research area involving sensory perception, psychology, bio-inspired systems, bioengineering, mechatronics, artificial intelligent, and so on. In terms of applications, we can highlight the use of social-robots as guiders, teachers or therapeutic facilitators. In such cases, the robot receives inputs (such as gesture and speech recognition) and present feedback by means of an user-friendly interface that a person can understand and interact with the robot: this is possible by employing emotional/facial expressions that a person can easily interpret and then a clear human-robot communication and interaction. Regarding the potential solutions to be used in a robotic head to transmit an emotional feedback to the end-user, the most common are: LED interactive, kinematic, animatronic and LCD-based robotic heads. LCD interactive robotic heads, like the one presented in this paper, represent faces mostly in tablet like screens and can achieve a wide variety of human expressions [1].

1) Robotic Heads: All the robotic head solutions have the common objective of capturing a person's attention by giving the robotic system the required social complexities that are characteristic of human social behaviour. This serves to enhance human interaction with the robot, which demonstrates to be crucial in the execution of tasks such as a house servant or a healthcare giver [2].

Despite its simplicity, LED-based robotic heads are capable of displaying a wide range of colours and are very cost-effective. This category has advantages and disadvantages regarding expressiveness [4], but the provided features are enough to keep the human attention. Kinematic heads are animatronic heads developed to provide a more appealing communication with humans. These solutions are equipped with mechanical actuators to create eye and mouth movements in a more natural way than LEDs but, conversely, they have more technical complexity. Robot heads most close to imitate human-like characteristics are animatronic robot heads with artificial and flexible skin. Similarly to the kinematic ones, these robot heads recreate human expressions through the use of mechanical actuators. However, these solutions may be uncomfortable to interact with, because of the attempt to look too human for an artificial system [5].

2) Applications: Children with autism tend to exhibit difficulty in interacting with other humans. With this in mind, researchers have been conducting HRI experiments involving children with autism; the results obtained suggest that these children develop some social skills with the increase exposure to such interactive robots [6].

Another application worthy of mention was an experiment where the researchers have used a robot to give a science class to children [7]. The research suggested that the use of robots can engage students in active learning, keep attention to subject and attract interest in the lesson.

Overall, research works in CRI still require further development and experimentation to validate robots effectiveness in children development.

B. Emotion Expressions

For a robotic head, it is not enough to just display emotional expressions like a human being, but also to provide interaction skills with the observer in an appealing way, so persons can feel empathy with the robotic head. In an experiment performed by Bruce *et al.* [8], a robot tries to engage persons to answer a set of questions, by tracking them, and then responding with emotional expressions regarding the persons' willingness or unwillingness during the interaction with the robot. The results suggest that, between the facial expressions and the person's tracking by the robot, persons' interest towards the robot is the same. However, by combining both features the persons were more willing to stop and interact with the robot, which enforces the idea that emotional expressiveness in a robot is important to enhance the experience in HRI.

Still in the field of emotional expressions, Paul Ekman [9] tried to identify if persons from different cultures and backgrounds were able to identify a set of human emotional expressions and, additionally if each expression was characterized by the same emotion regarding each person's interpretation. Pictures of persons performing emotions such as happiness, sadness, surprise, fear, disgust and anger were shown to each subject that participated in this experiment, and results confirm the hypothesis that each of these six basic expressions can be identified by different persons from different cultures and backgrounds. These expressions were also implemented in some robotic faces to convey emotions in HRI settings [10], [11]. These emotional expressions were also implemented in the ISR-RobotHead for experimental evaluation.

II. The Robotic Head System

The ISR-RobotHead falls into the LCD based category of robotic heads since it represents expressions through the use of LCD screens. This robotic head also has multiple peripherals to enhance the HRI experience, which are: an output sound system, two cameras for vision applications, a pan and tilt orientation system and three LCDs to represent facial expressions, two for the eyes and one for the mouth. All the aforementioned peripherals (sensors and actuators) are connected to a central control module composed by a Raspberry-Pi with serial and wifi communication.

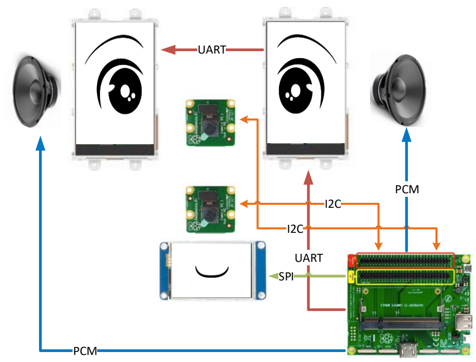

Fig. 1. ISR-RobotHead hardware overview.

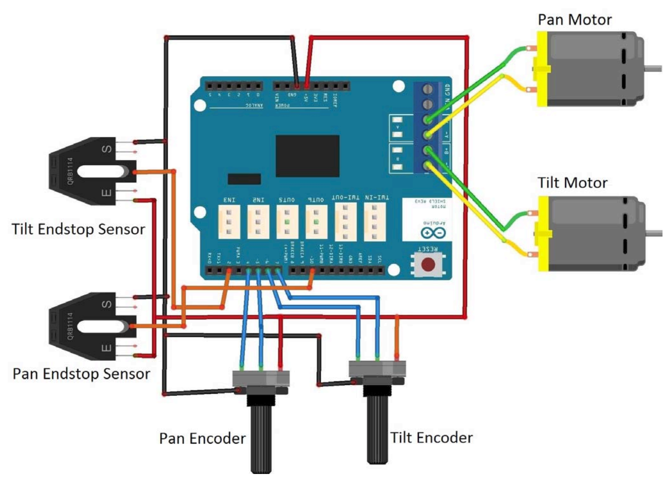

Fig. 2. ISR-RobotHead pan-tilt hardware system.

A. Hardware

The hardware architecture consists in a central acquisition and control module (as illustrated in Fig. 1), based on a Raspberry-Pi, connected to each peripheral. The additional hardware components can be divided in four modules: vision cameras; sound system; pan and tilt; eyes and mouth LCDs.

1) Raspberry Pi control module: All tasks related to communication, control and sensor interfacing are carried out by a Raspberry Pi Compute Module (RPiCM). The RPiCM is a small and cost effective computer that operates with a Debian based Linux operating system and has multiple General Purpose Input/Output (GPIO) ports available for interaction with external devices and sensors (by default it supports UART, SPI and I2C). The RPiCM operates at a speed of 700 MHz and has 4 GB of flash storage, two micro-USB ports (for power and communication), two Camera Serial Interfaces (CSI) and two Display Serial Interfaces (DSI).

2) Stereo cameras: The RPiCM has the capacity to support stereo vision since it has two CSI ports. We adopted 2 standard

Raspberry Pi camera modules that can be used to take high-definition frames. Each camera is connected to a CSI port on the RPiCM.

3) Sound system: The sound output system is composed by two modules. two modules, an audio HiFIberry DAC+Lite module and a sound amplifier. The HiFIberry has three output pinouts, left and right audio channels and ground. These channels are wired to the audio amplifier to the corresponding inputs which then outputs to the left and right speakers.

4) Pan-tilt system: The pan-tilt mechanism was build to allow the ISR-RobotHead's orientation vertically and horizontally. The mechanism uses two 6 V brushed DC motors with a 297.92:1 metal gearbox, which are coupled to quadrature magnetic encoders, to acquire the motors shaft position. Each encoder adds a reduction ratio of 12:1 to the motor rotation. The pan motor is coupled at the base of the mechanism and rotates the upper plate, where the tilt mechanism is assembled. The tilt mechanism is composed by two different worm teeth wheels hence when the motor rotates clockwise, the tilt's platform moves forward and when the motor rotates counter-clockwise, the platform moves backward. To control the motors coupled to the pan and tilt, an Arduino Duemilanove microcontroller (connected to the RPiCM), with a Motor Shield, was employed to drive the two motors (see Fig. 2). The Motor Shield is a dual full-bridge driver designed to drive inductive loads (e.g., relays, solenoids, DC and stepping motors).

5) Eyes and mouth LCDs: Each eye is composed by a uLCD-32PTU LCD, which is a compact and cost effective Intelligent Display Module controlled by a PICASO processor. The LCDs have a 240 x 320 pixel resolution with a 16 bit (65k) colour depth, a Serial Interface to operate the module and a micro-SD card socket for data storage, where the eye's images are stored. The LCDs for the right and left eyes are connected in parallel to the same peripheral (UART) due to limitations on the base RPiCM operating system. With this solution the RPiCM only needs to send one command to operate both LCDs. However, this poses a constraint since the LCDs will not be able to operate individually because the Raspberry can not send different data to a single LCD. To display eye expressions, each pair of left and right eye images must be uploaded into the respective micro-SD cards in an orderly sequence. Next, the RPiCM only needs to load the stored images parameters (memory address, images size and name) and send commands for image displaying in the LCDs. For the mouth display a ITDB02-1.8SP was used, which is a 1.8" TFT LCD module with 65K colours and 128 x 160 pixel resolution. The mouths module uses the Serial Peripheral Interface protocol. The manner in which the mouths LCD works follows a similar procedure/routine as the eye module. It receives a set of commands and its arguments and acts accordingly.

B. Software

The software implemented in this project was mainly developed for the purpose of generating emotional expressions by the robotic head (see Fig. 3). The implemented software packages controls the LCD peripherals to display a set of stored images in a database. Each image represents a given emotional expression or transition between expressions, and by displaying these images in the corresponding LCDs it is possible for the ISR-RobotHead to convey emotional states. The design of the images, for the human-like emotional expressions, got some inspiration from [11]. It were designed images to display the following common emotions: fear, sadness, joy, surprise, anger and disgust. The designed images for each expression, however, must be encoded beforehand in a raw 16-bit format and organized in a database. Each expression is scripted into the RPiCM with a sequence of images to generate animations for each expression. The other peripherals (vision cameras and sound output) were configured and are operational, however, at the current stage of the project, the results using vision cameras and sound are very preliminary and are not addressed in this paper.

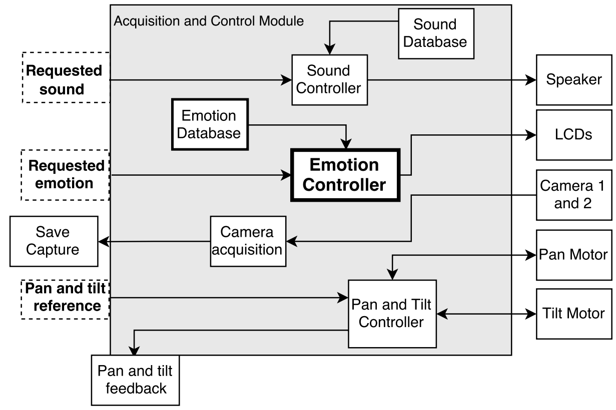

Fig. 3. High level software overview.

III. Experimental Evaluation

A. Method

It was collected a convenience sample for this study in February 2017, at the Cerebral Palsy Association of Coimbra in Portugal and at a private clinical centre for children and youths (Psikontacto, Lda.), based on the following inclusion criteria: (1) chronological age between 6 and 10 years old; and (2) attending the services accompanied by one of their primary caregivers during the period established for sample collection. Children who presented moderate to severe intellectual disabilities (as indicated by their clinical teams) were excluded from the study. Accordingly, 13 children were enrolled to participate in the study, but 4 were unable to do so because of the overlap with other therapeutic activities (n = 2) or the presence of specific difficulties of speech (n = 2). Therefore, the final sample comprised 9 children aged between 6 and 10 years old: most of them were referred to the services because of some form of psychological disorder (n = 7); 3 of these children had a mild to moderate intellectual disability; and 2 of them had a neurodevelopmental condition. Children were

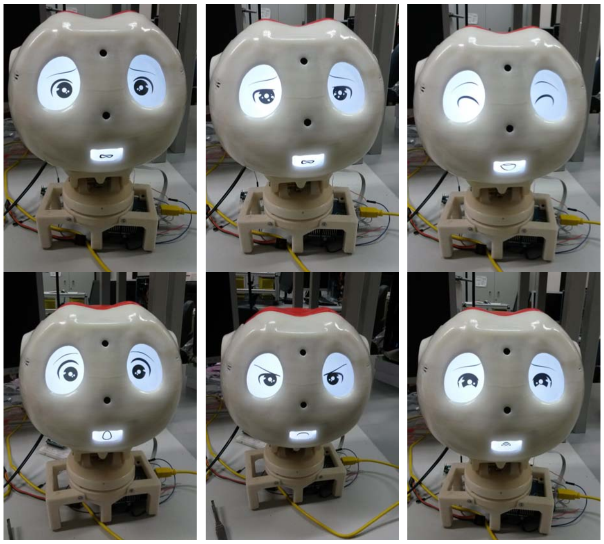

Fig. 4. Pictures of the ISR-RobotHead representing a set of encoded emotional expressions. On top from left to right: fear, sadness, joy. On bottom from left to right: surprise, anger and disgust.

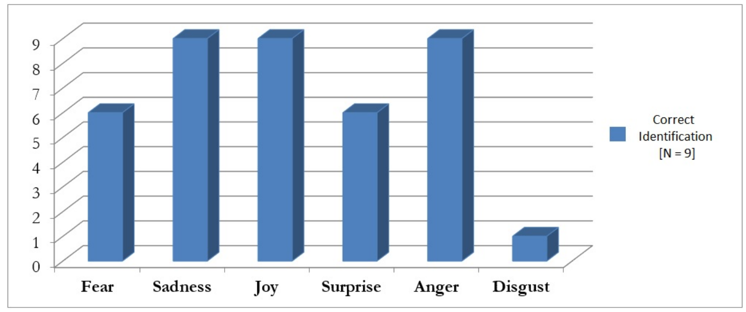

Fig. 5. Frequencies of correct detection of "robotic emotional" expressions by children.

presented the robotic head (see Fig.4) and asked to identify the robot's six emotional states under examination (fear, sadness, joy, surprise, anger, and disgust).

B. Results and discussion

As depicted in Fig. 5, all participants correctly identified the emotions of Sadness, Joy, and Anger, thus attesting the ability of this LCD-based robotic head for non-verbal communication of these emotions. Likewise, most participants (n = 6) correctly detected the emotions of Fear and Surprise. However, only one of the participants was able to identify the emotion of Disgust, which indicates a clear need of improving the LCD animations created for this particular emotion. Children aged, in the range considered in our study, (either typically developing or having a health problem) are able to detect a variety of emotions, including disgust [12]; this is generally so, even if gender differences may exist in the detection of disgust [4], or the easiness in the detection of emotions varies across different emotional states [13]. The small sample size precluded the conduction of comparative analyses between age-groups or different levels of cognitive ability, but nonetheless, these are aspects to be fully taken into account in similar studies to be conducted in the future.

IV. Conclusion

In this paper we presented a robot head solution for future studies in the field of CRI, along with a brief overview of its current hardware modules and functionalities. The experimental study to validate the robot's ability to express emotions yielded positive results, since the surveyed children were able to identify positively most of the emotions represented by ISR-RobotHead, thus attesting its capability of conveying emotions trough facial expressions. These results motivate us to continue improving this project in order to enhance some of the emotions representations and also to endow the robotic head with automatic and intelligent control.

Acknowledgment

The authors would like to thank Dr. Maria do Céu Salvador, for her kind availability in hosting part of the exploratory study at Psikontacto, Lda.

References

[1] F. Faria, "A study on robotic heads design within the scope of social and emotional expressiveness for intuitive human-robot interaction," Institute of Systems and Robotics-University of Coimbra, Tech. Rep., 2015.

[2] J. Broekens, M. Heerink, and H. Rosendal, "Assistive social robots in elderly care: a review," *Gerontechnology*, vol. 8, no. 2, pp. 94–103, 2009.

[3] T. Belpaeme, P. E. Baxter, R. Read, R. Wood, H. Cuayáhuitl, B. Kiefer, S. Racioppa, I. Kruijff-Korbayová, G. Athanasopoulos, V. Enescu *et al.*, "Multimodal child-robot interaction: Building social bonds," *Journal of Human-Robot Interaction*, vol. 1, no. 2, pp. 33–53, 2012.

[4] A. De Beir, H.-L. Cao, P. G. Esteban, G. Van de Perre, D. Lefeber, and B. Vanderborght, "Enhancing emotional facial expressiveness on NAO," *International Journal of Social Robotics*, vol. 8, no. 4, pp. 513–521, 2016.

[5] 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.

[6] B. Robins, K. Dautenhahn, R. Te Boekhorst, and A. Billard, "Robotic assistants in therapy and education of children with autism: can a small humanoid robot help encourage social interaction skills?" *Universal Access in the Information Society*, vol. 4, no. 2, pp. 105–120, 2005.

[7] T. Hashimoto, H. Kobayashi, A. Polishuk, and I. Verner, "Elementary science lesson delivered by robot," in *8th ACM/IEEE Int. Conf. on Human-Robot Interaction, 2013.*

[8] A. Bruce, I. Nourbakhsh, and R. Simmons, "The role of expressiveness and attention in human-robot interaction," in *IEEE Int. Conf. on Automation and Robotics (ICRA'02), 2002.*

[9] P. Ekman, *"Facial expression"*. In Nonverbal Behavior and Communication, A. Siegman S. Feldstein (Eds.), New Jersey: Lawrence Erlbaum Association, 1977., 1978.

[10] J. H. Karsten Berns, "Control of facial expressions of the humanoid robot head roman," Robotics Research Lab Department of Computer Science, University of Kaiserslautern, Germany,, Tech. Rep., 2006.

[11] K. Itoh, H. Miwa, M. Matsumoto, M. Zecca, H. Takanobu, S. Roccella, M. C. Carrozza, P. Dario, and A. Takanishi, "Various emotional expressions with emotion expression humanoid robot WE-4RII," in *in 1st IEEE Technical Exhibition Based Conference on Robotics and Automation (TExCRA '04), 2004.*

[12] M. Gagnon, P. Gosselin, I. Hudon-ven der Buhs, K. Larocque, and K. Milliard, "Children's recognition and discrimination of fear and disgust facial expressions," *Journal of Nonverbal Behavior*, vol. 34, no. 1, pp. 27–42, 2010.

[13] N. Wong, D. C. Beidel, D. E. Sarver, and V. Sims, "Facial emotion recognition in children with high functioning autism and children with social phobia," *Child Psychiatry & Human Development*, vol. 43, no. 5, pp. 775–794, 2012.