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Facial expressions recognition with an emotion expressive robotic head

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Abstract. The purpose of this study is to present the preliminary steps in facial expressions recognition with a new version of an expressive social robotic head. So, in a first phase, our main goal was to reach a minimum level of emotional expressiveness in order to obtain nonverbal communication between the robot and human by building six basic facial expressions. To evaluate the facial expressions, the robot was used in some preliminary user studies, among children and adults.

1. Introduction

In the last decade, an increased number of robotic platforms were developed in order to be used as partners of human beings, to work in close collaboration with them. This feature requires robotic structures with advanced skills, and if we refer to social robots, as the word "social" underlines, the basic skill needed is either verbal or nonverbal communication. Furthermore, it can be noticed the increasing need of social platforms that can be used in Robot Assisted Therapy (RAT) for children or elderly persons. In this case, robots are used as the substitute of animals in Animal Assisted Therapy (AAT). Although it was demonstrated the useful psychological, physiological and social effects of the AAT, it could not be overlooked the facts that animals are unpredictable, difficult to control and can carry diseases and allergies [1]. So robots can overcome these drawbacks and can be used much easily in medical institutes.

One of the most important aspects in the field of social robotics is communication between humans and robots. Humans communicate through complex languages, and use different types of nonverbal cues, such as haptics, kinesics, proxemics and paralanguage [2]. For social robots, kinesics is particularly important, as facial expressions play an important role [3, 4].

Facial expression plays an important role in our daily activities the human being a rich and powerful source, which is full of communicative information about human behavior and emotion. The most expressive way that humans display emotions is through facial expressions, which play a major role in human interaction and nonverbal communication [5].

For the robot, to express a full range of emotions and to establish a meaningful communication with a human being, nonverbal communications such as body language and facial expressions is vital. The ability to mimic human body and facial expressions lays the foundation for establishing a meaningful nonverbal communication between humans and robots [6]. Moreover, according to [2], in any face to face communication, there are three basic elements: words, tone of voice and body language. He stated that body language (nonverbal communication) represents 55% of the communication of feelings and attitudes. Most robot faces express emotion in accordance with Ekman and Frieser's Facial Action Coding System (FACS) system [7]. They devised a list of basic emotions containing anger, disgust, fear, joy, sadness, surprise (universal facial expressions).

Through facial expressions, robots can display their own emotion just like human beings. The face is the most important element to express social cues and different projects have been developed, focusing on the face, like eMuu [8], Feelix [9], iCat [10] and Kismet [11]. There are other robots that also include gestures by moving the whole upper body, including arms and hands, like Leonardo [12], Infanoid [13], Kaspar [14], Robovie-IV [15], WE-4RII [16] and Nexi [17]. ASIMO [6], QRIO [2], Kobian [7], Kobian-R [3, 4], and iCub [18] are complete humanoids that use their full body to interact with the humans and the environment. The seal robot Paro [19], Necoro [20], iCat [10], Aibo [21], Keepon [22], Pleo [23], the Huggable [24], Probo [25], Kaspar [14] and Robota [26], are social robots that especially focus on Robot Assisted Therapy (RAT). These social robots place the human central during human–robot interaction instead of the robot itself.

The research in the field of social robots is called Human–Robot Interaction (HRI) being a multidisciplinary field, with contributions from human–computer interaction, artificial intelligence, robotics, natural language understanding, and social sciences. This new research area requires proper design of the mechatronic systems [27]. During the last years, different social robots have been built and some of them are commercialized, like Aibo [21] and Pleo [23], that appeared on the market as robot pets. Despite the potential this was not a great success yet, because of their price. Only the cheap robotic toys, like Furby [28] and the WowWee robots were able to have commercial success. Even if these systems are robotic toys they are contributing to the future market for social robots. Results from research will be gradually implemented in these toys to enhance the interactions with the user.

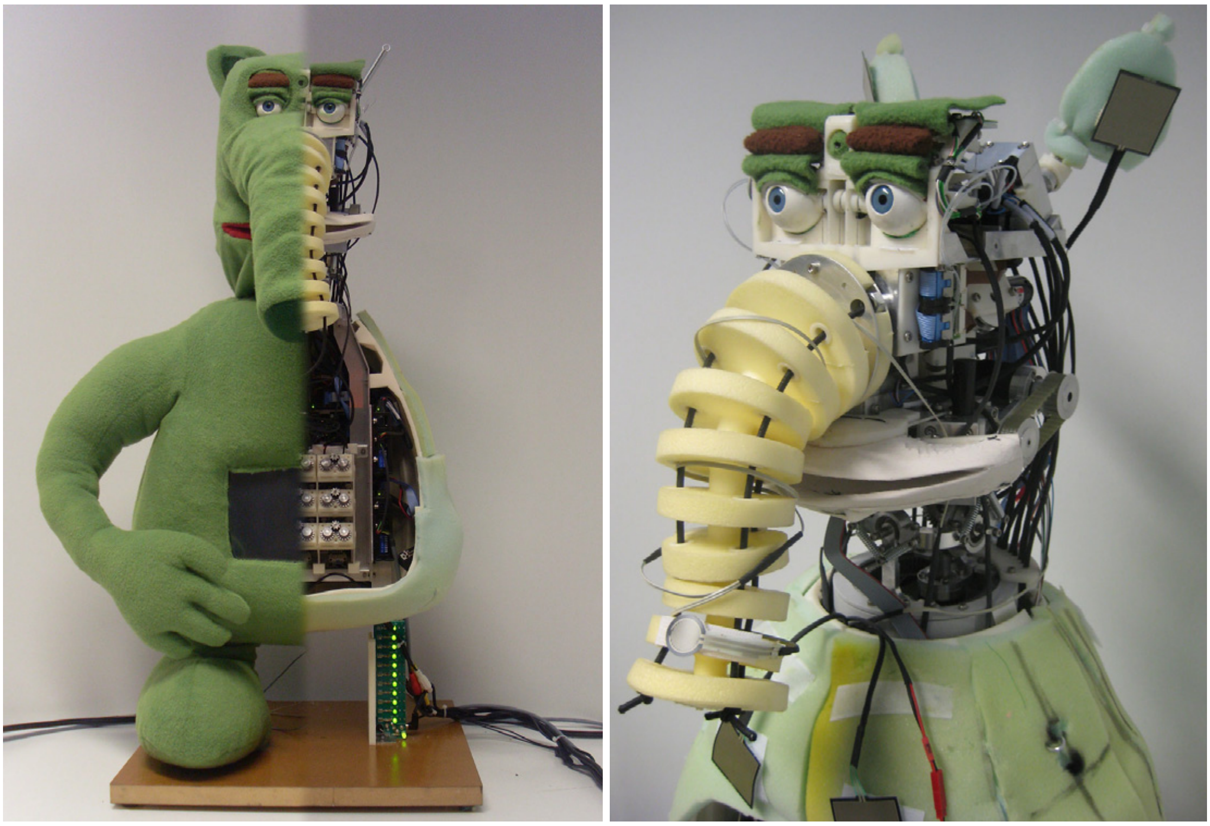
Most of the social robots now are used for HRI studies. In most projects the research is mainly focussed on vision and audio, the study of tactile communication being often neglected [14], excepting projects as Paro [19], Leonardo [12], the Huggable [24] and Robovie-iv [15]. In this context, Robotics and MultiBody Mechanics Research Group, at Vrije Universiteit Brussel (VUB), developed a social robot, called Probo, to serve as a multidisciplinary research platform for HRI focused on children [27, 29]. Besides cognitive interaction, Probo robot aims also physical interaction. This desire leads to other design requirements that need to be fulfilled. For example, safety aspects are one of the most important issues during physical HRI. To achieve these goals, Probo has a concept of a child-friendly artificial creature [30]. The main difference with other social robots is the use of compliant actuators, lightweight design and the fur to achieve intrinsically safety and providing a soft touch and a huggable appearance.

Based on these results, it was investigated the possibility to reproduce the robotic platform to be used for HRI and RAT studies by other research groups around the world. Due to the fact that the first prototype of Probo is rather complex and uses expensive actuators and electronics, it was rather difficult to achieve this goal. Hence a new version needed to be developed to meet and resolve these drawbacks. In a first phase, since the new concept had to be actuated using only "hobby" servos, it was necessary to redesign all the subsystems of the robot, but maintaining the external mechanic aspect and the compliant and safe design of the first version. In this paper, the new version of Probo robot will be described and some preliminary results on facial expressions recognition, as a result of collaboration between VUB and TUI, will be presented.

The paper is organized as follows: first a brief description of the new social robot concept is given; then the emotional behavior of the robot is built through a graphical user interface; section 4 presents some recognition tests of the robot's emotional behavior, conducted among children and adults, and underlines the results of these user-studies; conclusions are given in section 5.

2. The social robot

Children with autism spectrum disorders have difficulties in identifying situation-based emotions, which is a fundamental ability for mind reading [25]. Social robots received increased attention as assisting tools for improving the social and emotional skills of children with autism. In this context, Robotics and MultiBody Mechanics Research Group, at VUB, developed the first version of a social robot, named Probo (figure 1), which was meant to be used as a companion for vulnerable children, to enhance their performance in identifying situation-based emotions [25]. Since most of the communication passes through non-verbal cues, and since people rely on face-to-face communication, the focus of Probo's communicative skills laid initially on rendering facial expressions. To achieve the emotional behavior, Probo was equipped with 20 degrees of freedom (d.o.f.) [30]. Because safety aspects are one of the most important issues during physical HRI, Probo has a concept of a child-friendly artificial creature, using compliant actuators, lightweight design and the fur to achieve intrinsically safety and providing a soft touch and a huggable appearance. Another aspect in the development process was to create a multi-disciplinary research community, hence it was investigated the possibility to reproduce the robotic platform in order to be used for HRI and RAT studies by other research groups around the world.



(a) (b)

Figure 1. First version of the Probo social robot [27]: (a) section view of the entire robot; (b) the uncovered robotic head

Due to the fact that the first version of Probo is rather complex and uses expensive actuators and electronics, it was rather difficult to reproduce the robotic platform. Hence a new version needed to be developed to meet and resolve these drawbacks (figure 2). In a first phase, since the new concept had to be actuated using only "hobby" servos, it was necessary to redesign all the subsystems of the robot, but maintaining the external mechanic aspect and the compliant and safe design of the robot. To obtain facial expressions and eye-gaze based interaction, the new robotic head is a cheaper version of the social robot Probo, with 21 d.o.f. This fully actuated head can be seen as five subsystems, namely: *eyes, ears, trunk, mouth* and *neck* (figure 3).

(a) (b)

Figure 2. Second version of the social robot: (a) uncovered robot; (b) robot with artificial fur

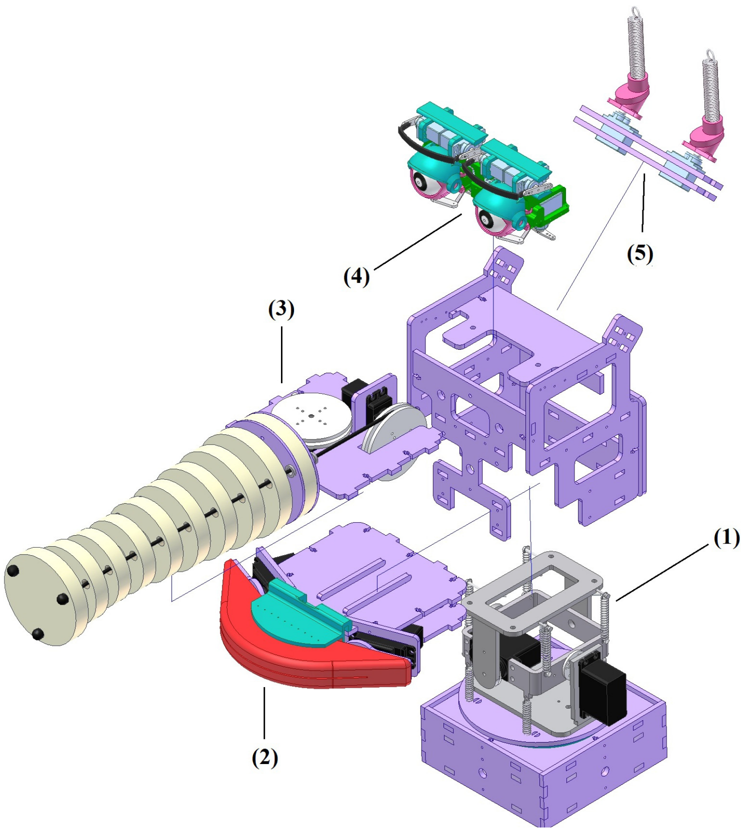


Figure 3. 3D CAD exploded view of the new concept [31]

The eye system (noted with *4* in figure 3) has 10 d.o.f. and includes the eyeballs (4 d.o.f.), the eyelids (2 d.o.f.) and the eyebrows (4 d.o.f.). Comparing to first version of the robot, this new solution has an additional d.o.f., providing independent motions for all the actuated parts. Also, under the new concept the components are driven directly or through spatial linkages and not through cables, as they have been operated in the previous version (where the motors were mounted in the belly of the robot).

The ears (with 1 d.o.f. each), *5* in figure 3, are represented by two helical springs, placed at an angle of 45° from the top of the head, ensuring compliance during interaction. The helical springs will be covered with a flexible foam core, which will have the shape of an animal ear. In comparison with Kismet's ears which have 2 d.o.f. each [11], in our case, to reduce complexity, the two rotations are combined in a single one.

In contrast to other robotic heads, an intriguing anatomical part was added to the robot, namely the trunk (noted with *3* in figure 3), to enhance certain facial expressions and to increase interactivity. This part has three combined d.o.f. components of this system are represented by the trunk itself, made from an expandable foam core, three flexible cables, and the drive mechanism. The cables are wounded around three discs attached directly to the servo output shaft providing a spatial movement of the trunk. Due to the fact that the trunk's core and cables are flexible, the trunk system gives a safe and compliant characteristic.

The silicone mouth (*2* in figure 3) has three actuated parts (lower lip and mouth corners) and a fixed part (upper lip), constrained by the acrylic glass structure. Because in the previous prototype the trunk obstructed the visibility of the mouth (disadvantage in creating facial expressions), for the new concept, in order to prevent this drawback, bigger dimensions were adopted for this subsystem.

A serial mechanism was used as mechanical solution of the neck (*1* in figure 3), equivalent to a spherical wrist, with three d.o.f., providing three motions: head pan, head tilt and head swing. To compensate the gravity, and consequently to reduce the required motor torque for tilting or swinging the head, the neck was equipped with helical tension springs, similar to the robotic head ROMAN [18] and Twente [32].

Due to the fact that the robot will interact with children, its exterior resembles to a stuffed toy and it has a friendly appearance. For this it was used a sponge layer placed on the base structure and on top a green artificial fur, providing a soft touch during interaction.

3. Expression of emotion

Monitoring and facilitating social interactions are the two big challenges of social robotics [33]. Emotion displays are robots with the ability to express emotions. These robots use facial expressions, gestures, or other non-verbal signals. Some of them also use speech to express emotions. The comparative study of facial and postural expressions of emotions by Clavel et al. [34] demonstrates that the emotions are better recognized when they are conveyed by facial expressions than by postural expressions. Trovato et al. [4] implement facial and bodily postures with a humanoid robot. The authors show that when body postures are used with facial expressions they improve the recognition rate. It is also pointed out that emotional expression, whether facial, vocal or postural, depends on the culture.

As a good example of facilitating social interaction, Kozima et al. [13, 22] develop the Keepon robot with emotional expressiveness for therapy and entertainment purposes. The authors state that an appropriately designed robot can facilitate not only dyadic interaction between the child and the robot, but also triadic interaction between the child, caregiver, and robot, where the robot functions as an interpersonal pivot. Eddie robot [35] is able to generate different facial expressions corresponding to the six basic emotions (anger, disgust, fear, happiness, sadness, and surprise). iCat [10] is developed as user interface and should interact with humans using emotional expressions. Based on parameters obtained from a simulation system that was used to test facial expressions, the design of a human-like head, called ROMAN, has been developed at the University of Kaiserslautern [18, 36].

To express emotion with our new robotic head, a Graphical User Interface has been built (Figure 4), and the emotion display can be controlled in two ways: by a set of push buttons for the discrete basic emotions (*Facial Expressions* panel), or by a control panel which sets each servo motor separately (*Servomotors* panel).

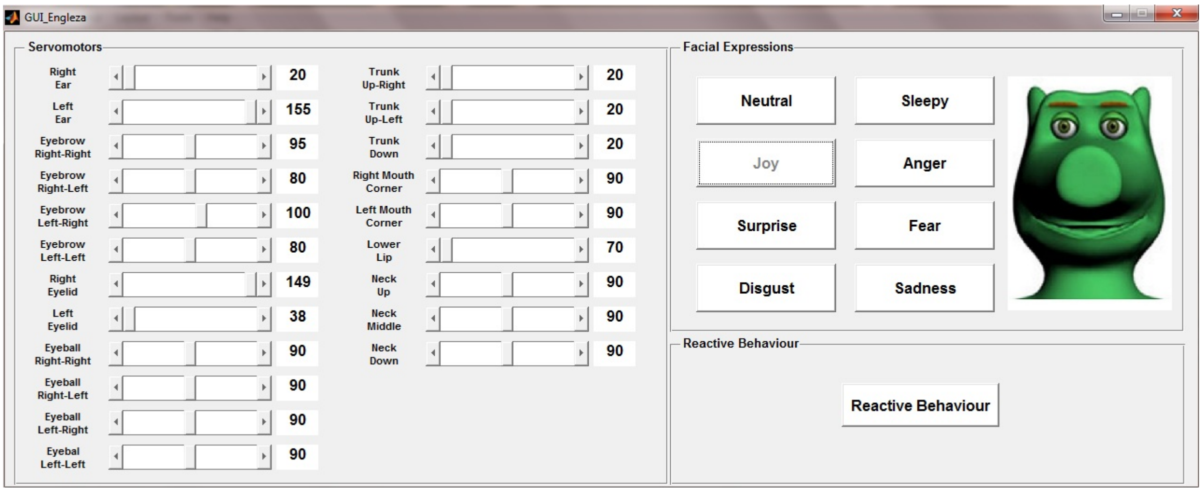
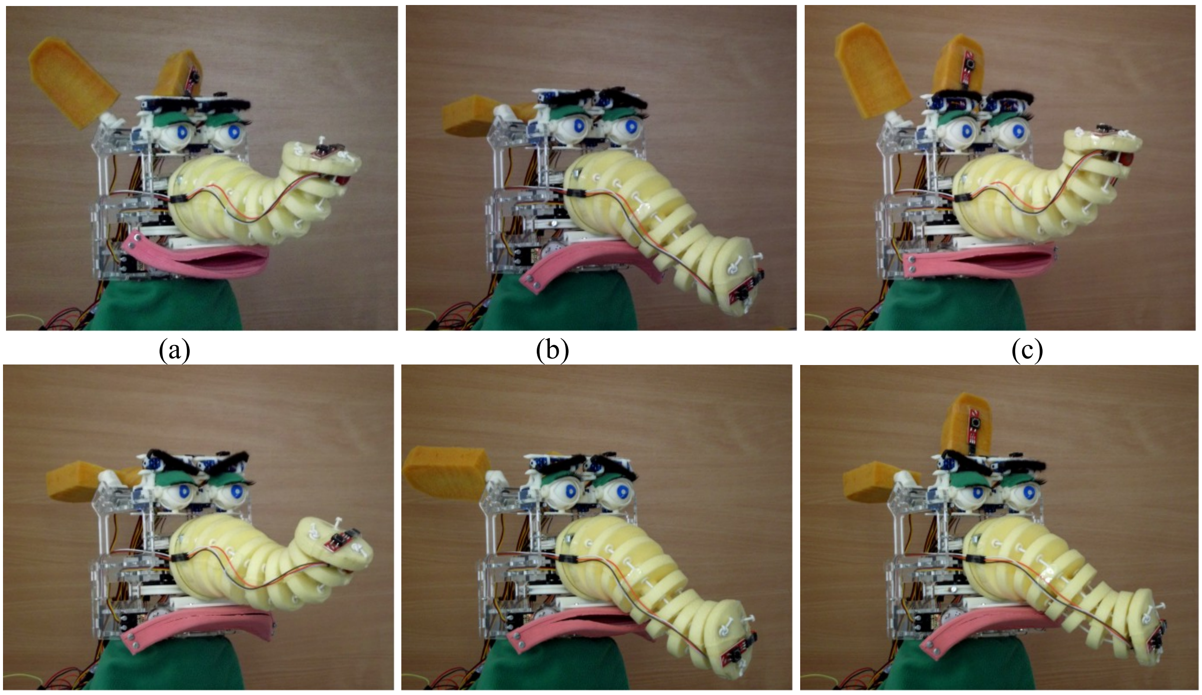


Figure 4. Graphical User Interface [37]

To control the discrete basic emotions six push buttons trigger default position settings for the six basic emotions, defined by [7], namely: *joy*, *sadness*, *anger*, *disgust*, *surprise* and *fear*. Additionally, there are two push buttons which enables the neutral and sleepy state (*Facial Expressions* panel). When a button is pressed, the robot shows that particular state, and the GUI displays an image with the corresponding expression created by the robot's virtual model, developed by [29] (in e.g., in figure 4 is displayed the facial expression which corresponds to the *joy* state). There is no soft transition between these states and the robot changes emotions suddenly. The facial expressions shown by the robot are highlighted in figure 5 and figure 6.



(a) (b) (c)

(d) (e) (f)

Figure 5. Facial expressions of the uncovered second prototype: (a) joy; (b) sadness; (c) surprise; (d) anger; (e) fear; (f) disgust

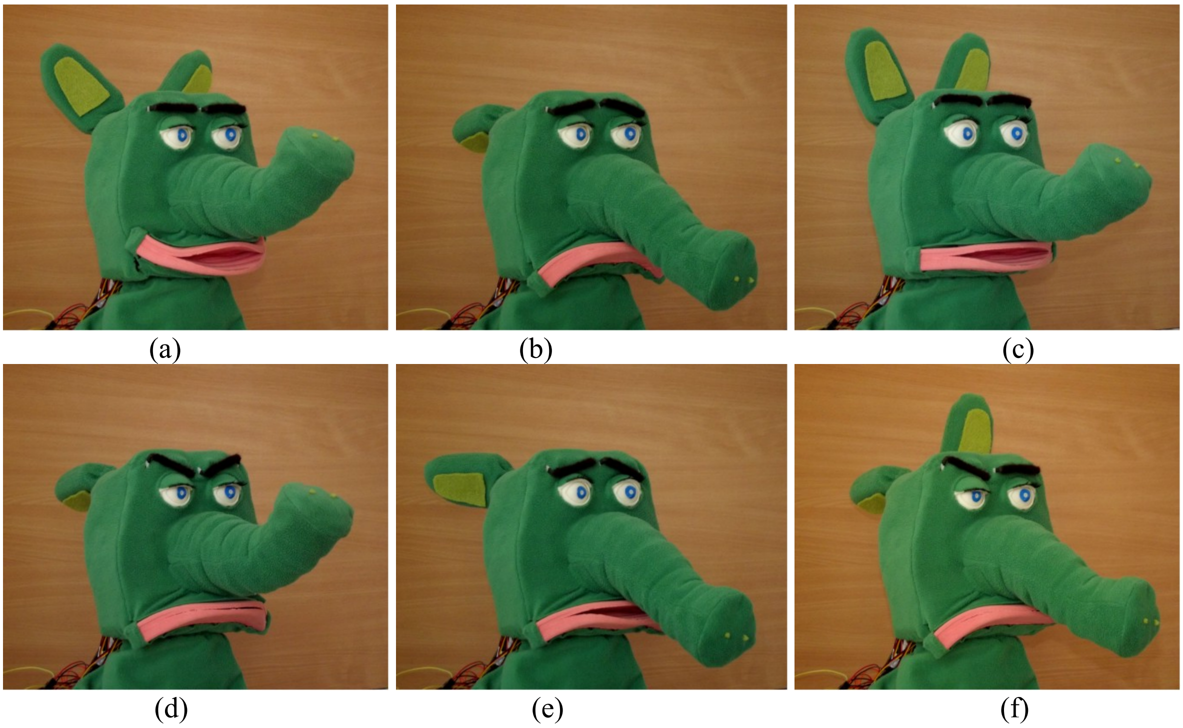


Figure 6. Facial expressions of the covered second prototype: (a) joy; (b) sadness; (c) surprise; (d) anger; (e) fear; (f) disgust

If it is desired to control servo movements separately, the *Servomotors* panel has 21 sliders, setting each servo in its own operational range. The minimum and maximum values of the servo position are defined and limited for each motor in order to prevent servo damage during operation. When the GUI becomes active, all the servo motors are placed in a defined neutral position and the robot is set in the neutral state.

The *Reactive Behavior* panel is referring to the robot reactions based on the feedback received from the sensorial system. At this point, the robot will reach semiautonomous level since it will respond to different external stimuli. In this way, the robot will reach the *joy* state when the tactile sensor from the eyebrow will be touched or the robot will be *angry* when its trunk will be tightened.

4. Experimental evaluation

The experiment set-up was a multiple-choice-test, in which people were asked to match the 6 color images with 6 given answers (words, see figure 7), identifying each emotion. For this study a paper version was used: we presented 6 pictures with facial expressions of our robot (uncovered, and covered with artificial fur) to 54 children (26 girls and 28 boys, at the age of 8-10 years) and to 21 students/men at the age of 20-23 years. Every person has to determine the correlation between presented expression and the 6 basic facial expressions. The results of the experiment should help to get more information of the recognition and the demonstration of facial expressions and also, with help of the results, the facial expressions of the new version of Probo should be rectified.

Our first test was based on the six facial expressions showed by the uncovered robot (without artificial fur, see figure 5). The results of these tests are presented in table 1 (children - adults). It was observed that global recognition percentages are lower by 66% in children and 70% in adults, probably due to the visibility of the mechanical structure of the robot (the children showed a slight confusion seeing the uncovered robot during this test), so the identification of facial features is more difficult in this case.

A

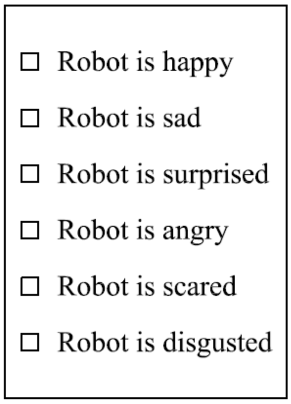

☐ Robot is happy
☐ Robot is sad
☐ Robot is surprised
☐ Robot is angry
☐ Robot is scared
☐ Robot is disgusted

Figure 7. The multiple-choice answer form used

In the next test, we used images of the robot covered with artificial fur (Figure 6), and the results are presented in table 2 (children - adults). It was observed that the children presented a difficulty in recognizing *surprise* and *disgust*, these two expressions achieving very low percentage. To prevent a new similar situation, we rectified these two facial expressions. Thus, the eyebrows have been raised more to enhance *surprise*, and for *disgust*, the mouth left corner was also raised above. Further tests have to be done, to see if these modifications will increase the rate of recognition.

Table 1. Results of the first study - the robot is uncovered (children - adults)

%	joy	disgust	anger	fear	sadness	surprise
joy	**81 - 76**	4 - 0	0 - 5	4 - 9.5	0	11 - 9.5
disgust	0	**67 - 71**	15 - 14.5	4 - 5	7 - 9.5	7 - 0
anger	0	19 - 23.5	**63 - 62**	0	11 - 14.5	7 - 0
fear	4 - 0	4 - 0	0 - 9.5	**60 - 67**	0	32 - 23.5
sadness	0	11 - 5	14 - 9.5	4 - 9.5	**67 - 76**	4 - 0
surprise	32 - 23.5	0	4 - 0	0 - 9.5	4 - 0	**60 - 67**
	Global %	**66 - 70**				

Table 2. Results of the second study - the robot is covered (children - adults)

%	joy	disgust	anger	fear	sadness	surprise
joy	**89 - 90**	0	4 - 5	0	0 - 5	7 - 0
disgust	0	**81 - 76**	15 - 24	0	4 - 0	0
anger	0	12 - 23	**81 - 67**	0 - 5	7 - 5	0
fear	0	0	0	**89 - 76**	11 - 14.5	0 - 9.5
sadness	0	0	0	0 - 19	**100 - 76**	0 - 5
surprise	18 - 9	4 - 0	4 - 5	0	0	**74 - 86**
	Global %	**86 - 79**				

Although the main components involved in the emotions expression are the eyelids, eyebrows and the mouth of the robot, it was demonstrated that also the motion of the trunk and ears contributed significantly to the achievement of facial expressions, which were much easy to identify. The trunk has been used to intensify expressions, equivalent to the action unit (AU) which corresponds to the human nose. Furthermore, although human ears have no influence on the achievement of facial expressions, it was shown that the robot ears, similar to animal ears, had also a significant role in emphasizing these expressions (for example, in case of *fear* or *sadness* the ears are oriented to the rear of the head, while for expressions of *joy* or *surprise*, they are oriented to the front).

The results of these tests revealed that the percentage of recognition of facial expressions was higher when the robot was covered with artificial fur, which is about 86% for children and 78.5% for adults, comparing to the previous test, when the robot was uncovered and the proportion was 66% with children and 70% with adults.

In table 3, a comparison between the recognition rates of facial expressions obtained in our project with those obtained in other similar projects is presented. The robotic platforms considered are: new concept of Probo (version 2), described above, previous version of Probo (version 1) [29], Kismet [11], Eddie [38], Aryan [39], Feelix [40], Nao [41]. These results demonstrate that the facial expression recognition rate obtained by the new concept of the robot Probo is higher comparing to the percentages obtained by older platforms and comparable with the recognition rate of recent studies (with Nao and ROMAN robots). This could be explained by the fact that the older robotic platforms considered have a more mechanical aspect, so the extraction of facial features is more difficult in these cases. Comparing to the previous version of the robot Probo global recognition percentages achieved are similar, but one can observe a decrease in the identification rate of *joy*, *disgust* or *anger*, or an increase in the identification rate of *fear* and *surprise*.

Table 3. Recognition rate of different robotic projects

`	Probo Version 1 [29]	Version 2	Kismet [11]	Eddie [37,40]	Aryan [38]	Feelix [9]	Nao [39]	ROMAN [36]
joy	100	90	82	75	-	60	78	88
disgust	87	79	71	20	-	-	-	52
anger	96	74	76	75	94	40	73	88
fear	65	83	47	85	41	16	92	72
sadness	87	88	82	90	-	70	88	78
surprise	70	80	82	90	71	37	-	82
global (%)	82	84	73	72	69	45	82	77

5. Conclusions

The purpose of these conducted tests was to evaluate the recognition of facial expressions displayed by the new version of social robot Probo. This is particularly important in realizing human robot interaction and for robot assisted therapy studies, based on the fact that a better recognition of facial expressions influences the level of social acceptance of the robot and helps creating effective nonverbal communication between the robot and the human. The results demonstrate that the facial expression recognition rate obtained by the new concept of the robot Probo is higher comparing to the percentages obtained by older platforms and comparable with the recognition rate of recent studies, proving the effectiveness of our design.

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