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Probo, an Intelligent Huggable Robot for HRI Studies with Children

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1. Introduction

Nowadays, robots are mostly known for their work in factories in industries such as automotive, electrical and electronics, chemical, rubber and plastics and many others. Robots are used for a wide variety of tasks like handling of materials and processes, welding and soldering, etc. The next generation of robots will be used in close collaboration with people in a wide spectrum of applications. For example, service robots will help elderly and assist disabled people. Household robots will be used in our homes and offices. Our children will play with entertainment robots. Medical robots assist in surgery and robotic prostheses replace limbs for amputees. Orthoses and exoskeletons can facilitate the rehabilitation process to regain mobility or manipulation skills. They also enlarge human strengths to carry heavy objects, for instance, nurses lifting a patient in and out of a bed. In lots of applications human and robots will work in a more close collaboration. For instance, NASA is developing a Robonaut to work together with astronauts in space.

Statistics from the International Federation of Robotics (IFR) show worldwide an increasing request of innovative robots, especially in non-automotive sectors. A growth can be noticed in both traditional and new markets, ranging from the industrial field to the service robotics, both for professional use and for domestic applications. However, European society has a different relationship towards robots than the Japanese or US society. The Japanese are more accepting of technological change. For instance, robots have always been a source of comics and amusement in Japan, making it easier to introduce robots into a personal environment. The Japanese Robot Association (JARA) predicts that the personal robot industry will be worth more than $50 billion dollars a year worldwide by 2025, compared with about $5 billion today. The technology of current industrial robots is insufficient to respond to this issue. This means that human-robot interaction using social robots must be studied in the different regions all over the world to address the different needs. Reasons why personal robotics is emerging now are the fact that actuators and sensors can be made very small and cheap, and the required computational power for computing real time all the software components is still increasing. And, last but not least, the markets for such robots are coming. Especially the aging population in Japan, Europe and United States faces a number of daunting societal problems. Also its dwindling work force and the increased cost of care demand out-of-the-box thinking. Companion and service robots are one part of the solution.

However, the shift from industrial robots towards these service, personal and domestic robots leads to specific design criteria. For instance, an industrial robots can carry heavy

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loads with high accelerations to be able to work with high precision at high speed. Safety is established by putting them in cages, away from humans. This is possible because a factory is a well know environment. While the goal of the next generation of robots is to work in close collaboration with humans in daily life circumstances. These environments are often unknown and very dynamic. Tracking and precision performances become less stringent, while safety, cognition aspects, energy efficiency, etc. become the challenges to conquer. For acceptable human robot interaction, a good communication between the human and the robot is needed. According to Mehrabian (1968) its 7%-38%-55%-rule, most of our communication goes over non-verbal means, like facial expression and gestures. In order to communicate properly, the robot must be able to have those capabilities as well. That way the robot becomes a social robot. Idea of this approach is to adapt the communication with human-centered design instead of adapting to the technology of machines, which is now the case with computers and mobile devices.

2. The Probo project

The entire Probo project focuses on physical and cognitive human-robot interaction (HRI) especially with hospitalized children. A hospitalization can have serious physical and mental influences, especially on children. It confronts them with situations that are completely different from those at home. These children need to be distracted from the, in their eyes, scary and unfortunate hospital life, for instance, by getting in contact with their family and friends. Furthermore, they require moral support and they have specific needs for relevant information about their illness, the hospital environment, medical investigations, etc. Several projects already exist that 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 and to provide information as described by Fels et al. (2003). However, these ICT applications are usually computer animations displayed on PC, television screens or laptops. Breazeal (2002) shows the importance of embodied creatures during interaction with the environment and with others.

Animals could be such an embodied creature. In medical applications there exists animal assisted therapy (AAT) and animal-assisted activities (AAA). AAT and AAA are expected to have useful psychological, physiological and social effects. Some psychological studies, by Burch (1991), Allen et al. (1991), Ballarini (2003), have already shown that animals can be used to reduce heart and respiratory rate, lower levels of stress, progress mood elevation and social facilitation. Nonetheless animals are difficult to control, they always have a certain unpredictability, and they are possible 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. There is existing early research on using robots in care settings for the elderly or mentally challenged, but the majority of these studies use wizard-of-oz methodologies to explore the patients' attitudes towards the robots. Recently, social pet robots are utilized just for these purposes, termed robot-assisted therapy (RAT). For example, the seal robot Paro by Shibata et al. (2001a) and Shibata et al. (2001) is used for pediatric therapy at university hospitals. Currently, Sony's dog robot AIBO by Tamura et al. (2004), Philips' cat robot iCat by van Breemen (2005) and Omron's cat robot Necoro (in Libin & Libin (2004)) are also being tested for RAT. However there is few research into using robots in therapeutic settings for young patients. Some research in this area is done by Dautenhahn (1999) and her co-workers studies into the interaction between autistic children and robots.

The development and construction of the social robot Probo, with the main ideas described in the former section in mind, is part of the entire project. Probo will serve as a multi-disciplinary research platform for similar studies where not only the cognitive HRI aspects are important, but also the physical HRI aspects such as touch and hug. The next section will show some remarkable robotic platforms used for research on cognitive human robot interaction and some of their features will be compared with those of the Probo platform in the section after it.

3. Remarkable social robots

In recent decades, research labs and companies all over the world are developing social robots. Social robots could be defined as robots that people anthropomorphize in order to interact with them. Pioneer robot is MIT's robot Kismet by Breazeal (2002). Kismet is an expressive anthropomorphic robotic head with twenty-one degrees of freedom (DOF). Three DOF are used to direct the robot's gaze, another three DOF control the orientation of its head, and the remaining fifteen DOF move its facial features such as eyelids, eyebrows, lips, and ears. To visually perceive the person who interacts with it, Kismet is equipped with a total of 4 color CCD cameras and a lavalier microphone is used to process vocalizations.

Kismets' successor Leonardo is developed in collaboration with the Stan Winston Studio. It combines the studio's artistry and expertise in creating compelling animatronics characters with state of the art research in socially intelligent robots. Leonardo has 69 degrees of freedom. With 32 of those in the face alone, Leonardo is capable of near-human facial expression. Moreover, Leonardo can gesture and is able to manipulate objects in simple ways. Leonardo is about 2.5 feet tall. Unlike the vast majority of autonomous robots today, Leonardo has an organic appearance. It is a fanciful creature, clearly not trying to mimic any living creature today. A camera in Leonardo's right eye captures images and a real-time face recognition system can be trained via simple social interaction with the robot. The interaction allows people to introduce themselves and others to Leonardo, who tries to memorize their faces for use in subsequent interactions.

The Huggable is another type of robotic companion being developed at the MIT Media Lab. It is being used for healthcare, education, and social communication applications (Stiehl et al. (2005)). It has a full body sensitive skin with over thousendfivehundred sensors, quiet back-drivable actuators, video cameras in the eyes, microphones in the ears, an inertial measurement unit, a speaker, and an embedded PC with 802.11g wireless networking. An important design goal of the Huggable is to make the technology invisible to the user. The movements, gestures and expressions of the bear convey a personality-rich character, not a robotic artefact. A soft silicone-based skin covers the entire bear to give it a more lifelike feel and heft, so you do not feel the technology underneath.

Nexi is being developed as a team member of four small mobile humanoid robots that possess a novel combination of mobility, moderate dexterity, and human-centric communication and interaction abilities (Breazeal et al. (2008)). The purpose of this platform is to support research and education goals in HRI, teaming, and social learning. MIT's collaborative partners in this project are UMASS Amherst, Meka Inc. and Xitome Design. Nexi has an expressive head with fifteen DOF in the face to support a diverse range of facial expressions including gaze, eyebrows, eyelids and an articulate mandible for expressive posturing. A four DOF neck mechanism support a lower bending at the base of the neck as well as pan-tilt-yaw of the head. Perceptual inputs include a colour CCD camera in each eye, an indoor Active 3D IR camera in the head, four microphones to support sound localization and a wearable microphone for speech. The five DOF lower arm has forearm roll and wrist flexion. Each hand has three fingers and an opposable thumb. The thumb and index finger are controlled independently and the remaining two fingers are coupled. The fingers compliantly close around an object when flexed, allowing for simple gripping and hand gestures.

Keepon is a small creature-like robot designed to interact with children by directing attention and expressing emotion. It is developed by BeatBots LLC. The company's core design philosophy centres around cuteness, personality, simplicity, and rhythmic interaction. Keepon's minimal design makes its behaviors easy to understand, resulting in interactions that are enjoyable and comfortable, particularly important in the research on human social development. It has soft rubber skin, cameras in its eyes, and a microphone in its nose. Keepon has 4 degrees of freedom. Attention is directed by turning and nodding, while emotion is expressed by rocking side-to-side and bobbing up. It has been used since 2003 in research on social development and communication. Behaviors such as eye-contact, joint attention, touching, emotion, and imitation between Keepon and children of different ages and levels of social development have been studied. In the case of children with autism and other developmental disorders, one have had encouraging results with the use of Keepon as a tool for therapists, pediatricians, and parents to observe, study, and facilitate social interactions (Kozima et al. (2009)).

TOFU is a project that introduces a robotic platform for enabling new opportunities in robot based learning with emphasis on storytelling and artistic expression. This project introduces a socially expressive robot character designed to mimic the expressive abilities of animated characters by leveraging techniques that have been used in 2d animation for decades. Disney Animation Studios pioneered animation tools such as squash and stretch and secondary motion in the 50's. Such techniques have since been used widely by animators, but are not commonly used to design robots. TOFU can also squash and stretch. Clever use of compliant materials and elastic coupling, provide an actuation method that is vibrant yet robust. Instead of using eyes actuated by motors, TOFU uses inexpensive OLED displays, which offer highly dynamic and lifelike motion (Wistort & Breazeal (2009)).

Philips' robot cat iCat (van Breemen (2005)) is a plug & play desktop user-interface robot that is capable of mechanically rendering facial expressions ideal for studying human-robot interaction. The robot has been made available by Philips Research to stimulate research in this area further and in particular to stimulate research topics such as social robotics, humanrobot collaboration, joint-attention, gaming, and ambient intelligence. For facial expressions and body control iCat has eleven RC servos and two DC motors. Four multi-colour RGBLEDs and capacitive touch sensors are located in the feet and ears. The RGBLEDs can be used, for instance, to communicate iCat's mode of operation (e.g. sleeping, awake, busy, and listening). Besides the iCat itself, the iCat Research Community has been set. The goal of the community is to exchange experiences with the iCat Research Platform, brainstorm on new iCat projects or modifications, track bugs, and benchmark applications.

Another robot cat is NeCoRo developed by Omron. NeCoRo realizes natural human robot communication by its ability to react to human movement and express its own emotions. People pour their affection into this robot and feel attached to it as they would to a pet. NeCoRo has a synthetic fur giving it a feline appearance. Via internal sensors of touch, sound, sight, and orientation, it can perceive human action and thoughts. NeCoRo has fifteen actuators inside the body. NeCoRo has been used as a therapeutic tool for persons with dementia by Libin & Cohen-Mansfield (2002).

Sony's robot dog AIBO was the first commercially available robotic pet. Besides entertaining the user with its behaviours it can also read out web pages and emails and can therefore be considered as a robotic user interface. It is highly autonomous and with the additional "AIBO Life" program it also develops its own character and behaviours. Its interaction with humans is highly reactive. The user can initiate the interaction by giving a voice command or touching the robot, to which AIBO will react with a set of behaviours and expressions by LED display in its head.

Paro is a robotic user interface based on a baby of harp seal. It is developed by the National Institute of Advanced Industrial Science and Technology (AIST). It has a fur coat and is equipped with several sensors, like ubiquitous surface contact sensor, whisker sensor, stereoscopic optical sensor, a microphone for voice recognition and 3D source orientation, temperature sensor to control body temperature, and a posture sensor. Paro has 9 DOF for movement of eyelids, upper body, front paw and hind-limb. It responses to various stimuli like, daily rhythm (morning-midday-night-time) and it shows animal-mimic. Paro has been used as a mental commit robot in AAT by Shibata et al. (2001b).

Since 1997 a platform named ROBOTA dolls exists, it is a family of mini humanoid robots based on a doll. They can engage in complex interaction with humans, involving speech, vision and body imitation. The Robota robots have been applied as assistive technologies in behavioral studies with low-functioning children with autism Dautenhahn (1999).

4. The huggable robot Probo

4.1 A story about 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 children. Classical animators are masters at conveying intentionality through characters. In the "Illusion of Life" ,Thomas & Johnston (1981) 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. By developing an imaginary creature MIT's philosophy (Breazeal (2003)) is followed. They believe that robots are not and will never be dogs, cats, humans, etc. so there is no need to make them look as such. Rather, robots will be their own kind of creature and should be accepted, measured, and valued on those terms.

The name Probo is derived from the word Proboscidea. Proboscidea is an order that now contains only one family of living animals, Elephantidae or "the elephants", with three species (African Bush Elephant, African Forest Elephant, and Asian Elephant)Wilson & Reeder (2005) (see Figure 1). 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 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.

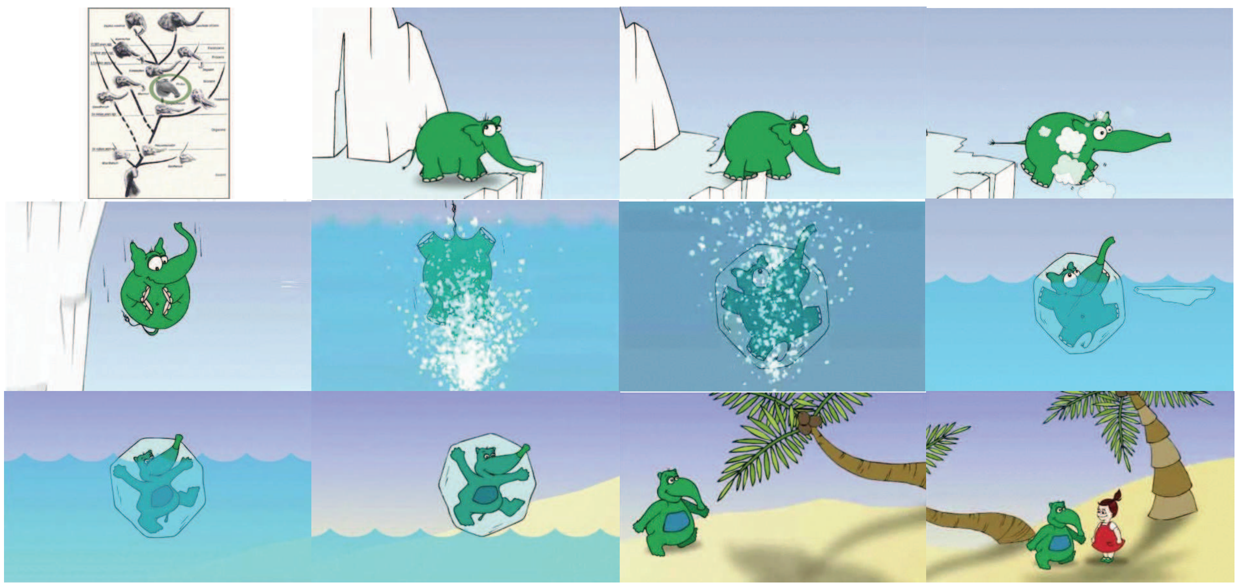

Fig. 1. Origin of Probo.

4.2 Design of Probo

The first prototype of the robot Probo has a fully actuated head and trunk, giving a total of twenty 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 Goris et al. (2009). Probo is about 80cm tall and it feels like a stuffed animal. In contrast with other robotic heads, a special body part, namely the trunk, is added to intensify certain emotional expressions and to increase interactivity. Due to its actuated head, Probo is, in contrast with other comparable companion robots such as Paro, Huggable, AIBO and Necoro, capable of expressing a wide variety of facial expressions as shown in Figure 2. Philip's iCat has also the ability to render mechanically facial expression with emotions, but lacks the huggable appearance and warm touch that attracts children. A section view of Probo is shown in Figure 2.

To build safety aspects intrinsically in the robot's hardware all the actuators have a flexible components in series, this kind of actuation is referred to as soft or compliant actuation. In case of a collision the robot will be elastic and will not harm the child who's interacting with it. A triple layered construction also contributes to the safe interactions and soft touch for the user. The layered construction (Figure 2) consists of hard ABS covers mounted on the aluminium frame of the robot. The first covers shield the internals and protects the internal mechatronics. These covers are encapsulated in a PUR foam layer, which act as the second layer. The third layer is a removable fur-jacket. 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 feeling and ensure safe interaction. Furthermore, Probo is equipped with a wide range of sensory input devices, such as a digital camera, microphones and force sensing resistor (FSR) touch sensors under the fur. These sensors give the robot the ability to capture the stimuli from its environment. With various inputs from these sensors, and outputs like emotional facial expressions and a affective nonsense speech, Probo becomes a true robotic user interface. Another special and unique feature on the Probo platform is the touch screen in the belly of the robot. This creates a window to the outside world and through the use of wireless internet it opens up a way to implement new and/or existing computer applications such as social networking, teleconferencing, etc Saldien et al. (2008).

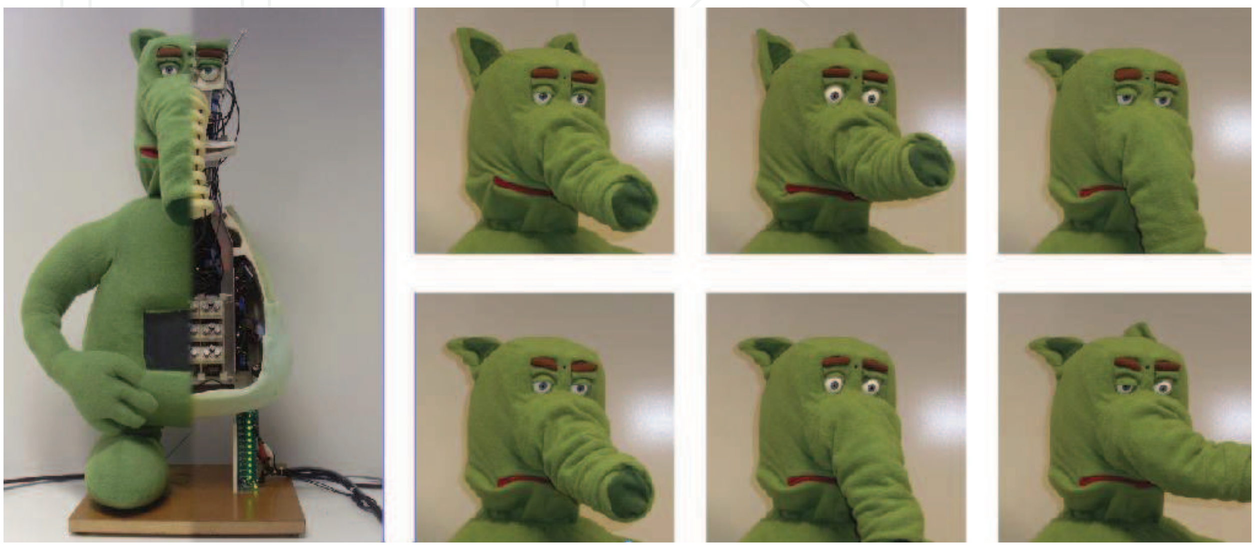

Fig. 2. Left: A section view of Probo. Right: 6 basic emotions (happy, surprise, sad, anger, fear and disgust) by Probo.

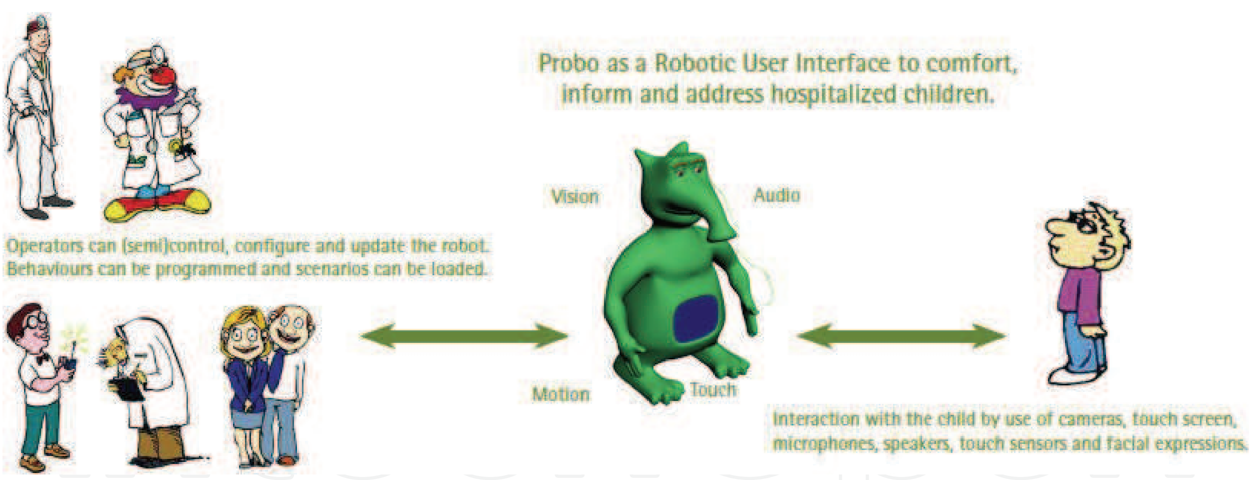

Fig. 3. As a robotic user interface (RUI) between the operators and a child.

4.3 Probo as an interface

At first, Probo is used as a Robotic User Interface (RUI) (Figure 3) interacting with the children and controlled by an operator Goris et al. (2008). The operator can be anyone who wants to communicate with the child, in particularly caregivers and researchers. At the moment there is a shared control between the operator evoking behaviors, emotions and scenarios, and the robot, performing intrinsic (pre-programmed) autonomous reactions. The robot reacts on basic input stimuli and performs pre-programmed 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. These are classified into painful, annoying or pleasant touch. A larger classification of haptic interactions will be developed. Now, the prototype is being tested as a RUI interacting with children and controlled by an operator. Some basic behaviors are included; e.g. playing animations, controlling the facial expressions and point of attention. The goal for Probo is to gradually increase its autonomy by implementing new cognitive modules in the RUI to finally obtain an intelligent autonomous social robot. In the mean time Probo will serve as a platform to test and implement new modules for input, processing and output. More pictures and videos of the robot in action can be found on http://probo.vub.ac.be.

5. Future work

Gestures play a major role in many aspects of human life. They are a crucial part of everyday conversation. The word gesture is used for many different phenomena involving human movement, especially of the hands and arms. Only some of these are interactive or communicative. The pragmatics of gesture and meaningful interaction are quite complex cf. Kendon (1970), Mey (2001), Kita (2003). Applications of service or "companion" robots that interact with humans, will increasingly require human-robot interaction (HRI) in which the robot can recognize what humans are doing and to a limited extent why they are doing it, so that the robot may act appropriately. Most of the research now being done is focused on the recognition of human gestures from the robot's point of view. In the line of the Probo project we want to focus on the human point of view, how does a human perceive a robot and its gestures. The language of gesture allows humans to express a variety of feelings and thoughts, from contempt and hostility to approval and affection. Social robots will need the ability of gesturing in order to express social-emotional behavior. Therefore more research has to be done to address the following questions. Which gestures are necessary for social interaction and how can they be implemented in robots? The next generation Probo will therefore be equipped with actuated arms and hands.

6. Conclusions

This chapter surveys some of the research trends in social robotics and its applications to human-robot interaction (HRI). The past four years a unique robotic research platform, called Probo, is developed by the Robotics & Multibody Mechanics (R&MM) group to study physical and cognitive human-robot interaction (HRI) with a special focus on children. The robot Probo is designed to act as a social interface, providing a natural interaction while employing human-like social cues and communication modalities. The concept of the huggable robot Probo is a result of the desire to improve the living conditions of children in hospital environment. These children need distraction and lots of information. Probo can be used in hospitals, as a tele-interface for entertainment, communication and medical assistance. Probo has to be seen as an imaginary animal based on the ancient mammoths. By giving the robot a origin, Probo gets an identity in contrast to other similar robots. The huggable and child friendly robot pal Probo is able to communicate naturally with people using nonverbal cues. Therefore Probo uses its actuated head with eyes, eyelids, eyebrows, trunk, mouth and ears. With these parts Probo is able to express its emotions by showing facial expressions and changing its gaze in contrast with other comparable robots such as: Paro, Huggable, AIBO and Necoro. Philip's iCat has facial expression of emotions, but lacks the huggable appearance and warm touch that attracts children. Besides the prototype of the real robot, a virtual model has been developed. With user friendly software this model can be used as an interface between an operator and a child. Probo will emphasize its expression of emotions by the use of a nonsense affective speech. The next generation Probo will be equipped with arms and hands, together with movements of its torso. Probo will then be able to enforce its emotional expressions with gestures and body language. That way Probo becomes even more the ideal robotic user interface of a research platform for experiments concerning cognitive human robot interaction with great opportunities in different disciplines such as robotics, artificial intelligence, design, sociology, psychology, and many more.

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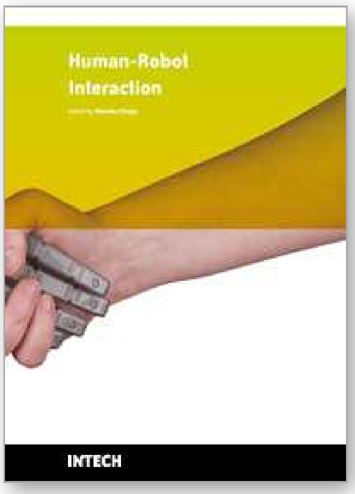

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Human-robot interaction (HRI) is the study of interactions between people (users) and robots. HRI is multidisciplinary with contributions from the fields of human-computer interaction, artificial intelligence, robotics, speech recognition, and social sciences (psychology, cognitive science, anthropology, and human factors). There has been a great deal of work done in the area of human-robot interaction to understand how a human interacts with a computer. However, there has been very little work done in understanding how people interact with robots. For robots becoming our friends, these studies will be required more and more.