On the design of an emotional interface for the huggable robot Probo

Jelle Saldien and **Kristof Goris** and **Bram Vanderborght** and **Dirk Lefeber**[1]

Abstract. Recently, more robots are being created to interact with human beings in order to satisfy certain social needs. From this point of view we started with the development of a social robot named Probo, intended to comfort and emotionally interact with hospitalized children. In this paper we present the objectives of this new robot and describe the concepts of the first prototype. The robot will be employed in the hospital, as a tele-interface for entertainment, communication and medical assistance. Therefore it requires the ability to express emotions, in order to do so, an emotional interface is developed to fully configure the display of emotions. The emotions, represented as a vector in an emotion space, are mapped to the degrees of freedom used in our robot. A 3D virtual model is created, providing realistic visual feedback to evaluate our design choices for the facial expressions. Images of these expressions were used in a comparison test with children.

1 INTRODUCTION

The development of the huggable robot Probo is part of the ANTY project, of which the main objective is to bring some solutions to the problems and special needs of hospitalized children. A hospitalization has a serious physical and mental influence, particularly on children. It confronts them with situations which are completely different from the ones at home. In hospital, children's experiences are more limited due to the closed and protective environment, which leads to many difficulties [11].

In medical applications, especially in the United States, animal-assisted therapy (AAT) and animal-assisted activities (AAA) are becoming commonly used in hospitals [5]. 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 disease and allergies. Therefore, the use of robots instead of animals has more advantages and has a better chance to be allowed in hospitals. Recently, social pet robots are utilized just for these purposes, termed robot-assisted therapy (RAT). For example the seal robot Paro, who is used for pediatric therapy at university hospitals [20][21]. Currently, Sony's dog robot AIBO [24], Philips' iCat [25] and Omron's NECORO [14] are also being tested for RAT.

The main idea for our robot Probo is to create a friend for children, functioning as an interface between the real, sometimes hard and difficult, hospital world and the imaginary and happy, fantasy world in which children grow up. The robot will also be used as a multidisciplinary research platform, giving other researchers the opportunity to improve and explore the possibilities of RAT. Communication will be the first focus of this robot, having a fully actuated head, capable of expressing a wide variety of facial expressions in contrast to the robots Paro, Aibo and NECORO. The robot iCat also focuses on the facial expression of emotions but lacks the huggable appearance and warm touch that addresses to the children. Probo will emphasize his expression of emotions by using his nonsense affective speech.

2 PROBO

2.1 A huggable robotic imaginary animal

Figure 1. A 3D computer model representing the huggable robot Probo.

The name *Probo* is derived from the word ***Proboscidea***, the order containing only one family of living animals, ***Elephantidae*** or *the elephants*, with three living species (African Bush Elephant, African Forest Elephant, and Asian Elephant) [26]. During the period of the last ice age there were more, now extinct species, including a number of species of the elephant-like *mammoths* and *mastodons*.

[1] Vrije Universiteit Brussel, Belgium, email: jelle.saldien@vub.ac.be

The external of the robot in figure 1 resembles an imaginary animal based on the ancient mammoths. The main aspects are a huggable appearance, an attractive trunk or proboscis, and an interactive belly-screen. The internal mechanics of the robot will be 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. Thereby avoiding Mashiro Mori's uncanny valley [16], stating that as a robot increases in humanness, there is a point where the robot is not fully similar to humans but the balance between humanness and machine-likeness is uncomfortable for a user. The combination of a caricatured and zoomorphic [9] representation of a mammoth-like animal is more useful and effective to accomplish our goals, than using more complex, *realistic* representations. The color of our robot is green, because this color evokes mainly positive emotions such as relaxation and comfort. In [13] the relationship between color and emotion were tested, whereas the color green attained the highest number of positive responses (95.9%), closely followed by yellow (93.9%). The majority of emotional responses for the green color indicated the feelings of relaxation and calmness, followed by happiness, comfort, peace, hope, and excitement. Green was associated with nature and trees, and thus creating feelings of comfort and soothing emotions.

2.2 A tele-interface

We want to employ our robot Probo as a tele-interface focusing on entertainment, communication and medical assistance. A touch screen in the belly of the robot creates a window to the outside world and opens up a way to implement new and existing computer applications.

2.2.1 Entertainment

Young children have a need for distraction and entertainment, providing them with a robotic user interface (RUI) will extend the possibilities of interactive game playing and include the capability of emotional feedback.

2.2.2 Communication

Hospitalized children are sometimes placed in a social isolated environment, strongly reducing the communication with friends and family. The robot can function as the perfect interface to contact others using standard videoconferencing techniques. The eyes of the robot will house the cameras, whereas the screen in the belly will display the image, resulting in the possibility to do interactive video-communication.

2.2.3 Medical Assistance

The robot interface can be used by medical staff to make the children easy about medical routines or operations by providing appropriate information via their pal Probo. In the same philosophy, Probo can accompany the child to comfort it during difficult medical procedures. The unknown environment will be first explored and examinations will be described in a child friendly manner. By using predefined scenarios with pictures, video and sounds Probo can pre-experience, by using its emotions, the medical routines together with the child. A good preparation before the examinations will reduce the child's fear, providing the doctor with better results when assessing the child's pain factor.

2.3 A social interface

The children will have some basic expectations as the robot represents a living animal, resulting in the necessity to react on primary stimuli and to have natural movements. In order to establish some bond with the children, Probo must be able to communicate. In our daily life we rely on face-to-face communication and the face plays a very important role in the expression of character, emotion and/or identity [6]. Mehrabian [15] showed that only 7% of 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. To start face-to-face communication with children our robot is equipped with an intriguing trunk, provoking the children to interact with the robot and stimulate them to maintain focused on its face.

In [3], Breazeal 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. With this project we want to start working with our robot as a social interface, providing a *natural* interface by employing human-like social cues and communication modalities. In this first phase the focus is the construction of a physical prototype with an actuated head,trunk and facial expressions.

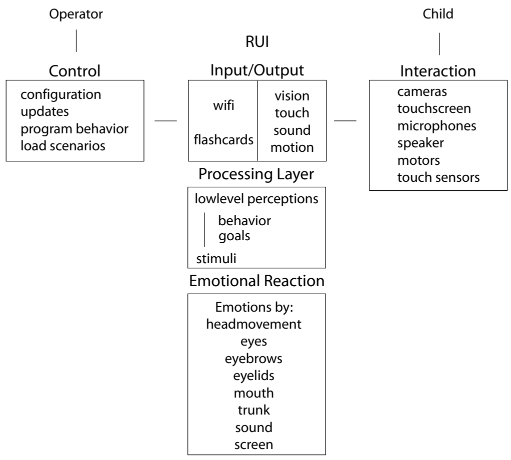

Figure 2. The Robotic User Interface (RUI) between an operator and the children

2.4 Operational Concept

At first, the prototype is a RUI (Figure 2) 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. The robot functions as an interface performing preprogrammed scenarios and reacting on basic input stimuli. The input stimuli, coming from 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 facial features such as facial expressions. Audio analysis includes detecting the direction and intensity of sounds and the recognition of emotions in speech.

To realize a full, body sense of touch, a sensitive skin needs to be implemented. A good example is being developed (by Stiehl et al. [23]) for a therapeutic robotic companion named: The Huggable. A specific behavior-based framework is being developed to process these input stimuli. The framework is based on earlier work of Ortony, Norman and Revelle [17], who focus on the interplay of affect, motivation and cognition in controlling behavior. Each is considered at three levels of information processing: the reactive level is primarily hard-wired and has to assure the quick responses of the robot making it look alive; the routine level provides unconscious, un-interpreted scenarios and automotive activity; and the reflective level supports higher-order cognitive functions, including behavioral structures and *full-fledged* emotions, finally resulting in a sociable robot. As we start out with a social interface, the reactive and routine level are being implemented. At this stage there is a shared control between the operator, configuring behavior, emotions and scenarios, and the robot, having basic autonomous reactions. Further research and development is needed to enhance the robot's emotions and behavior, by implementing a cognitive software architecture at the reflective level to successfully reach a sociable robot in the end. Therefore we started with the study and implementation of joint attention mechanisms for human-robot communication.

2.5 Display of emotions

For the display of the emotions most of the Degrees Of Freedom (DOF) in the face are based on the Action Units (AU) defined by the Facial Action Coding System (FACS) developed by Ekman and Friesen [8]. 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, sorrow, and surprise. Which are often supported as being the 6 basic emotions from evolutionary, developmental, and cross-cultural studies [7]. Because our robot 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 will be replaced by the movement of the 3 DOF trunk and the movement of the ears and the greater visual influence of the trunk will add extra gestures to express the emotions.

2.6 Mechanical Design

The first prototype of the robot has a fully actuated head and trunk. 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 [19]. The trunk of our robot is the most intriguing element according to the children, used to grab and maintain the child's attention. When a child interacts with the trunk, he points his attention towards the face of the robot, locating itself in the scope of the onboard cameras, allowing to do proper vision analysis. Using the cameras in its eyes the robot will be able to focus on a point of attention and follow it with natural eye-movements [10]. The robot will use eyebrows, ears and eyelids to express moods and feelings. The robot must as well fulfill the specifications to operate in a hospital environment and to guarantee a smooth interaction with the children. The intrinsic safety when dealing with child-robot interaction is of very high priority. Children are expecting a huggable friend that never has the intention to hurt them. Flexible materials and compliant actuators are being applied considering these constraints. Because of the high requirements on hygiene requested in hospitals, the fur of our robot can easily be replaced and washed before each visit. The prototype measures about 66cm in height and 32cm in width.

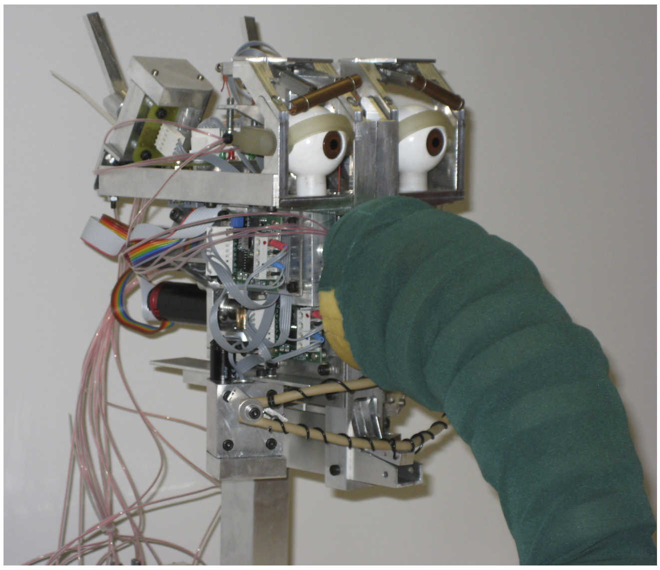

Figure 3. The prototype of the head of Probo

3 FACIAL EXPRESSIONS

3.1 Emotional interface

Several theorists argue that a few select emotions are basic or primary, they are endowed by evolution because of their proven ability to facilitate adaptive responses to the vast array of demands and opportunities a creature faces in its daily life [7] [12]. To realize a translation from emotions into facial expressions, emotions

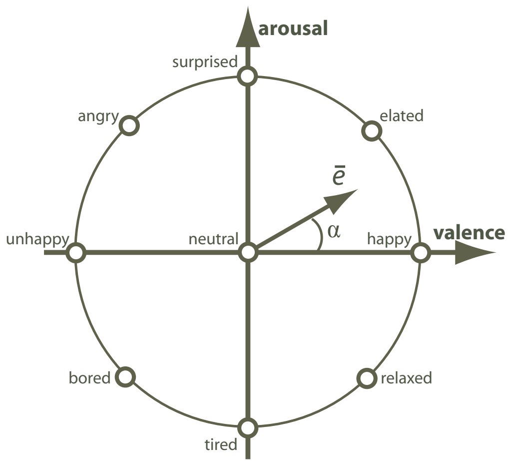

Figure 4. Emotion space based on Russells circomplex model of affect.

need to be parameterized. In the robot Kismet [4], facial expressions are generated using an interpolation-based technique over a three-dimensional, componential *affect space* (arousal, valence, and stance). In our model we started with the two dimensions; valence and arousal to construct an emotion space, based on the circumplex model of affect defined by Russell [18], which has as well been implemented in the robot EDDIE [22]. In our emotion space we use a Cartesian coordinate system, 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 (Figure 4). In this way we can specify basic emotions on a unit circle, placing the neutral emotion $e(0, 0)$ in the origin of the coordinate system. Now each emotion can also be represented as a vector with the origin of the coordinate system as initial point and the corresponding arousal-valence 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, we set a value for each basic emotion on the unit circle and use linear interpolation to attain a contiguous relation. 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 (Figure 5) for the DOF controlling the eyelid, extra points were added in the first half of the emotion space respectively starting and ending with the happy emotion ($\alpha = 0° = 360°$).

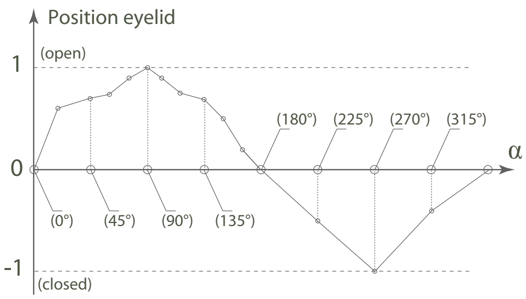

Figure 5. Adjustable interface for defining the value off the DOF (controlling the position of the eyelid) for each emotion (angle α).

An emotional interface (Figure 6) has been developed where the user can fully configure the facial expressions and use the emotion space to test the different emotions and transitions. The user will have visual feedback from a virtual model of the robot.

3.2 Virtual model

A 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

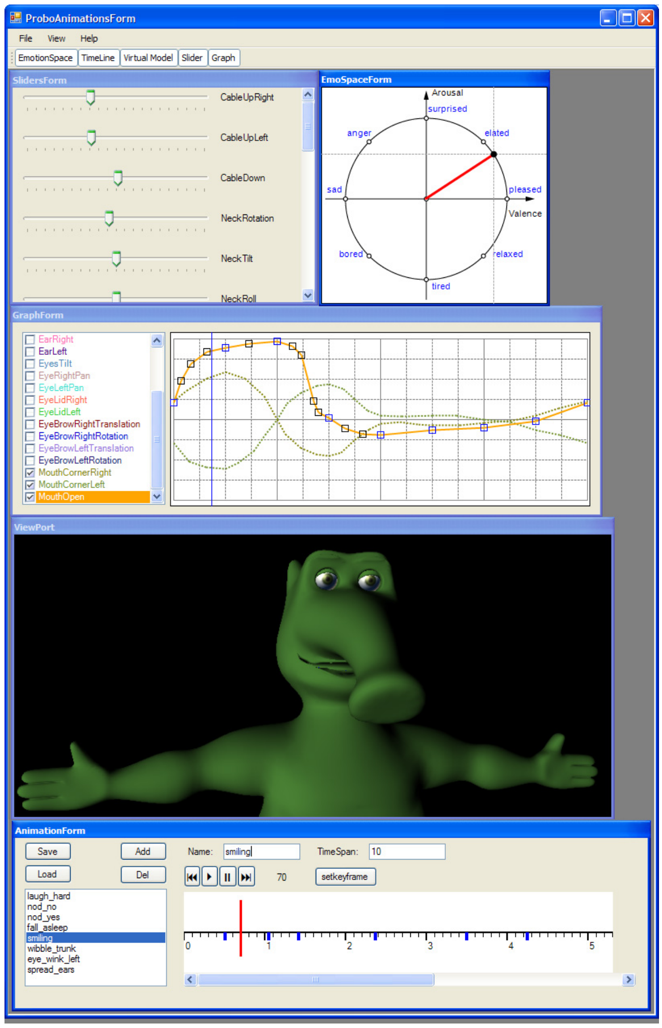

Figure 6. Emotional interface for testing facial expressions.

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 (Figure 7). This model has also been implemented in Microsoft XNA environment where it is linked with the emotional interface and used to create different animations. Each animation consist of different key frames, which hold the values of the DOFs at a given time. There is a linear interpolation between the key frames resulting in a contiguous animation. The emotional interface can be used to easily insert emotions at a certain point in an animation. The different animations are stored in a database. The animations will be employed later to build scenarios for the robot.

4 RECOGNITION TEST

To test the recognition of facial expression the virtual model was used in a preliminary user-study. The study was based on a survey performed by Cynthia Breazeal evaluating the expressive behavior of Kismet [4]. We asked the subjects to perform a comparison task

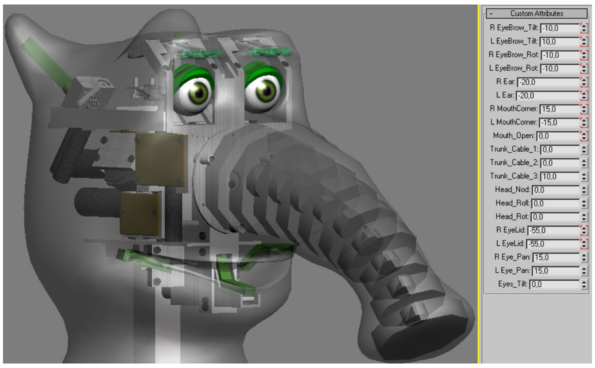

Figure 7. Virtual model with control slider for the DOF.

where they compared color images of the virtual model (Figure 8) with a series of line drawings of human expressions (Figure 9).

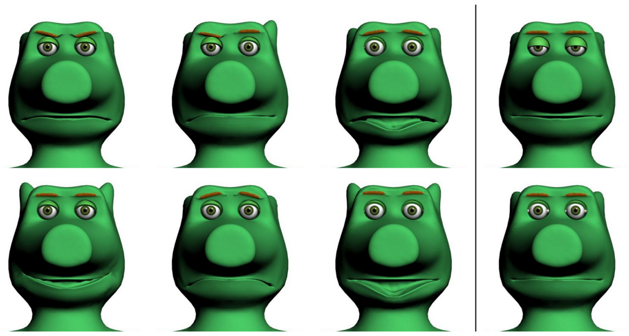

Figure 8. Facial expressions of the virtual model used in preliminary user-study. The 6 basic emotions (anger, disgust, fear, happy, sad and surprise) on the left and the emotions tired and neutral on the right.

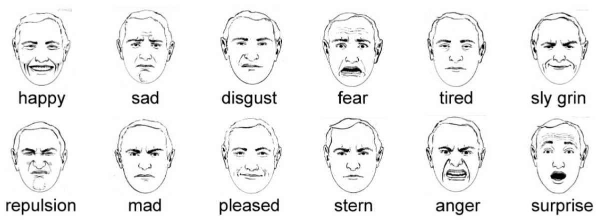

Figure 9. The sketches used in the evaluation, copied from Kismets survey, adapted from (Faigin 1990) [4].

Twenty-five subjects (6 - 8 years of age) filled out the questionnaire. The children were presented an image of our virtual model representing one of the 8 emotions. For each of those images they had to choose the best matching sketch representing human emotions. The results are shown in Table 1.

The results from the test show that the intended emotions *surprise, fear* and *happy* have a low similarity with the sketches. Because the sketches contain also a drawing stating a *pleased* emotion, the low result for *happy* can be explained. Combing the two gives even a 90% similarity between the *happy* emotion and a *happy* or *pleased* human face. The image expressing fear was often related to *sorrow* and *pleased*. There is a strong resemblance between the images representing *fear* and *sorrow* (15%). This can partly be explained because our model lacks lower eyelids resulting in a smaller difference in eye-opening. The lowest similarity was found with the *surprise* emotion, where slightly more children linked the *surprise* image with the *fear* sketch (29%). During the test, the observation was made that the children were really seeking for a visual resemblance without recognizing the underlying emotions. When performing the same test on fifteen adult people (20 - 35 years of age) the results (Table 2) were similar with the exception of *surprise*. Where the children had difficulties identifying the emotion of surprise most of the adults (81%) had a positive match. We also observed that some of the adults, first try to recognize the underlying emotions rather than just look for a graphical similarity, resulting in better matches.

Table 1. The result of the comparison test with children shown in percentage match.

% match	happy	sad	disgust	mad	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

Table 2. The result of the comparison test with adults shown in percentage match.

% match	happy	sad	disgust	mad	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

5 CONCLUSION

The first steps in the creation of a social interface succeeded. The interface can be used to program new animations that can be displayed using the virtual model. All the DOF of the physical prototype can be tested and configured. Using our emotional interface we can translate all the emotions into the values for each DOF. To fully cover all the emotions, we will extend the emotion space with a third dimension: stance, which will allow us to make more difference between anger and fear. The 3D virtual model has helped a lot with the mechanic CAD. By combining techniques from CAD and animation software, we created a fully realistic virtual prototype for simulation. In the next steps the virtual model will be connected with the software controlling the physical prototype, resulting in a real time control interface that can be used by an operator. The results of the preliminary test are taken into account for the preparations of a full scale user study. In this study the children will be asked to look for the underlying emotion instead of finding a matching sketch. The facial expressions of our robot will also be tested with different configurations for the trunk, to see how the trunk can emphasize certain emotions.

ACKNOWLEDGEMENTS

This work was supported by the Brussels-Capital Region.

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