On The Emotional Transparency of a Non-Humanoid Social Robot*

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Abstract. Non-anthropomorphic robots have issues in conveying internal state during a Human-Robot Interaction (HRI). A possible approach is to let robots communicate their states or intentions through emotions. However, the robot's emotional responses are not always clearly identified by people, and it is also difficult to identify which and how many cues are most relevant in affecting people's ability of recognition of robots' emotions during the ongoing interaction. We involved 102 participants in an online questionnaire-based study where they rated the robot's behaviours, designed in terms of colours, movements and sounds, according to the perceived emotions in order to identify the cues to be used for making robots more legible. The results suggest that emotional transparency can benefit from multimodal interaction. Our results underline that single modes can be capable of conveying effectively the desired emotion, and little benefit is obtained by the use of additional modes that may be not necessarily noticed by the users.

Keywords: Affective Robotics · Human-Robot Interaction · Emotional Transparency.

1 Introduction

People are able to communicate and interpret multimodal communication signals, including natural language, gesture, pose, and body language. In addition to those, they might engage other humans with a bidirectional and mutual understanding [25] that allows them to understand and predict others' intentions and behaviours.

Current literature has identified a number of social cues that could influence people's perception of a robot as social entity, and, as a consequence, their behaviours and trust towards a robot during an interaction [21]. However, it is not

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clear if the cues composing the multimodal interaction affect equally the quality of the interaction, or if one or some of them are shadowed by the others [24]. In this work, we investigate how emotions are attributed to the behaviour of a non-humanoid social robot whose main purpose is to help the learning experience of students in schools. The robot used in this work is the ClassMate developed in collaboration with Protom Group S.p.a.[3]. It is designed as a social robot for classroom environments and allows the development of social expressions in terms of body motion, facial expression, tactile interaction and sounds [5]. Thanks to its design, it can be deployed on top of a standard desk without the need of securing the structure to it.

We design a set of affective behaviours on the robot and vary the multi-modal dimension of these to investigate whether users can match the desired emotions to them. To span the most important emotions perceived by humans, we developed six affective behaviours where each aims to represent the desired emotion. As target emotions, we used the distinctive universal emotions defined by Ekman [8]: anger, fear, disgust, sadness, joy and surprise. We consider facial expression, body motion, and sound as a component for achieving multimodal interaction.

2 Background and Related Work

The social behaviours of a robot designed to constantly be exposed to users must be carefully designed in order to improve its acceptance.

2.1 Robots in education

Vernier et al. [27] present a science lesson mediated by a life-size humanoid robot. Parts of the lesson were given through the Wizard of Oz (WoZ) and the authors show that the interaction with the robot teacher achieved its educational objectives. Kanda et al. [11] design interactive behaviours for long-term interaction in an elementary school and report how the design principles promote such interaction. Their field study lasted two months and the authors have found that once the novelty effect vanishes two-thirds of students become bored and reject social robots over time. Once the interaction is prolonged in time, relationships are likely build. In this sense, the children-teacher relationship evolves and when a robot is deployed as a teacher, children treat it as a social actor [9].

Davison et al. [7] present the results of a four-month study in which the interactions between children and a social robot were totally motivated by the firsts. In their work, the robot is not actively looking for the interaction but is behaving socially if triggered. The authors investigated also the extent to which the children could self-regulate the learning process if exposed to a prolonged interaction with the robot. However, if the robot takes initiative in a team during a learning task, perceived engagement does not necessarily improve [10].

[3] https://www.protom.com

A typical learning scenario aims to maximize the quality and quantity of content that students are receiving. Introducing a robot in this type of context surely creates a novelty effect at first, but for long-term interactions, the robot should be capable to adapt its behaviour to the interacting user [1]. However, in this field, the problem of maintaining the interest of the students is yet to be solved. Low interest in a classroom can come from individual physical status, lack of interest in the content or the way the content is exposed by the robot teacher. Such use-case, despite its great benefits [20], should also be treated carefully in terms of ethics [26]. However, on a robot-perception level, engagement can be measured on the students and the robot could employ behaviours to recover it. For instance, Leite et al. [12] presents a strategy by which the robot could classify disengagement automatically with the aim to adjust its behaviour to re-acquire the attention of the children. More recently, Nasir et al. [17] showed that in educational HRI engagement does not necessarily correlate with learning performances. In their work, authors show that in order to maximize learning a robot should seek a productive engagement that allows gaps in which the student is not engaged. Suggesting that a little bit of distraction can actually improve learning.

Clearly, in order to successfully adopt robots in social contexts, the emotional response of the users has also to be taken into account.

2.2 Emotional robotics

The future of social robotics is strictly related to the capability of these to elicit emotions on humans [4]. Beck et al. [2] evaluated children's ability to interpret a robot's emotional body language, demonstrating, for instance, the impact of head position on the perception of various body postures. The goal of these studies is to improve educational objective performance with the aid of robotics. However, a common issue when conducting user studies in HRI is the gap between users' expectations of the robot and its real capabilities. The expectations are driven by socio-cultural factors like movies, books and other types of arts. Frequently robots are represented as embodied Artificial Intelligent (AI) agents that can process information and interact smoothly with surrounding users. When focusing on learning context, it is important to realize the effect of robotics on younger generations. Ligthart et al. [13] investigate the role of expectations in child-robot interaction and found that the effectiveness of the social assistance of the robot is negatively influenced by misaligned expectations.

Despite Beck et al. [2] suggests that the lack of an anthropomorphic face in a social robot does not impede emulating emotions, Löffler et al. [14] highlights the importance of empowering social robots with artificial emotions that are effective given by a combination of three low-cost output channels (colour, motion and sound). For instance, when focusing on the latter, Rossi et al. [23] showed that children aged 3–8 years perceive the robot's behaviours and the related selected emotional semantic free sounds in terms of different degrees of arousal, valence and dominance: while valence and dominance are clearly perceived by the children, arousal is poorly distinguished. Designing behaviours for non-humanoid robots with the goal of intentionally eliciting emotions is not a trivial task.

In this work, we present the results of an online user study in which the robot ClassMate is showing six different artificial emotions via using its face, body movements and sounds to users that are asked to associate an emotion with each behaviour.

3 The ClassMate robot

The ClassMate Robot is an open chain robot with 6 degrees of freedom (DoF) implemented as revolute joints. The robot could be divided into (fixed) base, body and head. The base allows a rotation of the body along the vertical axis, the body contains 4 parallel-axes joints. Finally, the head is controlled by a revolute joint whose axis is orthogonal to its parent's. Figure 1 shows one of the first prototypes of the robot and highlights (1) Infrared (IR) Sensors, (2) Touch Sensors, (3) Camera with a built-in microphone, (4) LCD Display, (5) Left and right RGB LEDs + Frontal camera flash, (6) Sound Sensors and (7) Motors. The robot is designed to engage students, teachers and school personnel in social interactions while providing different functionalities, such as small talks, and learning applications [5]. The ClassMate's framework has been developed following four main principles that allow an easy personalization, update, and extension of the available skills/applications: 1) the robot needs to be interacting and have personalised behaviours, 2) the robot needs to be able to have natural and social interactions, 3) new applications can be easily added by non-programmers, and 4) the applications/services provided need to be perceived as part of the robot and not external tools.

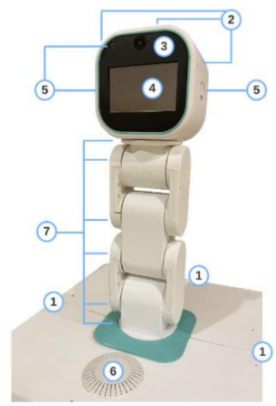


Fig. 1: Robot's prototype

To this purpose, affective modalities can be used by social robots to convey their internal states and intentions [3], and improve the success of the social interaction. The social component of the interaction is manipulated on the ClassMate robot's facial gestures, body motions and sounds, as suggested by [14]. In particular, we endowed the robot with the capability of expressing Ekman's basic emotions (joy, sadness, disgust, fear, surprise and anger) [8]. The next sections describe how the robot's face, body and sounds are controlled and combined in order to simulate the desired emotions.

3.1 Facial expressions

The screen located on the head of the robot shows two simple eyes on a black background. The shape and colour of the robot's eye animations have been designed considering relevant studies [6, 18]. Figure 2 shows examples of the facial expressions designed in this work with the relatively intended emotion.

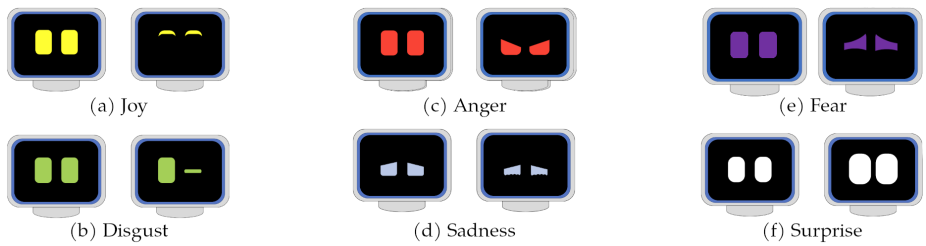


Fig. 2: Examples of facial expression with relative intended emotion.

3.2 Body expressions

The body movements of a robot are also used to convey emotions [22]. However, the kinematics of this robot allow limited motion of the joints, so the range of emotional expressions that can be designed is also limited. To convey emotions, we can rotate the last joint (head), control the body to represent "closeness" or "openness" to the interaction [16], and rotate the whole body using the base joint. As discussed in [15], the emotions that a robot's body can express, surely depend on its design and anthropomorphism. In this work, only three separate body expressions are implemented. Bearing in mind that across all the body motions the robot always starts at the initial configuration (Figure 3a).

Figure 3b, 3c, 3d show the final configuration of the body at the end of the expression of each motion.

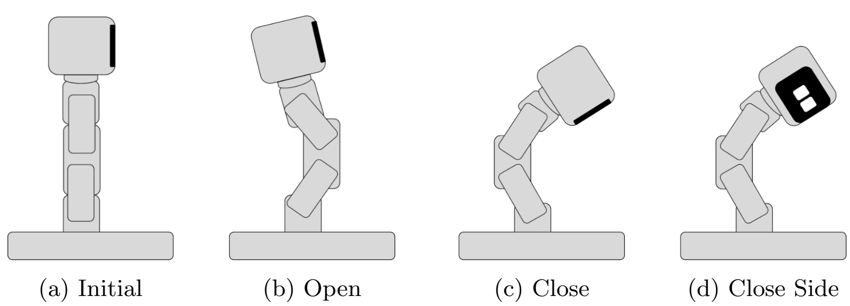


Fig. 3: Examples of ClassMate's body motions for emotional expression.

3.3 The sound

Several non-verbal sounds are used to mimic the natural backchannelling cues that are often used by humans to express a specific emotion. In HRI, backchannelling cues are important as they can be used to maintain a person engaged with a robot or to attract attention [23].

4 User study

The purpose of this study was to evaluate which is the minimum type of modalities needed by the ClassMate robot for expressing internal states and responses to effectively communicate with people. This is not a trivial task since developed emotions are not always perceived as intended both in humanoid and non-humanoid robots [22]. A misinterpretation of the emotions may have negative effects on the legibility of the robot's intentions and, as a consequence, on the overall success of the interaction. In this context, we classified several multi-modal affective (para-verbal and non-verbal) behaviours according to people's perceived emotions. In particular, we hypothesised that multimodal interactions for such non-humanoid social robot improve the legibility of its simulated emotions. Therefore, we combined three modalities to identify which are the social cues that make transparent a robot's emotional state for people.

4.1 Methodology

We conducted an online questionnaire-based study that was organised as a between-subject experimental design to evaluate the perceived expressions of the robot's animations. Participants watched several animations in which the ClassMate robot simulated emotions using: 1) **C1** only one modality, i.e. facial expressions; 2) **C2** facial expressions and body motions; and 3) **C3** facial expressions, body motions and sounds.

Overall, we developed six robot affective behaviours that mimic distinctive universal emotions (anger, fear, disgust, sadness, joy and surprise). In condition **C1**, the robot's eyes displayed on the screen were white eyes with a fixed shape [4]. In condition **C2**, the robot's eyes assumed the colour as described in Section 3.1[5]. In condition **C3**, we used the same facial animations of **C2**, and we added paraverbal sounds that are often used by people to convey the respective emotion[6]. In our design, condition **C3** is the baseline, and we expect that people would clearly associate these animations to the respective emotional expression.

The presented animations also included two variations of the fear and anger emotions using a different movement directions. The combinations of the body

[4] The animations used in **C1** condition can be viewed on `https://tinyurl.com/2a9bhjzj`

[5] The animations used in **C2** condition can be viewed on `https://tinyurl.com/yc72srkp`

[6] The animations used in **C3** condition can be viewed on `https://tinyurl.com/ycynm64d`

expressions and emotions was inspired by the results presented in Löffler et al. [14]. Each animation lasted about 3 seconds, and were displayed in random order to the participants.

During the different stages of the questionnaire study, we asked participants to complete several questionnaires. A pre-experimental questionnaire collected participants' demographics data (age, gender), and their previous experience with robots, including what kind of previous interactions and type of robots they interacted with.

After each video, participants were asked to associate to the robot's behaviours one of Ekman's six basic affective states (joy, sadness, disgust, fear, anger and surprise), and rate their own confidence in the choice on a 5-point Likert Scale [1 = "Not at all" to 5 = "Very much"].

At the end of their interaction, we assessed their overall perception of robot by asking them whether they would like to interact with a physical robot on a scale from 1 ["Not at all"] to 7 ["Very much"].

4.2 Participants

An a priori sample size calculation using G*Power considering ANOVA as analysis ($\alpha = .05$, power = .95, number of groups = 3, number of measurements = 5), and moderate effects (f(V) = 0.25), resulted in a sample size of 96 participants.

We recruited 102 participants (54 male, 48 female, no non-binary), aged between 18 and 66 years old (avg. 36.45, stdv. 13.99). The majority of participants (79.4%) did not have any experience with robots, 7.8% of participants were programmers, researchers, while the remaining participants had mainly saw robots on TV, social media, or demos. Participants' experience with robots included Furhat, Pepper and Roomba robot.

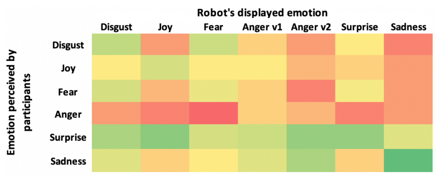
Each participant was assigned to one condition, and they were overall distributed among the three experimental conditions as follows: 1) 33 people in the only-face (**C1**) condition, 2) 32 participants in the pose-face (**C2**) condition, and 3) 37 participants in the pose-face-sound condition (**C3**) condition.

5 Result

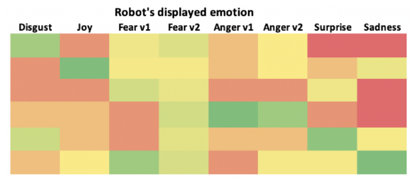
Our results allowed us to classify a set of modalities for expressing robot emotions (see Figure 4). Note that 4a and 4b share a common y-label.

The heatmap in Figure 4a shows that participants were able to correctly recognise sadness and surprise emotions with the robot's pose showed. They were more undecided in associating the robot's poses to the disgust, joy and fear emotions, even though we can observe that they were confused with emotions having similar polarity. These results also show that anger was the only emotions completely misinterpreted in the condition **C1**.

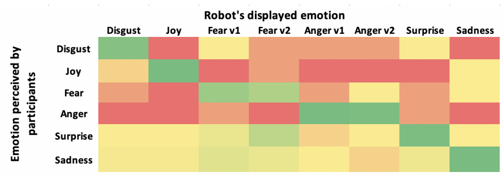
In conditions **C2**, participants correctly associated the robot's animations with the disgust, joy, anger, surprise and sadness emotions (see Figure 4b). Observing this heatmap, we can also notice that both animations representing



(a) Condition 1: only pose.



(b) Condition 2: pose and facial emotions.



(c) Condition 3: pose, facial emotions and sounds.

Fig. 4: A heatmap for the affective expressions associated with the robot's behaviours by the participants. Colors ranging from low scores in red to high scores in green.

fear were not as clear as the others. Interestingly, previous studies [19, 22] also highlighted the difficulty for participants to recognise it as expressed by most robots.

As expected, the sounds used in condition **C3** allowed participants to almost uniquely associate an emotion to the robot's animation showed (see Figure 4c).

Finally, at the end of the study, participants were asked to express their desire to use in person the robot. The majority of participants (76%) stated that they would like to interact with a physical ClassMate, the 9% of participants were unsure if they would like to interact the ClassMate, and the remaining expressed a negative response.

6 Conclusion

The emotional transparency of a non-anthropomorphic robot deployed in schools is important for long-term interactions. In this regard, we developed six different social expressions that aim to represent emotions and manipulate the multimodality degree in an online questionnaire-based user study. We observed that participants were able to differentiate most of the emotions using either one or two modalities, i.e. robot's pose or robot's pose and facial expression. Interestingly, we also found that participants were not able to differentiate clearly fear from other negative emotions. Löffler et al. [14] show that multimodal interaction improves emotional transparency, however, our results suggest that for robot emotions designed with single modes and correctly identified, little improvement is obtained by the use of additional modes. Moreover, in line with [23], this work shows that para-verbal cue is extremely important for improving human's emotional understanding of social robots.

In future studies, we want to conduct a similar study with participants physically interacting with the robot to observe any change in the perception of the robot's emotion. Moreover, we also expect that contextualising the emotional response might also affect people's perception. For this reason, we will deploy the robot in a real classroom to collect students and teachers' perception and considerations of the legibility of the robot's behaviours and emotions.

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