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Expressing Emotions with the Social Robot Probo

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Abstract Probo is a huggable animal-like robot, designed to act as a social interface. It will be used as a platform to study human robot interaction (HRI) while employing human-like social cues and communication modalities. The robot has a fully actuated head, with 20 degrees of freedom, capable of showing facial expressions and making eye-contact. The basic facial expressions are represented as a vector in the 2-dimensional emotion space based on Russel's circomplex model of affect (Posner et al. in Dev. Psychopathol. 17(03):715–734, 2005). The recognition of the underlying emotions based on the robot's facial expressions were tested in different user studies and compared with similar robotic projects. This paper describes the concepts of the robot Probo and the ability to express emotional states.

Keywords HRI · Social robot · Facial expressions · Emotions

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1 Introduction

In the last few decades most of the robotics research and development was done in automation and industrial robots. It is most likely that in the future more robots will be introduced to work in our houses and offices rather than as industrial robots working in factories [24]. The working environment of an industrial robot is completely different from a robot that acts in our daily life, working among humans. A factory is an organized environment with predefined tasks, while working in close collaboration with humans requires more advanced skills. Besides the necessary functions for sensing and moving, the robot must exhibit a social behaviour and be able to communicate with humans at the appropriate level of abstraction according to context. A social robot will need the cognitive skills enabling it to focus its attention, to understand and interact with the spatial and dynamic structure of its environment. Social robots will need to be able to communicate naturally with people using both verbal and non-verbal signals. They will need to engage us not only on the cognitive level, but on an emotional level as well [28]. Breazeal [4] defines four classes (social evocative, social interface, socially receptive, sociable) of social robots in terms of (1) how well the robot can support the social model that is ascribed to it and (2) the complexity of the interaction scenario that can be supported. The robot Probo, presented in this paper, can be classified as a social interface, providing a platform for *natural* HRI by employing human-like social cues and communication modalities. The *natural* HRI mentioned here is defined as the daily interaction commonly used between people.

As a general platform for HRI, Probo can be used in numerous applications. But one specific goal of this project is to focus on interaction with hospitalized children. In medical applications, especially in the United States, animal assisted therapy (AAT) and animal-assisted activities (AAA) are commonly used in hospitals [6]. AAT and AAA are expected to have useful psychological, physiological and social effects. Some psychological studies have already shown that animals can be used to reduce heart and respiratory rate [1], lower levels of stress [2], progress mood elevation and social facilitation. Nonetheless animals are difficult to control, they always have a certain unpredictability, and they are carriers of diseases and allergies. Therefore, the use of robots instead of animals has more potential advantages and has a better chance to be permitted for use in hospitals. Recently, researchers are exploring the use of social pet robots for these purposes, termed robot-assisted therapy (RAT). For example, the seal robot Paro [26][27], Sony's dog robot AIBO [30], Philips' iCat [5], NICT's Keepon [16] and Omron's Necoro [18] are being tested for RAT. Probo will serve as a platform for similar studies. The platform contains modular building blocks that can easily be configured to comply with the demands for specific HRI studies.

2 The Robot Probo

Probo is a research platform to study human-robot interaction with a focus on non-verbal communication. The design of the robot is adapted to the needs of hospitalized children, the main target group for this project. The character Probo has its own identity, which is of major importance for communication and emotional interaction. The robot is able to show different expressions and in this paper the recognition of the underlying emotions is evaluated and compared with similar robots.

2.1 The Appearance of Probo

Probo (see Fig. 1) acts as an imaginary animal, having a huggable appearance, an attractive trunk or proboscis, animated ears, eyes, eyebrows, eyelids, mouth, neck, and an interactive belly-screen. The internal mechanics of the robot are covered with foam and a removable fur-jacket, in such a way that Probo looks and feels like a stuffed animal. With this approach, choosing an imaginary animal as the basic design, there is no exact similarity with a well-known creature and consequently there are no specific expectations towards the behaviour of this creature as would be in case of a cat or a dog. The combination of a caricatured and zoomorphic [14] representation of a elephant-like animal is more useful and effective to accomplish our goals, rather than using more complex, realistic representations. Since our robot is an imaginary creature, it has less resemblance to existing animals or humans. In this way we aim to avoid Mori's theory of the "uncanny valley" [21].

Fig. 1 The prototype of the huggable robot Probo

The green colour of the robot evokes mainly positive emotions such as relaxation and comfort. Kaya et al. [15] tested the relationship between colour and emotion, and the colour green attained the highest number of positive responses. The majority of emotional responses for the green colour indicated the feelings of relaxation and calmness, followed by happiness, comfort, peace, hope, and excitement. Green is associated with nature and trees, and thus created feelings of comfort and soothing emotions.

2.2 The Identity of Probo

One of the unique features of Probo, compared to other similar projects, is that this character has its own identity, which is of major importance for communication and emotional interaction with humans. Classical animators are masters at conveying intentionality through characters. In the "Illusion of Life" [31], Thomas and Johnston stress the importance of emotive expression for making animated characters believable. They argue that it is how characters express themselves that conveys apparent beliefs, intents, and desires to the human observer. In order for Probo to become a believable character, the identity of Probo includes a name, a family and a history. The name Probo is derived from the word *proboscidea*. Proboscidea is an order that contains only one family of current living animals, *Elephantidae* or "the elephants", with three species (African Bush Elephant, African Forest Elephant, and Asian Elephant) [32] (see Fig. 2). In the name Probo we can also see the word "ROBO" which emphasizes the robotic nature of Probo. Also the word "PRO" is recognized to underline the positive effects on research aspects on one side and education and welfare of children on the other side.

The history of Probo starts in the Ice Age where he lived among other similar species such as the elephant-like *mammoths* and *mastodons*. About 12.000 years ago, warmer, wetter weather began to take hold. The Ice Age was ebbing. As their habitats disappeared most of the Ice Age creatures

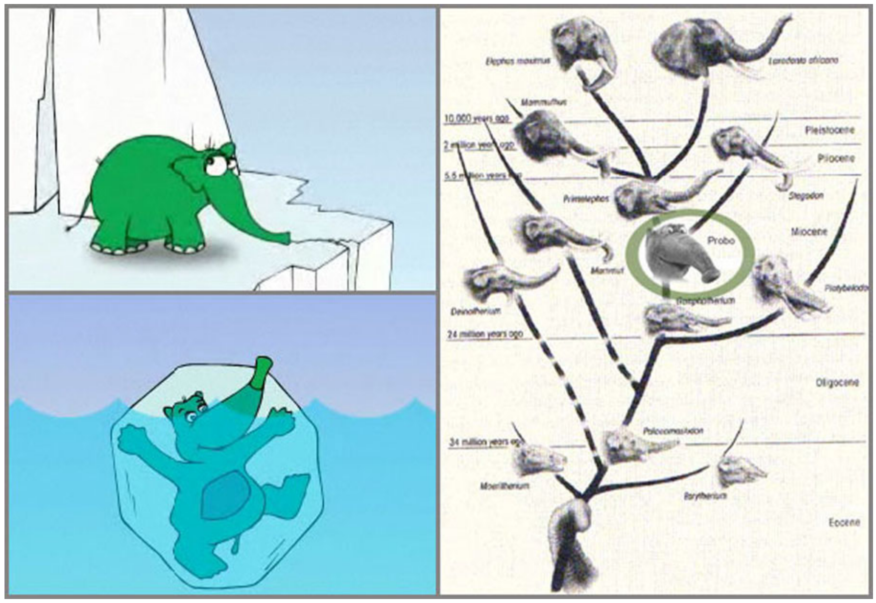

Fig. 2 The history of Probo *on the left* and the family tree of Proboscidea *on the right*

became extinct. Probo managed to migrate north and was frozen underneath the ice-cap at the North Pole. Due to recent global warming the polar caps started to melt and create large floating chunks of ice drifting into open sea. Probo escaped inside such a chunk of ice and finally arrived at Mainland Europe. His quest here is to help children overcome their difficulties and diseases and to bring more joy into their lives.

2.3 The Hardware of Probo

The first prototype of the robot has a fully actuated head and trunk (Fig. 3) giving a total of 20 Degrees Of Freedom (DOF). By moving its head (3 DOF), eyes (3 DOF), eyelids (2 DOF), eyebrows (4 DOF), ears (2 DOF), trunk (3 DOF) and mouth (3 DOF) the robot is able to express its emotions. In contrast with other robotic heads, a special body part, namely the trunk, is added to intensify certain emotional expressions and to increase interactivity. To build safety aspects intrinsically in the robot's hardware all the motors have a spring in series (series elastic actuation, SEA [23]) so in case of a collision the robot will be elastic and safe while providing a soft touch. A triple layered construction also contributes to the safe interactions and soft touch for the user. In addition it protects the mechatronics inside and gives our robot the final form. The layered construction consists of hard ABS covers mounted on the aluminium frame of the robot, shielding the internals. These covers are encapsulated in a polyurethane foam layer, that is covered with a removable fur-jacket (Fig. 4). The fur-jacket can be washed and disinfected. The use of the soft actuation principle together with well-thought designs concerning the robot's filling and huggable fur, are both essential to create Probo's soft touch and to guarantee a safe interaction.

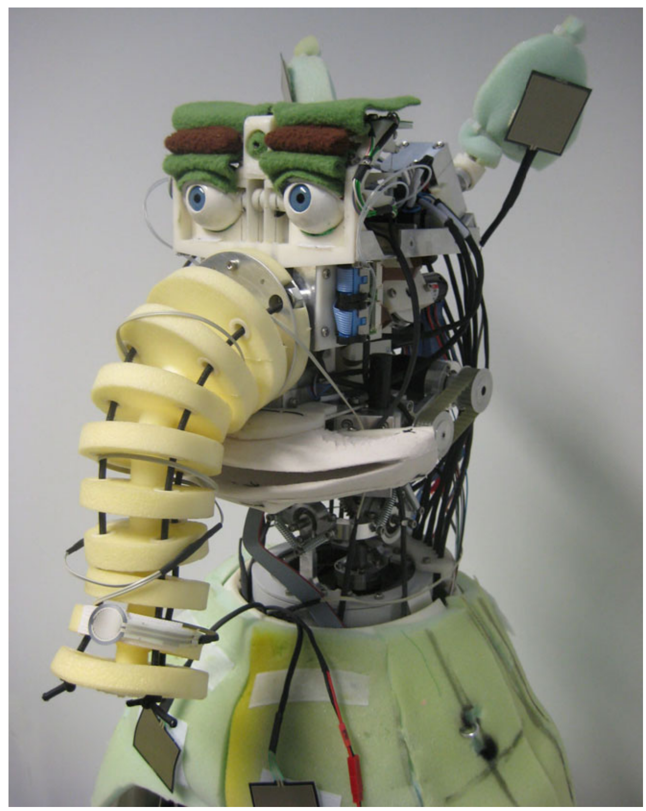

Fig. 3 The uncovered head of Probo

The robot is equipped with a range of sensory input devices, such as a digital camera, microphones,position sensors, temperature sensor, touch sensors under the fur, giving the robot the ability to capture the stimuli from its environment. A touch screen in the belly of the robot creates a window to the outside world through the use of wireless

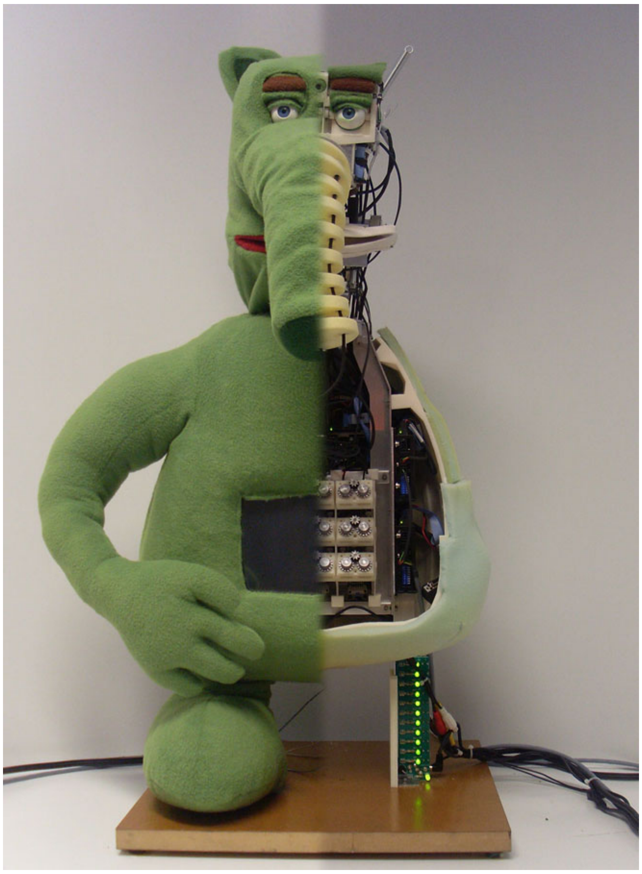

Fig. 4 Probo covered section *on the left* and uncovered section *on the right*

internet and opens up a way to implement new and/or existing computer applications. More information on the internal mechanics of Probo is described in earlier work of Saldien et al. [25].

2.4 Operational Concept

At first, Probo is used as a Robotic User Interface (RUI) interacting with the children and controlled by an operator. The operator can be anyone who wants to communicate with the child, in particularly caregivers and researchers. At this stage there is a shared control between the operator evoking behaviors, emotions and scenarios, and the robot, performing intrinsic (preprogrammed) autonomous reactions. The robot reacts on basic input stimuli and performs preprogrammed scenarios. The input stimuli, that can be referred to as the low-level perceptions, are derived from vision analysis, audio analysis and touch analysis. Those stimuli will influence the attention- and emotion-system, used to set the robot's point of attention, current mood and corresponding facial expression. The vision analysis includes the detection of faces, objects and later also facial features such as facial expressions. Audio analysis includes detecting the direction and intensity of sounds and later the recognition of emotions in speech. Touch analysis gives the location and force of touch, that is classified into painful, annoying or pleasant touch. A larger classification of haptic interactions will be developed in the future. Now, the prototype is being tested as a RUI interacting with children and controlled by an operator. Some basic behaviors are included; such as playing animations, controlling the facial expressions and point of attention. The goal for Probo is to gradually increase the autonomy by implementing new cognitive modules in the RUI to finally obtain an intelligent autonomous social robot. In the meantime Probo will serve as a platform to test and implement new modules for input, processing and output.

The modular structure of the software and an easy to use GUI gives an operator the ability to configure a control center (Fig. 5) for the robot that is well adapted to manage the desired interactions for the robot. The software includes also a 3D virtual model (described in the next section) that can be used for real time simulation before operating the robot. During operation the model will give feedback to the operator of all the robot's motions.

2.5 Virtual Model

A 3D virtual model of Probo has been created to evaluate our design choices and to advance on user testing, without the need for an actual prototype. The model is created combining the mechanical designs, made in Autodesk Inventor, with the visual exterior of our robot, represented by the skin, attached on the mechanical moving parts, using Autodesk 3ds Max. The mechanical parts are linked together to obtain kinematical movements for realistic visual motions of the model. The movements can be controlled by using sliders to set the desired angle for each DOF and simulating actuation of the parts (Fig. 6). This model has also been implemented in the control software, using the Microsoft XNA framework. Another advantage of this model is that the positions of the virtual body parts are known at every time, which are practically the same as these in the real robot.

3 The Emotional System

3.1 The Facial Expressions

In the daily life, people rely on face-to-face communication. The face plays a very important role in the expression of character, emotion and/or identity [8]. Mehrabian [19] showed that only 7% of affective information is transferred by spoken language, that 38% is transferred by paralanguage and 55% of transfer is due to facial expressions. Facial expression is therefore a major modality in human face-to-face communication. For the display of the emotions most of the

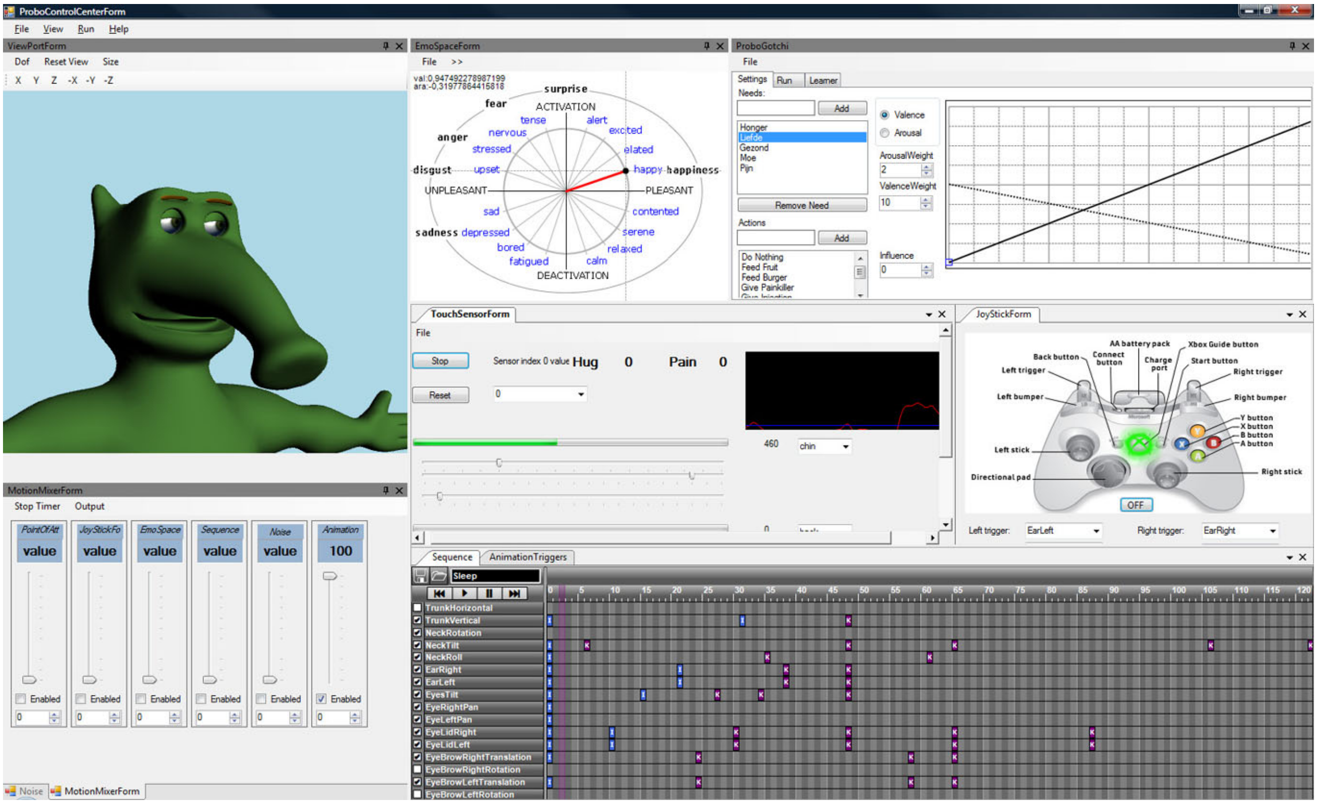

Fig. 5 The GUI of the control center with different modules and the virtual model

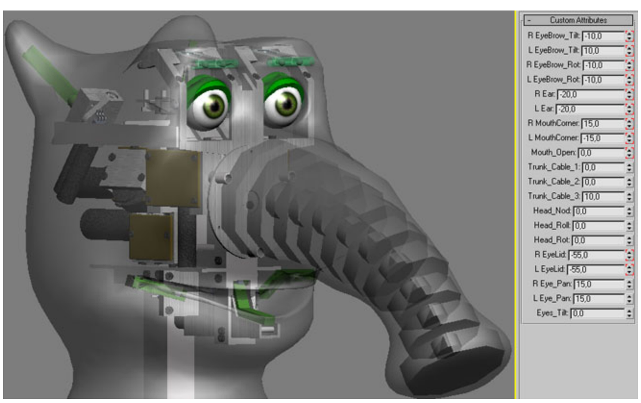

Fig. 6 Virtual model with control slider for the DOF

DOF in the face are based on the Action Units (AU) defined by the Facial Action Coding System (FACS) developed by Ekman and Friesen [11]. Table 1 shows the AU implemented in Probo. AU express a motion of mimic muscles as 44 kinds of basic operation, with 14 AU to express the emotions of anger, disgust, fear, joy, sadness, and surprise. Which are often supported as being the 6 basic emotions from evolutionary, developmental, and cross-cultural studies [10]. Because Probo does not have a human face and for simplifying the design, some of the AU are missing, others are replaced and some are added. The lack of the lower eyelid and a fixed upper lip lead to missing AU, the AU regarding the nose movements (AU 9 and 11) will be replaced by the movement of the 3 DOF trunk. Table 2 shows the AU that are triggered for each of the basic emotions. The movement of the ears and the greater visual influence of the trunk will add extra gestures to express the emotions. The number of DOF in Probo's head is compared to other prominent robot heads like: Kismet [3], iCat [5] and Eddie [29]. These robotic heads make use of eyes, eyelids, eyebrows and a mouth to conform with the AU. Table 3 shows the DOF of Probo's robot head compared to some other non-humanoid robot heads, and includes the ranges and corresponding AU.

3.2 The Emotion Space

For a robot to be able to express emotions, it cannot only cover the discrete basic emotions and their corresponding expressions. Therefore a continuous emotion space is needed, that translates each possible emotional state into a facial expression. To realize a general translation from emotions into facial expressions, emotions need to be parameterized. In the robot Kismet [3], facial expressions are generated using an interpolation-based technique over a three-dimensional, componential *affect space* (arousal, valence, and stance). In our model two dimensions; valence and arousal are used to construct an emotion space, based on the

Table 1 A description of the Action Units used in Probo

AU	Definition	Involved muscles
AU 1	Inner Brow Raiser	Frontalis (pars medialis)
AU 2	Outer Brow Raiser	Frontalis (pars medialis)
AU 4	Brow Lowerer	Corrugator supercilii, Depressor supercilii
AU 5	Upper Lid Raiser	Levator palpebrae superioris
AU 9	Nose Wrinkler	Levator labii superioris alaeque nasi
AU 11	Nasolabial Deepener	Zygomaticus minor
AU 12	Lip Corner Pull	Zygomaticus major
AU 15	Lip Corner Depressor	Depressor anguli oris (also known as Triangularis)
AU 17	Chin Raise	Mentalis
AU 26	Jaw Drop	Masseter, relaxed Temporalis and internal pterygoid
AU 43	Eyes Closed	Relaxation of Levator palpebrae superioris; Orbicularis oculi (pars palpebralis)
AU 45	Blink	Relaxation of Levator palpebrae superioris; Orbicularis oculi (pars palpebralis)
AU 46	Wink	Relaxation of Levator palpebrae superioris; Orbicularis oculi (pars palpebralis)

Table 2 The relationship between emotion and the AU

Emotion	Ekman and Friesen (2002)	Probo
anger	$4, 4+7+17+23$	4
disgust	$9, 4+6+9+10+17+22$	$9, 4+9+17$
fear	$1+5+25/26$	$1+5+26$
joy	$12/13, 6+11+12/13$	$12, 11+12$
sadness	$1+4, 1+4+15/17$	$1+4, 1+4+15/17$
surprise	$1+2, 1+2+5$	$1+2, 1+2+5$

circumplex model of affect defined by Russell [22], which has as well been implemented in the robot Eddie [29].

In our model two dimensions are used: valence and arousal to construct an emotion space. In the emotion space a Cartesian coordinate system is used, where the x-coordinate represents the valence and the y-coordinate the arousal, consequently each emotion $e(v,a)$ corresponds to a point in the valence-arousal plane (Fig. 7). In this way the basic emotions can be specified on a unit circle, placing the neutral emotion $e(0,0)$ in the origin of the coordinate system.

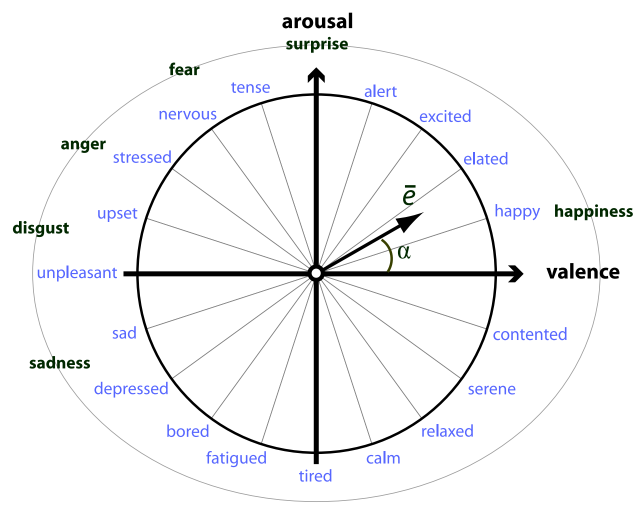

Fig. 7 Emotion space based on the circomplex model of affect defined by Russell [22]

3.3 The Emotion Vector

Each emotion can also be represented as a vector with the origin of the coordinate system as initial point and the corresponding valence-arousal values as the terminal point. The direction α of each vector defines the specific emotion whereas the magnitude defines the intensity of the emotion. The intensity i can vary from 0 to 1, interpolating the existing emotion $i=1$ with the neutral emotion $i=0$. Each DOF that influences the facial expression is related to the current angle α of the emotion vector. An adjustable interface is developed to define the specific value for each angle (0°–360°) of each DOF. When selecting one DOF, a value for each basic emotion is set on the unit circle. To attain a contiguous relation, a linear interpolation between the configuration points is applied.

By adding more (optional) points or values the curve can be tuned to achieve smooth, natural transitions between the different emotions. An example is shown (Fig. 8) for the DOF controlling the eyelid, extra points were added in the first half of the emotion space to achieve smoother transitions. The graph is respectively starting and ending with the

Table 3 DOF, ranges and AU of the actuated joints of Probo's head in comparison with other prominent non-humanoid robot heads

Kismet	Eddie	iCat	Probo			
	(DOF)				Range [°]	AU
Eyes (3)	Eyes (3)	Eyes (3)	Eyes (3)	Pan	100	
				Tilt	80	
Eyelids (2)	Eyelids (4)	Eyelids (2)	Eyelids (2)		150	5,43,45,46
Brows (4)	Brows (4)	Brows (2)	Brows (4)		45	1,2,4
Ears (4)	Ears (4)		Ears (2)		90	
Yaw (1)	Yaw (1)		Mouth (3)	Yaw	45	17,26
Lips (4)	Lips (4)	Lips (4)		Lipcorners	60	12,15
	Crown (1)		Trunk (3)		360	9,11

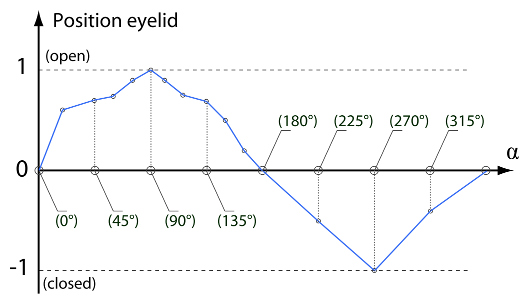

Fig. 8 Adjustable interface for defining the value off the DOF (controlling the position of the eyelid) for each emotion (angle α)

happy emotion ($\alpha = 0° = 360°$). A graphical emotion space module has been developed and plugged into the control center (Fig. 5) where the user can fully configure the facial expressions and use the emotion space to test the different emotions and transitions.

4 Recognition Tests

One of the most important aspects of the social interaction with Probo is the ability to read its social cues. The gaze of the robot is expressed using directed motion of the head, eyeballs and pupils. The facial expressions are generated by motions of the facial DOFs defined by the emotion space. It is important that people who interact with the robot recognize the correct emotion behind these facial expressions. To evaluate this recognition, different tests were taken as is presented in Table 4. To perform the first recognition tests (T1-T5) during the design phase, the virtual model was used to simulate the facial expressions. After the prototype was build, additional tests were performed with pictures of the physical robot (T6 and T7). In similar tests performed with other robot faces [3, 7, 20, 29] a closed answer format was used. For a good comparison, we used the same format in T5, T6 and T7 for testing the robot Probo.

To measure a certain level of agreement between the users the Fleiss' Kappa (κ) [13] value was calculated. This value is a statistical measure of inter-rater reliability and is given by Eq. 1 with $\bar{P}$ (Eq. 2) and $\bar{P}_e$ (Eq. 3). The factor $1 - \bar{P}_e$ gives the degree of agreement that is attainable above chance, and, $\bar{P} - \bar{P}_e$ gives the degree of agreement actually achieved above chance. The scoring range is between 0 (complete random) and 1 (complete agreement). In our studies: $i = 1, \ldots, N$ represents the participants, n is the number of pictures of Probo (with n_{ij} the number of ratings per picture) and $j = 1, \ldots, k$ represents the possible answers (words or drawings). An interpretation of the κ values has been suggested by Landis and Koch [17], and is presented in Table 5. This table is however not universally accepted, and can only be used as an indication.

$$\kappa = \frac{\bar{P} - \bar{P}_e}{1 - \bar{P}_e}, \tag{1}$$

$$\bar{P} = \frac{1}{Nn(n-1)} \left(\sum_{i=1}^{N} \sum_{j=1}^{k} n_{ij}^2 - Nn \right), \tag{2}$$

$$\bar{P}_e = \sum_{j=1}^{k} p_j^2. \tag{3}$$

4.1 Evaluation of the Virtual Model

To test the recognition of facial expression the virtual model was used in a first pilot study with children (T1) and adults (T2). The study was based on a survey performed by Breazeal evaluating the expressive behavior of Kismet [3]. The subjects were asked to perform a comparison task where they compared 8 color images of the virtual model (Fig. 9) with a series of line drawings of human expressions (Fig. 10). The second study was a multiple-choice-test, in which people were asked to match the 8 color images with 8 given answers (words), identifying each emotion. For this study a paper version was used to test the children (T3) and an electronic version was used to test the adults (T4). The electronic version was an online survey giving the possibility to test more people.

Table 4 An overview of all recognition tests for the facial expressions of Probo

Test	Age	Number	Model (expressions)	Answer format (emotions)	Result (%)
T1	6–8	25	Virtual model (8) (Fig. 9)	Sketches (12) (Fig. 10)	60 (Table 6)
T2	20–35	16	Virtual model (8) (Fig. 9)	Sketches (12) (Fig. 10)	67 (Table 7)
T3	8–12	20	Virtual model (8) (Fig. 9)	Multiple choice (8) (Fig. 11-L)	78 (Table 8)
T4	18–60	143	Virtual model (8) (Fig. 9)	Multiple choice (8) (Fig. 11-L)	73 (Table 9)
T5	8–12	143	Virtual model (6) (Fig. 12)	Multiple choice (6) (Fig. 11-R)	88 (Table 10)
T6	8–12	23	Uncovered robot (6) (Fig. 13)	Multiple choice (6) (Fig. 11-R)	83 (Table 11)
T7	8–12	23	Fur covered robot (6) (Fig. 14)	Multiple choice (6) (Fig. 11-R)	84 (Table 12)

Table 5 Guidelines for strength of agreement indicated with κ values (values from Landis and Koch [17])

κ	Interpretation
<0	Poor agreement
0.0–0.20	Slight agreement
0.21–0.40	Fair agreement
0.41–0.60	Moderate agreement
0.61–0.80	Substantial agreement
0.81–1.00	Almost perfect agreement

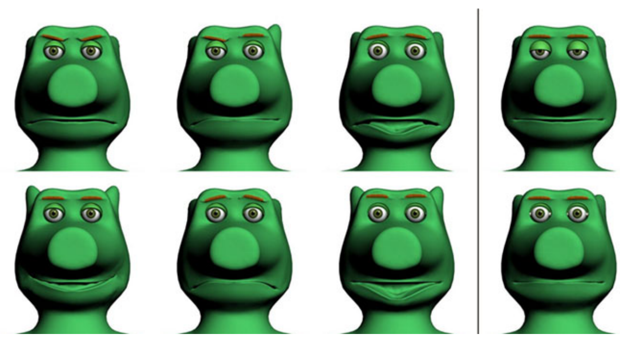

Fig. 9 Facial expressions of the virtual model used in a user-study. The 6 basic emotions (anger, disgust, fear, happy, sad and surprise) *on the left* and the emotions tired and neutral *on the right*

Fig. 10 The sketches used in the evaluation for T1 and T2, copied from Breazeal's survey, adapted from (Faigin 1990) [3]

Twenty-five subjects (6–8 years of age) filled out the questionnaire for the first test (T1). The children were presented an image of our virtual model representing one of the

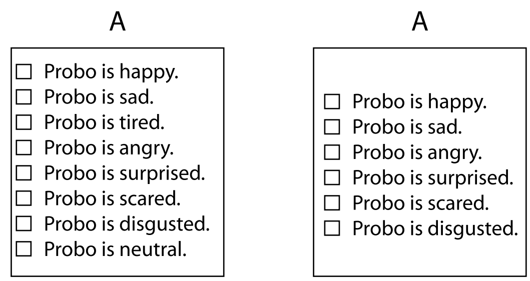

Fig. 11 The multiple choice answer forms used with *on the left* 8 emotions (used in T3,T4) and *on the right* 6 emotions (used in T5,T6,T7)

8 emotions. For each of those images they had to choose the best matching sketch representing human emotions. The results are shown in Table 6. During the test, the observation was made that the children were really looking for a visual resemblance without recognizing the underlying emotions. The same test was performed on sixteen adult people (20–35 years of age), the results of the test (T2) are shown in Table 7. The correct answers were similar with the children's test, with the exception of *surprise*, giving an overall match of 67% for the adults to 60% for the children. Where the children had difficulties identifying the emotion of *surprise* most of the adults (81%) had a positive match. The hypothesis was made that some of the adults, first try to recognize the underlying emotions rather than just look for a graphical similarity, resulting in better matches. It can be noted that there are some ambiguities when using these sketches. For example the match between happy and pleased is not necessarily a wrong answer. Another problem arose finding the matching sketch for the expression of anger, because the tree sketches *mad*, *anger* and *stern* all express a different level of angriness. The authors selected the match with the mad sketch as the most relevant, based on the results (66%). In our follow up studies the sketches were excluded and replaced by words of basic emotions to force the subjects to define the underlying emotions and to get rid of the ambiguities.

In the next user-study 20 children (age 8–12) were asked to identify the emotion expressed by the virtual model using a multiple-choice questionnaire (T3). In this way the chil-

Table 6 The result of the recognition of the virtual model (Fig. 9) using sketches (Fig. 10) with 25 children shown in percentage match (T1)

% match	happy	sad	disgust	anger	fear	tired	surprise	neutral
happy	**54**	0	7	0	0	0	18	0
sad	0	**74**	9	7	15	2	0	0
disgust	0	4	**62**	4	3	0	0	4
mad	1	2	2	**66**	3	9	0	16
fear	0	0	0	0	**48**	0	29	0
tired	0	4	5	2	0	**87**	3	4
surprise	0	0	0	0	9	0	**28**	0
sly grin	5	0	2	11	5	0	0	0
stern	0	12	9	0	2	0	0	40
anger	2	0	0	3	0	0	7	4
repulsion	2	4	0	7	3	0	0	0
pleased	36	0	4	0	12	2	15	32
	overall % 60 Fleiss' Kappa 0.46							

Table 7 The result of the recognition of the virtual model (Fig. 9) using sketches (Fig. 10) with 16 adults shown in percentage match (T2)

% match	happy	sad	disgust	anger	fear	tired	surprise	neutral
happy	**56**	0	0	0	6	0	13	0
sad	0	**88**	0	0	44	13	0	6
disgust	0	6	**63**	0	0	0	0	0
mad	0	0	6	**69**	0	0	0	6
fear	0	0	0	0	**44**	0	0	6
tired	0	0	6	6	0	**81**	0	44
surprise	0	0	0	0	0	0	**81**	6
sly grin	19	0	6	0	0	0	0	0
stern	0	6	19	19	6	0	0	19
anger	0	0	0	6	0	0	0	0
repulsion	0	0	0	0	0	0	0	0
pleased	25	0	0	0	0	6	6	13
	overall % 67 Fleiss' Kappa 0.46							

dren were obliged to look for the underlying emotion represented by the facial expression. The results of this study are shown in Table 8. These result are significantly better (overall 78% against 60%) than with the first test. In this user-study $\kappa = 0.56$ which means there is a moderate agreement between the answers that the children gave. The multiple-choice questionnaire was repeated in an online survey (T4), where 143 adults (age 18–60) completed the questionnaire. The results of T4 are shown in Table 9 and are slightly less (5%) than the test with children (T3). In both tests the recognition of the emotional states *disgust* and *fear* is the lowest.

4.2 Comparison of Display Modi

To compare the expressions of Probo with other similar robot projects, only 6 basic facial expression were included in the last 3 tests. These test include the 3 different display modi as there are; the virtual model, the uncovered prototype and the covered prototype. In these test the motion of the trunk is used to emphasize the expressions, based on the AU of the human nostrils. In the first test (T5), pictures of the virtual model (Fig. 12) were used in a user study with 143 children. This resulted in a overall identification rate of 88% with a substantial agreement ($\kappa = 0.75$) between the children. With the same settings pictures of the prototype of the robot were taken and tested. The results of the test (T6) with the uncovered robot (Fig. 13) are presented in Table 11. Next the results of the test (T7) with the fur covered robot (Fig. 14) are presented in Table 12. For each of the tests 23 different children were participating. Both tests followed the positive outcome of the test with the virtual model, giving an identification rate of respectively 83% and 84%. Evaluations for the projects EDDIE [29], Kismet [3], Aryan [20] and Feelix [7] are compared with the covered prototype of

Table 8 The result of recognition of the virtual model (Fig. 9) using a multiple-choice questionnaire (Fig. 11-L) with 20 children shown in percentage match. (T3)

% match	happy	sad	disgust	anger	fear	tired	surprise	neutral
happy	**95**	0	0	0	0	5	10	0
sad	0	**85**	5	0	20	0	0	0
disgust	0	0	**50**	5	15	0	0	10
anger	0	0	15	**90**	0	0	0	0
fear	0	5	0	5	**65**	0	0	10
tired	0	0	0	0	0	**70**	0	5
surprise	5	10	10	0	0	0	**85**	5
neutral	0	0	20	0	0	25	5	**70**
	overall % 78 Fleiss' Kappa 0.56							

Table 9 The result of recognition of the virtual model (Fig. 9) using an online multiple-choice questionnaire (Fig. 11-L) with 143 adults shown in percentage match (T4)

% match	happy	sad	disgust	anger	fear	tired	surprise	neutral
happy	**89**	1	1	0	0	0	9	0
sad	0	**81**	1	2	19	1	0	2
disgust	1	4	**43**	7	17	0	2	3
anger	0	0	34	**88**	0	1	0	0
fear	0	12	3	1	**51**	0	0	10
tired	1	1	2	1	1	**80**	0	1
surprise	1	0	11	0	11	0	**86**	14
neutral	8	1	4	1	1	18	3	**70**
	overall % 73 Fleiss' Kappa 0.57							

Table 10 The result of the recognition of the virtual model (Fig. 12) using a multiple-choice questionnaire (Fig. 11-R) with 143 children shown in percentage match (T5)

% match	happy	sad	disgust	anger	surprise	fear
happy	**92**	0	0	0	7	0
sad	0	**97**	2	0	0.5	4
disgust	1	2	**81**	2	5	8
anger	0	0	1	**97**	0.5	1
surprise	7	0	12	0	**82**	5
fear	0	1	4	1	5	**82**
	overall % 88 Fleiss' Kappa 0.75					

Table 11 The result of the recognition of the uncovered robot Probo (Fig. 13) using a multiple-choice questionnaire (Fig. 11-R) with 23 children shown in percentage match (T6)

% match	happy	sad	disgust	anger	surprise	fear
happy	**79**	0	0	0	21	0
sad	0	**96**	9	0	0	0
disgust	0	4	**88**	0	0	4
anger	0	0	0	**100**	0	0
surprise	18	0	0	0	**69**	26
fear	4	0	4	0	9	**70**
	overall % 83 Fleiss' Kappa 0.67					

Probo (T7) in Table 13. These results show that the recognition of the emotional states of Probo are significantly higher than the others. In all the projects the recognition of fear has the lowest score.

5 Conclusions and Future Work

The goal of the experiments in this paper was to evaluate the recognition of the facial expressions of our social robot Probo. The suggestion is made that facial expression does influence social acceptance of a child, based on the finding that people like expressive children and adults better than they do passive people [9]. In our opinion a better recognition of a robot's facial expressions contributes to the general social acceptance of that robot. The recognition of the facial expressions is also very important to realize a good non-verbal communication between a human and a robot. In the end it can contribute to a better understanding and collaboration between humans and robots.

This paper described an important module for the robot platform Probo to show emotions using facial expressions. Using a virtual model of Probo, made it possible to advance

Table 12 The result of the recognition of the fur covered robot Probo (Fig. 14) using a multiple-choice questionnaire (Fig. 11-R) with 23 children shown in percentage match (T7)

% match	happy	sad	disgust	anger	surprise	fear
happy	**100**	0	0	0	0	0
sad	0	**87**	0	0	0	9
disgust	0	0	**87**	4	4	4
anger	0	9	4	**96**	0	0
surprise	0	0	9	0	**70**	22
fear	0	4	0	0	26	**65**
overall % 84 Fleiss' Kappa 0.68						

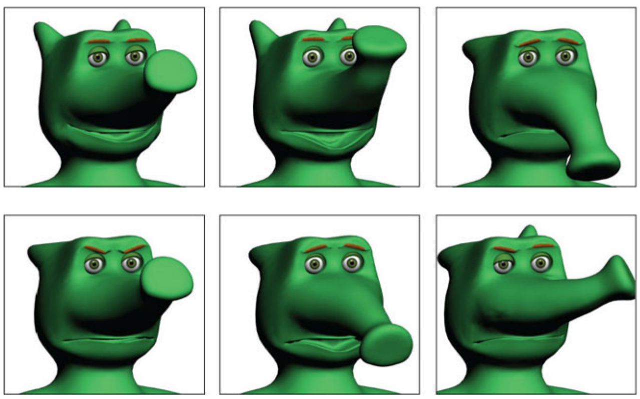

Fig. 12 The 6 basic facial expressions of the virtual model used in T5 (happy, surprise, sad, anger, fear and disgust)

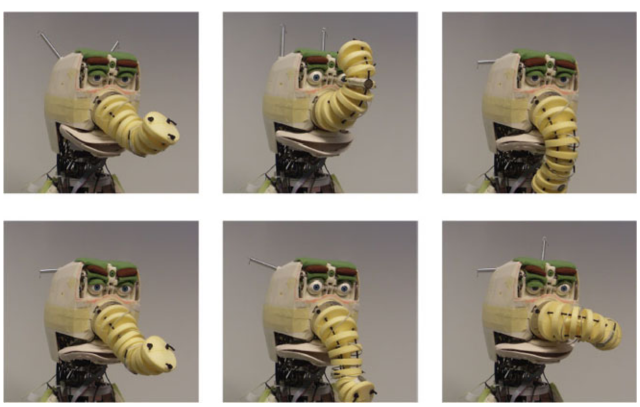

Fig. 13 The 6 basic facial expressions of the uncovered prototype used in T6 (happy, surprise, sad, anger, fear and disgust)

in user testing of the developed emotion space. From the first tests (T1-T4), we can conclude that it is better to use a list of words rather than a list of drawings to measure the recognition of emotions in facial expressions. These test have also shown that there is no significant difference in the ability to recognize the emotions based on gender or age of the participants. Using words forces the participants to look for the underlying emotion from the displayed facial expression. To

Fig. 14 The 6 basic facial expressions of the covered prototype used in T7 (happy, surprise, sad, anger, fear and disgust)

Table 13 Emotion recognition rate of different robot faces

	Probo	Kismet	Eddie	Aryan	Feelix
happy	100	82	58	–	60
sad	87	82	58	–	70
disgust	87	71	58	–	–
anger	96	76	54	94	40
surprise	70	82	75	71	37
fear	65	47	42	41	16
overall %	84	73	57	69	45

also resolve any ambiguity between similar emotions (e.g. *mad* and *anger* or *happy* and *pleasant*) only the basic emotions were taken into account. For the next test (T5) we concluded that after incorporating the trunk movement in the facial expressions an overall recognition rate of 88% was achieved for the virtual model. Connecting the prototype resulted in a recognition rate of 83–84% for the physical robot (T6–T7). It can be expected that the recognition of the virtual model exceeds the physical prototype, because it is harder to achieve the right facial expression with a physical prototype then with a virtual simulation. The expressions of the virtual model are better controllable then the robot itself. Taking a closer look at the differences between the covered and uncovered model, it can be noticed that the silicon mouth is less expressive when it is covered. Therefore it is hard to see if the covered mouth of the robot is open or closed. This can explain the differences in recognition of happiness and sadness between the covered and uncovered pictures. The mouth is better visible in the virtual model. In the pictures of the robot it is harder to see if the mouth is open, what could explain the lower recognition scores for surprise and fear. In comparison with other similar projects the recognition rate of the facial expressions for Probo is the highest. The recognition of emotions in facial expressions is based on social cues. Therefore it is important to emphasize the facial features that play an important role regarding the expression of emotions, such as the eyebrows, eyelids and mouth. Additional features such as ears and trunk increase the recognition rate. The other projects mentioned in Table 13 had a more mechanical appearance. This makes it more difficult to extract the facial features and explains the lower scores. In all the robotic projects the recognition of fear in facial expressions tends to be the most difficult. In comparison with recognition of human facial expressions the overall recognition rate is similar [12].

Future research will focus on the combination of a nonsense affective speech (that is under development [25]) with the facial expressions to further enhance the emotional expressions of Probo. The purpose is the use of the Probo platform for RAT. By adding more building blocks (homeostatic system, attention system, ...,) the autonomy of Probo will be gradually increased providing a higher layer of abstraction for an operator and a more social intelligent robot. More information including movies of the robot and its facial expressions can be found at the project website (http://probo.vub.ac.be).

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