The huggable robot Probo: design of the robotic head

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Abstract. Probo is a social robot intended to be used with children in a hospital environment. Its operational goals are to provide children with information, moral support and comfort in a possible difficult time. This paper reports on the early stages in the development of the expressive huggable robot Probo with potential applications for Human-Robot Interaction (HRI) and Robot-Assisted Therapy (RAT). Drawing on research in social communication, the robot-head, capable of displaying basic emotions, is designed and the design is compared with that of other social robots such as Kismet, Eddie and iCat. Some design criteria and their influence on the actual design are highlighted. This leads to a 17 Degrees of Freedom (DOF) modular non-anthropomorphic soft actuated robotic head.

1 INTRODUCTION

1.1 Research Motivation

Recently, more and more robots are created with intention to interact and communicate with humans while following social rules. The robotic field of social robots and safe Human-Robot Interaction (HRI) opens new areas of applications, like: healthcare, caretaking, assistance, edutainment and entertainment. One of the potential applications of a social robot could be Robot-Assisted Therapy (RAT). RAT is a type of therapy that involves a robot with specific characteristics which become a fundamental part of a person's treatment. RAT will improve the physical, social, emotional, and/or cognitive condition of a patient, as well as provide educational and motivational effectiveness for participants. Currently, RAT is established with social robots like Intelligent System's robot seal PARO [20] [21] , Sony's dog robot AIBO [23], Philips' cat robot iCat [24] and Omron's NECORO [14].

A specific group of young people needing special attention is that of hospitalized children. These children strongly need to be distracted from the scary and at the same time unfortunate hospital live e.g. by getting in contact with their family and friends. Furthermore, they have specific needs for relevant information about their illness, hospital environment, medical investigations and in general, they require moral support [11]. Different projects already exist which aim to use Information and Communication Technologies (ICT) like internet and webcams to allow hospitalized children to stay in contact with their parents, to virtually attend lectures at school, etc. [9]. These ICT applications are usually computer animations displayed on PC, television screens or laptops. However, people are used to interact with embodied creatures and have evolved communication skills, which both need a body for expression. People need a reference point to refer their communication to. In [7] Breazeal concludes that for a socially intelligent robot, it is better to be situated in real world because a three-dimensional robot can be viewed from all sides, without a viewer having to stand directly in front of the robot. From this perspective, we started with the development of a social robot named Probo. This paper is organized as follows: section one describes the research motivation and the project, section two describes the mechanical design of the robotic head considering some specific design criteria, in section three the electronics and Graphical User Interface (GUI) is described, section four shows some experimental results and finally, section five concludes this paper.

1.2 Project Overview

The development of the huggable robot Probo is part of the ANTY project, of which the main objective is to offer solutions to some specific needs of hospitalized children. The robot Probo has to be seen as an imaginary creature that will visit hospitalized children.

Another aspect of the ANTY-project is the creation of a multidisciplinary research community. The prototype of the robot will be used as a tool to investigate future possibilities and approaches to anticipate on arising social problems in Probo's work environment. Therefore, collaboration with pediatricians, sociologists and psychologists is a must. Together with the medical staff new opportunities, such as HRI and RAT, will be investigated.

Besides the development of the prototype and the set up of a multidisciplinary research community, the project also aims to be an educational stimulant for technological innovation by collaborations with other research groups and (high)schools.

1.3 The Huggable Social Robot Probo

Probo (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.

To communicate, our robot requires the ability to express emotions. In order to do so, a fully actuated head, for facial expressions, and a specific language, for nonsense affective speech, is being developed. At first the robot is controlled by an operator and functions as an interface performing preprogrammed scenarios and reacting on basic input stimuli. The input stimuli come from low-level perceptions, that 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. The touch analysis will be used to detect where the robot is being touched and the

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different types of affective touch such as tickling, poking, slapping, petting, etc.

Figure 1. A conceptual view of the huggable social robot Probo

2 MECHANICAL DESIGN

2.1 Design Criteria

2.1.1 Facial Action Coding System

Facial expression is a major modality in human face-to-face communication [16]. If we want to use Probo for displaying facial expressions and emotions, it will need to have some degrees of freedom (DOF) in its head. Most DOF of the face are based on the Action Units (AU) defined by the Facial Action Coding System (FACS) developed by Ekman et al. [8]. AU express a motion of mimic muscles as 44 kinds of basic operations, with 14 AU to express the 6 basic emotions: anger, fear, disgust, sad, happy, and surprise. The number of DOF in Probo's head is compared to other prominent robot heads like: Kismet [6], Leonardo [5], iCat [24], iCub [2], Roman [13], Robota [3], Eddie [22], Aryan [19], Saya [12], WE-4RII [1] and androids of the Intelligent Robotics Laboratory directed by Ishiguro [17]. Most of those robotic heads make use of eyes, eyelids, eyebrows and a mouth to conform with the AU. In contrast with other robotic heads, a special body part, namely the trunk, is added to possibly intensify certain emotional expressions and to increase interactivity. Table 1 shows the DOF of Probo's robot head compared to some other non-android robot heads.

Table 1. DOF and ranges of the actuated joints of Probo's head in comparison with other prominent non-humanoid robot heads

Kismet	Eddie	iCat	Probo		
(DOF)				Range [°]	
Eyes (3)	Eyes (3)	Eyes (3)	Eyes (3)	Pan Tilt	100 80
Eyelids (2)	Eyelids (4)	Eyelids (2)	Eyelids (2)		150
Brows (4)	Brows (4)	Brows (2)	Brows (4)		45(cf exp)
Ears (4)	Ears (4)		Ears (2)		90
Yaw (1)	Yaw (1)		Mouth (3)	Yaw	45
Lips (4)	Lips (4)	Lips (4)		Lipcorners	60
	Crown (1)		Trunk (3)		(cf exp)

2.1.2 Uncanny Valley

Since our robot has to be seen as an imaginary creature, it has no resemblances with existing animals or humans. In this way we avoid Mori's theory of the uncanny valley that states 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 [27].

2.1.3 Intrinsic Safety

Most of the robots are actuated by electric drives as these actuators are widely available and their control aspects are well-known. Because of the high rotational speed of the shaft and the low torque of an electrical motor, a transmission unit is often required. Due to the high reflected inertia of the transmission unit, the joint must be seen as rigid. This is in contrast with our goal to create a huggable robot that has to be felt smooth. 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 feeling.

Compliant actuation is an innovative actuation principle in the world of robotics. Pneumatic muscles (e.g. PPAM [26]), MACCEPA [25] and voice coil actuators [15] are some examples of soft actuators. While the stiffness of the actuated joint can be changed with [25] and [26], it is not required in our application. Thus, compliance is introduced using an easier way, namely by placing elastic elements in series with the motor before attaching the actuated robot joint. In this way the joint can be easily moved when an external force acts on it. Precision positioning is complex in comparison with classic high positioning actuators typically used in industrial applications but the intrinsic safety introduced in the system is of major importance in HRI.

2.1.4 Environment

Although Probo will look and behave like a huggable pal for hospitalized children, it implements some design restrictions. Strict rules concerning hygiene, mobility, noise, usage of electronic devices, etc. are being used in hospital environments. As the robot will be devoted to children, it has to be intrinsic safe, strong and light weighting while still being huggable. These demands imply restrictions on used materials, actuation mechanisms and overall control strategies. In this stage of the development, most parts are made out of aluminium because it 's a strong, light weighted and tractable material. Some very specific and complex parts are manufactered using advanced rapid prototyping techniques.

2.1.5 Modular System Architecture

Besides the restrictions mentioned above, the prototype designer has to keep in mind the need of a modular mechanical system architecture to simplify assemblance and maintenance. This approach leads to an effective development and realization of a robot prototype and requires the use of transferable mechanic and electronic components. By lack of commercially available standard mechanic and electronic modules e.g. eyes, eyebrows, trunk, etc. one must design prototype depended modules. To reduce development and production time, the different modules are designed using commercially available of the shelve components as much as possible.

In the next paragraphs the different modules with the AU needed to express facial expressions and the basic emotions are described. Each module can easily replaced without effecting the others.

2.2 Eyes & Eyebrows

Besides the role of the eyes to show some facial expressions, there are two additional reasons to equip a social robot with actuated eyes.

1. Eye-gaze based interaction
   The phenomenon that occurs when two people cross their gaze is called eye contact, and it enables communication [4]. The same phenomenon between robot and child will be used to encourage HRI. People use eye-gaze to determine what interests eachother. By focussing the robot's gaze to a visual target, the person interacting with the robot can use the robot's gaze as an indicator of the robot's intentions. This greatly facilitates the interpretation and readability of the robot's behavior, as the robot reacts specifically to what it is looking at [18].
2. Active vision
   When a robot is intended to interact with people, it requires an active vision system that can fulfill both a perceptual and a communicative function. An active vision system is able to interact with its environment by altering its viewpoint rather than passively observing it. For that reason, the designed eyes are hollow and can contain small cameras. As its cameras can move, the range of the visual scene is not restricted to that of the static view.

Although we aim a pet-type robot, we based the design of our robot eyes on that of human anthropomorphic data. The imitation of anthropomorphic eyes gives the impression of being natural. In many species, the eyes and its appendages are inset in the portion of the skull known as the orbits or eye sockets. The movements of different body parts are controlled by striated muscles acting around some joints. The movements of the eye are no exception. Each anthropomorphic based eye has six extraocular muscles that control its movements: the lateral rectus, medial rectus, inferior rectus, superior rectus, inferior oblique, and superior oblique. When the muscles exert different tensions, a torque is exerted on the globe causing it to turn. This is an almost pure rotation, having only about one millimeter of translation [10]. So we can consider that the eye rotates about a single point in its center. A seventh extraocular muscle, the levator palpebrae superioris, is the muscle in the orbit that elevates the upper eyelid. Since the lower eyelid is not really actuated by muscles and humans always tilt both eyes together, the eyes module has no actuated lower eyelid and has not the possibility of tilting the eyes separately.

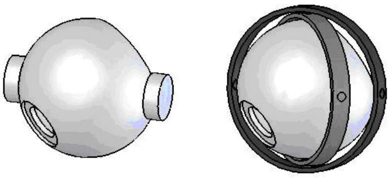

Figure 2. Different possibilities to support a sphere

Two possible eye-supports are shown in Figure 2. The former holds the eye-ball between Teflon parts with the same spherical curvature as the eye-ball. That way the eye has three DOF just like in a spherical joint, and allows smooth rotations around the center of the sphere because of its low friction coefficient. Not one mechanical part intersects the eye-ball. That way the eyes can bulge out of the head. The latter concept consists of two rings and two axes. One rotation axis passes through the center point of the eye and holds the eye in the inner ring, that way the eye can rotate relativly to the inner ring. A second rotation axis passes through the inner and outer ring, that way the inner ring (holding the eye) can rotate relativly to the outer ring. While panning the eye, the inner ring comes out of the plane of the other ring. That way the eye can not bulge out as far as in the former support. Most of the other mentioned robot heads uses the second support type or a variant on it. This often leads to visible mechanical parts and to Mori's theory of uncanny valley. For this reason we have choosen the first support type.

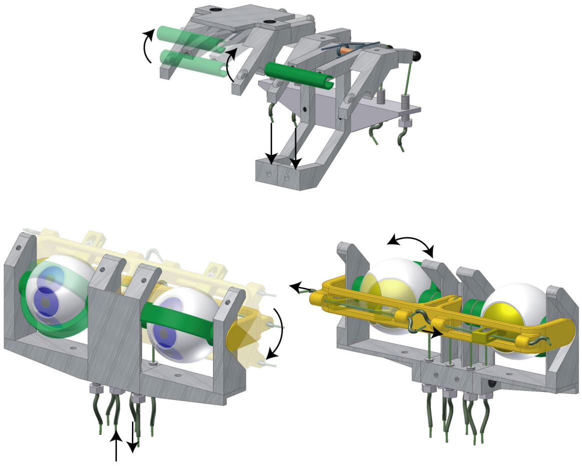

Figure 3. CAD and working principle of eyes and eyebrows of Probo

The five DOF eyes module exists of two hollow eyeballs supported in an orbit as shown in Figure 3. The eyes can pan separately and tilt together. Each eye can be covered by an upper eyelid. The eyelids can blink separately. The eyebrows module fits on top of the eyes module. Each eyebrow has two DOF meaning that both the vertical position and the angle of each eyebrow can be set independently. Nine commercially available hobbyist servomotors together with a Bowden cable mechanism are used to power the eyes, eyelids and eyebrows. Axial springs and the usage of flexible cables both introduce compliance. Position measurement is established by the embedded controllers in the servomotor. Using flexible Bowden cables creates the opportunity to group and to isolate the different servos and to place them anywhere in the robot. That way heat and noise dissipation can be controlled and the head can be held light-weighted, both resulting in a safe design.

2.3 Trunk

The proboscis or trunk of our robot seems to be the most intriguing element according to the results of a small survey amongst children aged 10-13. It is used to grab and maintain the child's attention. When the child's attention focussed on the trunk, the child's face fits within the scope of the on board eye cameras. This simplifies the recognition of the mood or emotional status of children. That way our robot can react properly to different situations.

The three DOF trunk as shown in Figure 4 consists of a foam core with segmented extension discs. Axial to the centerline, three flexible cables are guided through the discs. These cables are fixed to the

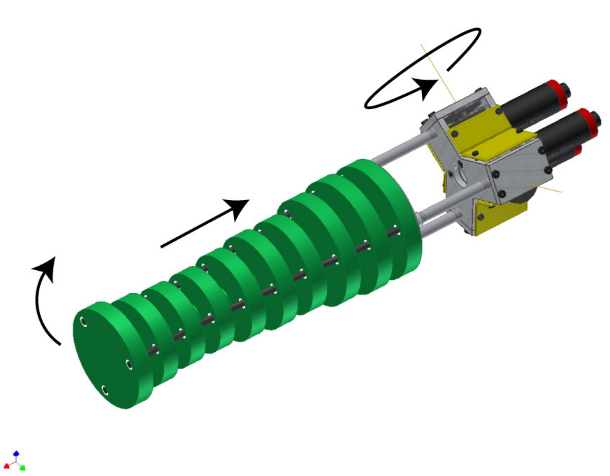

Figure 4. CAD and working principle of the trunk of Probo

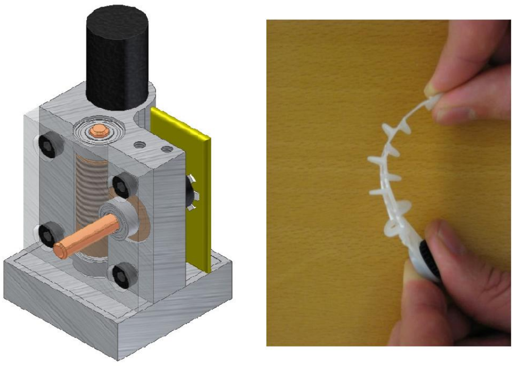

Figure 5. Mechanism to actuate ears and mouth corners

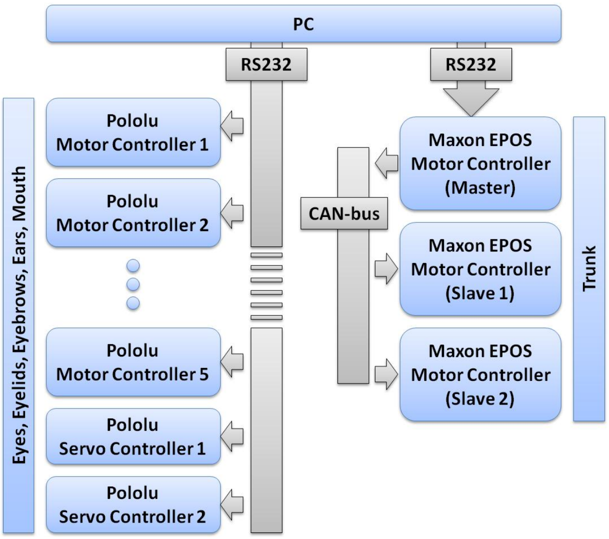

Figure 6. Architecture of the motor controllers

front disc. Each cable can be wind up on a pulley and this will result in a motion of the entire trunk. The motion of the trunk depends, upon other things, on: the number of discs, the dimensions of the discs and the core, the flexibility of the cables and the composition of the foam. The compliance of the trunk is secured by using the foam and the flexible cables. The trunk weighs very light. That way, possible impact during HRI does not harm the children.

Three maxon brushless motors are used to actuate the trunk. Each motor is coupled with a worm worm-wheel gear train to reduce the rotational speed and to increase the output torque. A worm drive is used because of its self locking capability. The direction of transmission (input shaft vs. output shaft) is not reversible, due to the greater friction between the worm and worm-wheel. That way the position of the trunk will not change after being set and no motor current will be dissipated, resulting in a energy efficient design. Optical encoders are used to calculate the angular displacement of the pulleys. An estimation of the trunk position can than be made.

2.4 Mouth & Ears

To reinforce the impression that Probo is a living creature, lip movements and speech are generated. Probo will communicate primarily with hospitalized children, whose reactions are very emotional due to their unfortunate situation. Hereby, it is of essence to apply emotions to Probo's speech communication. Because an intelligent free dialog with a human is currently beyond our technological capabilities, Probo will use nonsense affective speech [28],[30]. Probo's mouth has an upper lip and a lower lip. The middle of the upper lip is attached to the trunk. The middle of the lower lip can move vertically so that the mouth can jaw. Both lips come together in the mouth's corners. These mouth corners are actuated. The mechanism used for actuating the mouth corners is the same as that used in the ears module and is shown in Figure 5.

The mechanism consist of a brushed Maxon motor with a planetary gear train. The first gear train is followed by a second one which is a worm drive. The advantages of this drive are the same as mention above. Position measurement is done by an absolute position sensor fixed on the output shaft. On the output shaft either an ear or a mouth corner is attached. Jawing is established by movement of the middle of the lower lip. An axial spring in the lower lip and a well-thought design of the actuated parts as shown in Figure 5 secure the compliance. Compliance is introduced by the shape of the ear and mouth corners and by the use of flexible materials. The actuated part is flexible in a certain direction, and stiff in the tangent direction. Position measurement of the joints is also done by absolute position sensors. In comparison with [5],[13] and [18], Probo has less DOF in the mouth. In fact this is no restriction to express the basic emotions.

Each ear has one DOF. The movement of our roboic ear is a rotation which consits of two combined rotations. The first rotation turns the entire ear while the second rotation twists the ear axially. That way the ear's opening is pointed to the front when the robot is attended and the opening is pointed to the ground when the ear lies flat to the back.

3 ELECTRONICS & INTERFACE

As described above, three different kind of motors are used and each type of motor has a different motor driver. The Maxon brushless motors, which are used to actuate the trunk, are driven by Maxon's

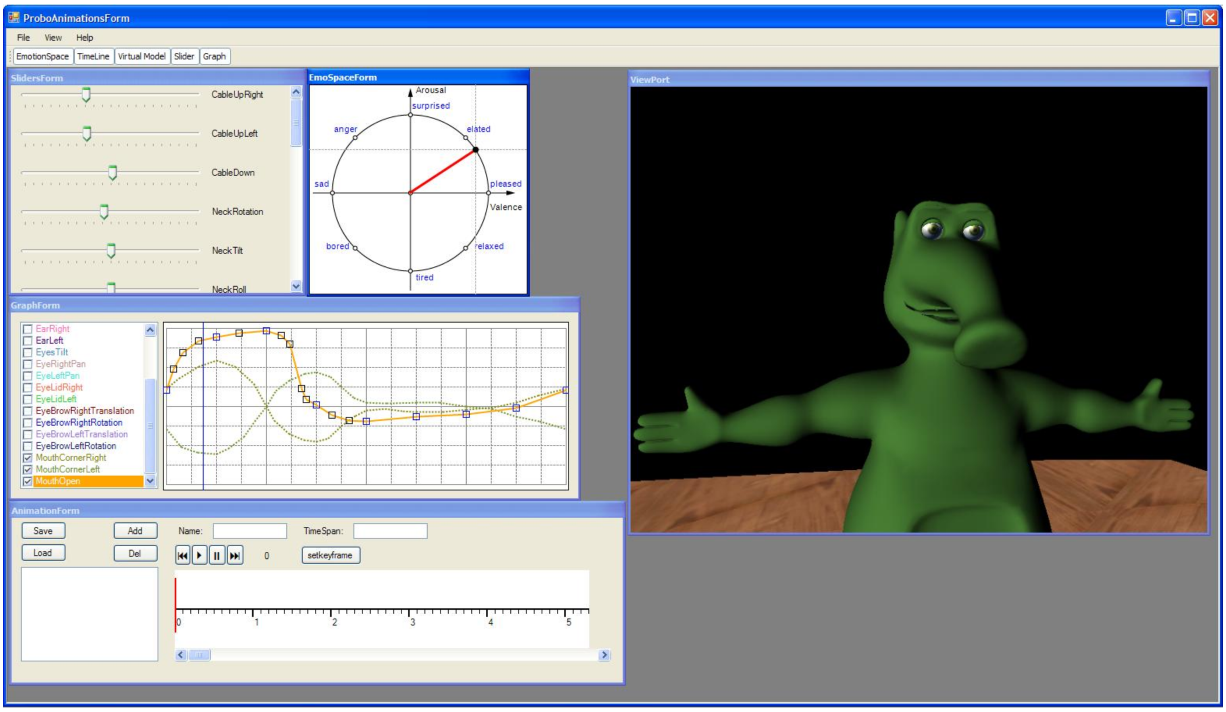

Figure 7. The GUI running on the host PC to control Probo and to create some behaviours. Realtime feedback is given by the virtual Probo

EPOS Motor Controllers. The Maxon brushed motors, used in the mouth and the ears, are driven by Pololu's Motor Controllers with Feedback and the hobbiest servo motors, for the eyes and eyebrows, are driven by Pololu's Micro Serial Servo Controllers. Figure 6 shows the architecture.

In this stage of the development, a PC with a GUI is used to control the different motors. Two serial ports, using the RS232 protocol, are used to communicate with the motor controllers. The first serial port communicates with one of the three Maxon EPOS motor controllers. This controller acts as a master in a master-slave set up with the other two Maxon EPOS motor controllers (slaves). The communication between master and slaves is done with CAN. The second serial port communicates with all Pololu controllers. Despite the use of serial communication and the high number of motor positions and speeds needed to refresh, the refresh time rests less than the mechanical inertia and consequently acceptable.

The software running on the host PC is written in C# in the .NET framework. Besides its use as GUI (Figure 7) the software sends the desired motor positions and speeds to the respective motor controllers. By moving sliders, all actuated parts can be moved. A virtual model on the screen shows the according expression of the face real time. A time bar with keypoints can be used to generate movements from one expression to another.

4 EXPERIMENTS

Several experiments and tests were performed during development phase. After conceptual experiments CAD drawings of the mechanisms were made in Autodesk Inventor and implemented in a virtual model. The virtual model, generated in Autodesk 3D Studio Max, was used to evaluate virtually the mechanisms and the possibility to express emotions with them (Figure 8).

The looks of the robot and the way it reacts can rather be evaluated subjectively than objectively. In this scope the virtual model based on the real intern mechanical designs will help converting faster to a nice looking and moving prototype in the iterative process of designing. Tests with different mechanisms were done until looks were fine and movements were smooth. Some of these tests and experiments were:

- display of basic emotions: the 6 basic emotions according to Ekman [8], more specific: anger, fear, disgust, sad, happy, and surprise are expressed with the virtual model and are demonstrated in Figure 8;
- eyes and eyebrows tests: the tendon driven eyes, eyelids and eyebrows were tested and some expressions are shown in Figure 11;
- trunk experiments: during these experiments different trunks were tested. The trunks differ in used materials (foams and flexible cables) and in shape (the number of discs). This iterative process leads to the designed trunk which moves quite smooth and natural. Figure 11 shows the result of such a test.

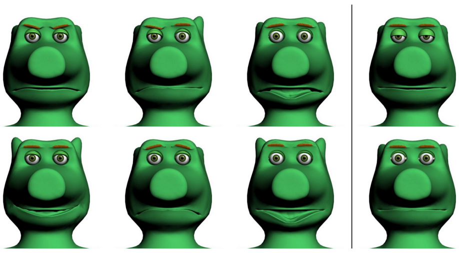

Figure 8. Virtual model expressing the 6 basicemotions: anger, disgust, fear, happy, sad and surprised. On the the right a sleepy and neutral face

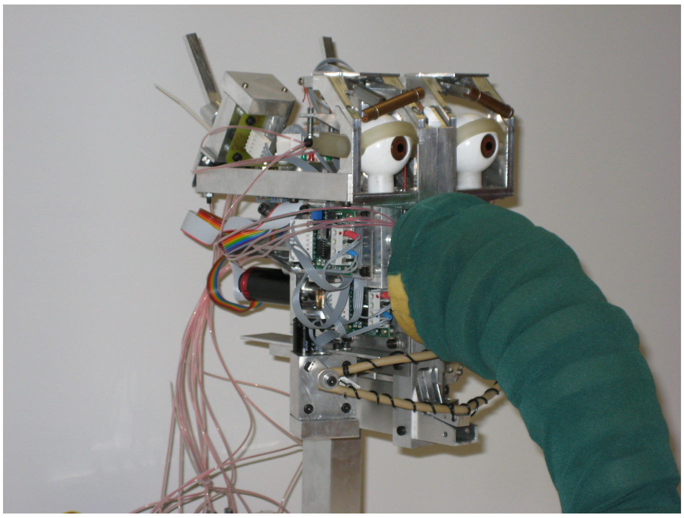

Figure 9. Assembled robotic head of the social robot Probo

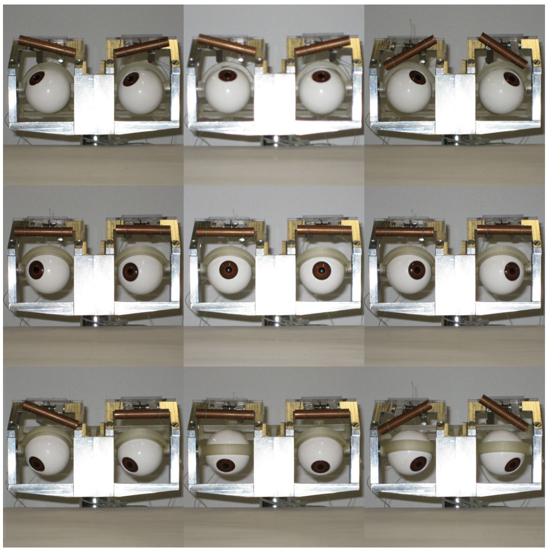

Figure 10. Experimental results of the eyes and eyebrows

Figure 11. Experimental results of the trunk

5 CONCLUSION & FUTURE WORK

In this paper the design of a new soft actuated, and intrinsic safe, robotic head is highlighted. The head uses a strict set of Action Units (AU) defined by the Facial Action Coding System (FACS) to express the 6 basic emotions; anger, fear, disgust, sad, happiness, and surprise. The robotic head will be used in the huggable social robot Probo. The head has 17 DOF. The eyes, eyelids, eyebrows, mouth, trunk and ears can be moved in order to show some facial expressions. In contrast with other prominent robotic heads, a specific element, namely the trunk is added. First experiments with some assembled modules, to test motions and ranges, are satisfactory. The GUI, running on a host PC, controls the robotic head and is used to program animations.

In the near future, three DOF will be added. The head will be supported an actuated neck module. In this way the entire head can pan, tilt and rotate. A fur jacket will be used to cover the robotic head and to give the robots head a nice, and friendly look. Meanwhile software will be written to generate emotional behaviours.

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REFERENCES

[1] M. AIZUDDIN, H. MIWA, K. ITO, M. MATSUMOTO, M. ZECCA, S. ROCCELLA, MC CARROZZA, H. TAKANOBU, and A. TAKANISHI, ‘Development of Emotional Expression Humanoid Robot WE-4RII-Integration of Humanoid Robot Hand RCH-1’, *Nippon Robotto Gakkai Gakujutsu Koenkai Yokoshu (CD-ROM)*, **22**, 3L13, (2004).

[2] R. Beira, M. Lopes, M. Praça, J. Santos-Victor, A. Bernardino, G. Metta, F. Becchi, and R. Saltaren, ‘Design of the Robot-Cub (iCub) Head’, *Proc. IEEE International Conference on Robotics and Automation, ICRA, Orlando, May*, (2006).

[3] A. Billard, B. Robins, J. Nadel, and K. Dautenhahn, ‘Building Robota, a Mini-Humanoid Robot for the Rehabilitation of Children with Autism’, *The RESNA Assistive Technology Journal*, (2006).

[4] C. Breazeal, ‘Regulation and Entrainment in Human-Robot Interaction’, *Experimental Robotics VII*, (2001).

[5] C. Breazeal, ‘Toward sociable robots’, *Robotics and Autonomous Systems*, **42**(3-4), 167–175, (2003).

[6] C. Breazeal and MASSACHUSETTS INST OF TECH CAMBRIDGE ARTIFICIAL INTELLIGENCE LAB, *Affective Interaction Between Humans and Robots*, Springer, 2005.

[7] C.L. Breazeal, *Designing Sociable Robots*, Mit Pr, 2002.

[8] P. EKMAN, ‘Are there basic emotions?’, *Psychological review*, **99**(3), 550–553, (1992).

[9] Website for hospitalized children. Simon & Odil: http://www.simonodil.com/.

[10] K. Goris, J. Saldien, B. Vanderborght, B. Verrelst, R. Van Ham, and D. Lefeber, ‘The Development of the Eye-System for the Intelligent Huggable Robot ANTY’, *CLAWAR*, (2006).

[11] H. Grietens, J. Vanderfaeillie, W. Hellinckx, and W. Ruijssenaars, *A perspective on remedial education with child en youth problems*, Leuven/Voorburg: Acco, 2005.

[12] T. Hashimoto, S. Hiramatsu, T. Tsuji, and H. Kobayashi, ‘Realization and Evaluation of Realistic Nod with Receptionist robot SAYA’, *Robot and Human interactive Communication, 2007. RO-MAN 2007. The 16th IEEE International Symposium on*, 326–331, (2007).

[13] J. Hirth, N. Schmitz, and K. Berns, ‘Emotional Architecture for the Humanoid Robot Head ROMAN’, *Robotics and Automation, 2007 IEEE International Conference on*, 2150–2155, (2007).

[14] A.V. Libin and E.V. Libin, ‘Person–Robot Interactions From the Robopsychologists’ Point of View: The Robotic Psychology and Robotherapy Approach’, *Proceedings of the IEEE*, **92**(11), 1789–1803, (2004).

[15] J. McBean and C. Breazeal, ‘u¿ Voice Coil Actuators for Human-Robot Interaction¡/u¿. IEEE’, *RSJ International Conference on Intelligent Robots and Systems (IROS04), Sendai, Japan*, (2004).

[16] A. Mehrabian, ‘Communication without words’, *Psychology Today*, **2**(4), 53–56, (1968).

[17] T. Minato, M. Shimada, H. Ishiguro, and S. Itakura, ‘Development of an Android Robot for Studying Human-Robot Interaction’, *Proceedings of the 17th International Conference on Industrial & Engineering Applications of Artificial Intelligence & Expert Systems*, 424–434, (2004).

[18] D. Miyauchi, A. Sakurai, A. Nakamura, and Y. Kuno, ‘Human-robot eye contact through observations and actions’, *Pattern Recognition, 2004. ICPR 2004. Proceedings of the 17th International Conference on*, **4**, (2004).

[19] H. Mobahi, ‘Building an Interactive Robot Face from Scratch’, *Bachelor of Engineering Final Project Report, Azad University, Tehran-South Campus, Tehran, Iran, Maggio*, (2003).

[20] T. Shibata, T. Mitsui, K. Wada, A. Touda, T. Kumasaka, K. Tagami, and K. Tanie, ‘Mental commit robot and its application to therapy of children’, *Advanced Intelligent Mechatronics, 2001. Proceedings. 2001 IEEE/ASME International Conference on*, **2**, (2001).

[21] T. Shibata, K. Wada, T. Saito, and K. Tanie, ‘Robot Assisted Activity for Senior People at Day Service Center’, *Proc. of Intl Conf. on Information Technology in Mechatronics*, 71–76, (2001).

[22] S. Sosnowski, A. Bittermann, K. Kuhnlenz, and M. Buss, ‘Design and Evaluation of Emotion-Display EDDIE’, *Intelligent Robots and Systems, 2006 IEEE/RSJ International Conference on*, 3113–3118, (2006).

[23] T. Tamura, S. Yonemitsu, A. Itoh, D. Oikawa, A. Kawakami, Y. Higashi, T. Fujimooto, and K. Nakajima, ‘Is an Entertainment Robot Useful in the Care of Elderly People With Severe Dementia?’, *Journals of Gerontology Series A: Biological and Medical Sciences*, **59**(1), 83–85, (2004).

[24] AJN van Breemen, ‘iCat: Experimenting with Animabotics’, *Proceedings, AISB 2005 Creative Robotics Symposium*, (2005).

[25] R. Van Ham, B. Vanderborght, M. Van Damme, B. Verrelst, and D. Lefeber, ‘MACCEPA, the mechanically adjustable compliance and controllable equilibrium position actuator: Design and implementation in a biped robot’, *Robotics and Autonomous Systems*, **55**(10), 761–768, (2007).

[26] B. Verrelst, R. Van Ham, B. Vanderborght, D. Lefeber, F. Daerden, and M. Van Damme, ‘Second generation pleated pneumatic artificial muscle and its robotic applications’, *Advanced Robotics*, **20**(7), 783–805, (2006).

[27] D.E. Wilson and D.A.M. Reeder, *Mammal Species of the World: A Taxonomic and Geographic Reference*, Johns Hopkins University Press, 2005.

[28] S. Yilmazyildiz, W. Mattheyses, Y. Patsis, and W. Verhelst, ‘Expressive Speech Recognition and Synthesis as Enabling Technologies for Affective Robot-Child Communication’, *LECTURE NOTES IN COMPUTER SCIENCE*, **4261**, 1, (2006).