33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

Development and evaluation of a social robot platform for therapy in autism

Daniele Mazzei, Nicole Lazzeri, Lucia Billeci, Roberta Igliozzi, Alice Mancini, Arti Ahluwalia, Filippo Muratori and Danilo De Rossi

Abstract— **People with ASD (Autism Spectrum Disorders) have difficulty in managing interpersonal relationships and common life social situations. A modular platform for Human Robot Interaction and Human Machine Interaction studies has been developed to manage and analyze therapeutic sessions in which subjects are driven by a psychologist through simulated social scenarios. This innovative therapeutic approach uses a humanoid robot called FACE capable of expressing and conveying emotions and empathy. Using FACE as a social interlocutor the psychologist can emulate real life scenarios where the emotional state of the interlocutor is adaptively adjusted through a semi closed loop control algorithm which uses the ASD subject's inferred "affective" state as input. Preliminary results demonstrate that the platform is well accepted by ASDs and can be consequently used as novel therapy for social skills training.**

I. INTRODUCTION

One of the main difficulties in people with ASD (Autism Spectrum Disorders) is their inability to understand and analyze the emotional state of their interlocutor and consequently to correctly manage interpersonal relationships and common life scenarios [1].

Recent research shows that ASD subjects perceive robots not as machines, but as their artificial partners [2]. Based on these observations several robots have been developed (Robota, Infanoid, Keepon, etc. [3], [4], [5]) in order to engage interactive responses in children with ASD, demonstrating the capability of computers and robots to improve their social interaction [6].

These innovative therapeutic approaches also require observation methods that allow the analysis of the subject's state and behavior during interaction with the robot. Suitable methods for evaluating HRI interactions are lacking and are usually adopted and modified from human-computer interaction, psychology, and social sciences [7].

For this reason we have developed a modular platform for HRI(Human Robot Interaction) and HMI (Human Machine Interaction) studies that can be easily tailored to fit a particular experimental set-up. This platform is called HIPOP (Human Interaction Persuasive Observation Platform) and here we present a specifically designed application for HRI studies on people with autism called FACET (FACE Therapy).

The work described in this paper has been partially supported by the EC funded project "CEEDS" (FP7-ICT-2009-5 - 258749).

D.M., N.L., L.B., A.A. D.D.R, are with Interdepartmental Research Center "E. Piaggio" Faculty of Engineering, University of Pisa, Italy. mazzei@di.unipi.it

R.I. and F.M are with Istituto Stella Maris, University of Pisa, Italy. roberta.igliozzi@inpe.unipi.it

FACET includes a multi sensory room in which a psychologist drives a stepwise protocol involving the FACE (Facial Automation for Conveying Emotions) android and the autistic subject. FACE is an humanoid artificial head well accepted by ASDs [8], [9] and it is used to vehicle emotions through the generation of facial expressions.

Using a robot endowed with the ability to change its behavior (simulating a human "mood") we aim to reproduce common life scenarios with autistic subjects by proposing an adaptive therapy approach. Our therapeutic scenarios are tailored by the therapist and oriented to robot-subject interaction. In this way the therapist can guide ASDs through specific social situations with different contexts. For example situations in which the subject is questioned by a peer, a teacher or a stranger. the teacher will drive the subject to interact appropriately with an interlocutor, in a manner which depends not only on the context but also on the interlocutor's mood and behavior. Not only will this possibly lead to the development of an appropriate mental machinery to cope with different situations, but will also enable ASDs to generalize.

Through the FACET platform the subject's physiological signals, eye gaze and videos are acquired using wearable and unobtrusive devices. The platform allows synchronization, storage and real time analysis of acquired data, used also to infer the subject's "Affective State" using real-time algorithms [10], [6].

The FACET set-up presented in this paper is based on a preliminary therapeutic protocol oriented to evaluate the capability of the platform to convey emotions and present social scenarios to ASD subjects.

II. MATERIAL AND METHODS

The FACET set-up in which the android guided therapy takes place is an application of a generic platform for Human-Robot and Human-Machine interaction studies called HIPOP. HIPOP is an acquisition platform composed of a set of software and hardware modules that can be connected together in order to assemble a desired configuration and data flow.

Thanks to its modularity HIPOP allows various HRI and HMI studies to be set up without requiring continuous and complex hardware/software re-designs.

A. FACET Platform Hardware

FACET is composed of various hardware modules used to pervasively observe the subject during the interaction with

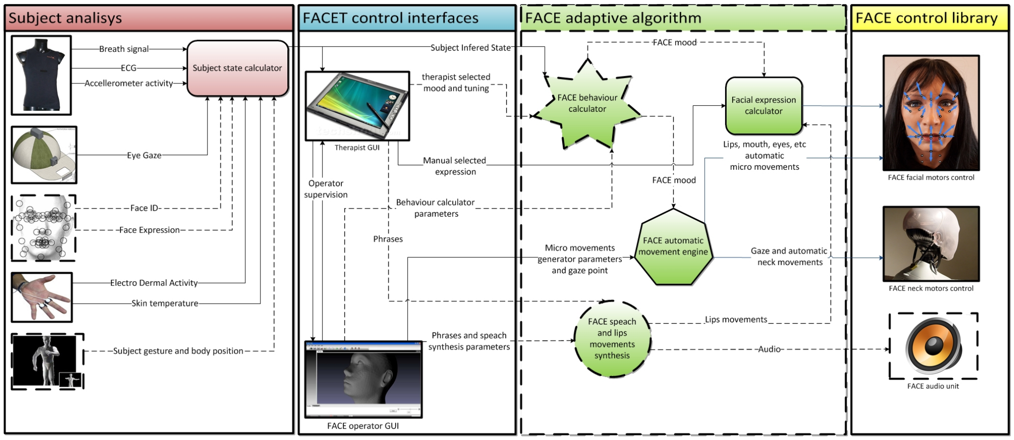

Fig. 1. The FACET platform modules. Dashed lines and blocks indicate modules not yet implemented and described in section IV.

the android (Figure: 1).

The therapeutic room is equipped with two motorized pan/tilt/zoom cameras mounted at opposite corners of the room. The cameras are used to record robot subject interaction allowing the therapist to evaluate subject behavior and participation off-line. Two microphones are used to acquire audio signals from the therapeutic environment and from the subject. These audio signals are used for an off-line analysis where the psychologists evaluate the subject's language in terms of prosody, tone and meaning.

A sensorized e-shirt (Smartex Srl, Italy) based on e-textiles, is used to acquire the subject's physiological signals (ECG, respiration rate)[11]. The sensing shirt is based on innovative fabric electrodes and piezo-resistive sensors used to acquire signals with minimal discomfort and total unobtrusiveness which are of paramount importance when dealing with autistic children. The wearable electronic unit stores the acquired signals which are also real-time analyzed.

Skin temperature and Electro Dermal Activity (EDA) are acquired through a wireless wearable unit that uses two electrode bands placed on the index and middle fingers of the subject's non dominant hand.

It is well known that ASD subjects have an atypical gaze when involved in social contexts and face to face conversations; they show reduced eye-region fixation time in favor of an increased focus on mouths and objects [12]. Gaze tracking is consequently a critical and useful indicator of a subject's interest and emotional involvement. This feature is integrated in the FACET platform through the HATCAM system. HATCAM is a wearable device that allows eye and head tracking and it was specifically designed to investigate early attention disorders in infants[13].

a) The FACE android: FACE is an android female face used as emotion conveying system in the FACET platform. It has been made, following our specifications, by Hanson Robotics who have developed a variety of robots for HRI studies [14]. FACE is actuated by 32 servo motors moving the artificial skin through cables acting as tendons, which allow human facial expressions to be re-created. FACE servo motors are integrated in the skull and controlled by a dedicated driver placed in the robot thorax. The android has also a CCD camera in the right eye used for the subject face tracking.

B. FACET platform software

The core of HIPOP is *Robotics4.NET* [15], a framework for robotic programming whose purpose is to provide a robust communication infrastructure between software modules, called *Roblets*. Each Roblet is autonomous and supervised by a main controller called *Bodymap*. In the HIPOP platform each hardware module is represented as a *Roblet* and is identified by a unique ID (*Roblet ID*) assigned during the system set-up. HIPOP *Roblets* can be used to create various acquisition set-ups connecting various *Roblets* and implementing the data flow routing in the *Bodymap*.

The FACET platform is an application of HIPOP where various hardware and control Roblets are connected together. FACET includes two control interfaces (perceived as *Roblets*) that are used by the therapist and the operator to control the entire system. The therapist interface allows manual selection of robot expressions and robot behavior. Information on heart rate, respiration rate and the emotional correlated signals are displayed on the therapist's GUI, enabling a real time view of subject's state and involvement during the therapy.

The operator interface controls all the robot algorithms and routines (face tracking, autonomous movement generator, etc) low level parameters as well as all the therapist GUI control functionalities. This supervision GUI is used by an operator placed in a different room (control room) and has a robot control priority higher than the therapist's allowing the operator to supervise the entire therapy and intervene in order to help the therapist during the therapy.

FACE robot behaviors are represented as emotions or "moods" similar to those used in the robots Kismet, Eddie and Probo [16], [17]. We implement an Emotion Cartesian Space (ECS) based on the Posner theory called "The circumplex model of affect"[18]. In the ECS 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 where the basic emotions are specified on a unit circle, placing the neutral emotion *e(0, 0)* in the origin of the coordinate system (Figure 2).

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 of each vector α defines the specific emotion, whereas the magnitude *i* defines the intensity of the emotion in the range 0-1. The ECS representation allows managing emotion operations as sum, difference and average and for this reason is used as a numerical representation of FACE's emotions. In future it will be used on the FACE adaptive algorithm IV to smoothly adjust the robot's expressions and behaviors according to the therapist requests and to the subject's inferred state.

In this paper we used the ECS emotion representation standard to select the robot's behavior and expressions ignoring the intensity value (Intensity is always equal to one). The selected robot behavior used by the *FACE autonomous movement generator* also modulates the robot's autonomous micro movements (e.g blinking frequencies and small head movements which endow additional believability to FACE) according to a pre-calibrated table of movement patterns.

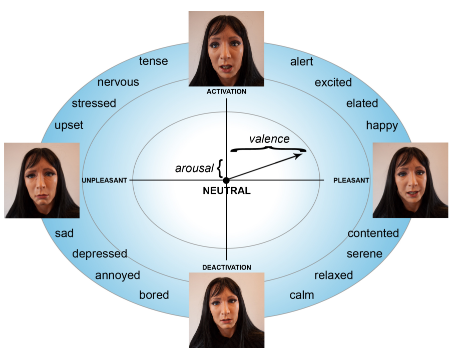

Fig. 2. The Emotion Cartesian Space (ECS).

C. The FACET protocol

The FACET application presented in this paper was tested with a preliminary therapeutic protocol divided in 5 phases (with a total duration of about 20 min). This preliminary protocol was oriented to evaluate the capability of the FACET application to perform HRI studies on ASDs subjects, test the acceptability of the acquisition units and verify the capability of the FACE android to convey emotions to ASDs.

The protocol phases were tailored in order to gradually increase the subject-robot interaction, starting from a familiarization phase and ending with a test of attention sharing where the subject is induced to focus his attention to an object being observed by FACE.

These experiments were carried out in order to explore three specific robot-subject interactions:

- Spontaneous behavior and reactions of the participants to therapist presses in correlation with physiological data
- Focusing of the attention towards FACE's eye movements
- Comprehension and imitation of FACE's expressions

D. Data Analysis

In this preliminary test only the ECG signals acquired by the e-shirt were analyzed off-line in order to find correlations between protocol phases and physiological parameters. ECG signals were pre-processed in Matlab through a stepwise filtering process oriented to remove typical ECG artifacts and interferences [19]. Once preprocessed, the ECG signal was submitted to a time-domain analysis in order to extract relevant temporal features namely R-R interval (RR), Heart Rate (HR) and Heart rate Variability (HRV).

The power spectrum density (PSD) was calculated using the parametric autoregressive (AR) methods [20]. The features extracted from the PSD estimate for each frequency band (very low frequency (VLF), low frequency (LF) and high frequency (HF)) include absolute and relative powers for each band, peak frequencies for each band and the LF/HF power ratio. HRV frequency studies are fundamental because the rhythms within the VLF and LF can be associated with sympathetic nervous system activity while HF has parasympathetic origin. The ratio LF/HF indicates the balance between sympathetic and parasympathetic systems [21]. The mean value and standard deviation of all the temporal and frequency features extracted (RR, HR, HRV, VLF, LF, HF and LF/HF) were computed for each phase of the therapeutic session.

III. RESULTS

The preliminary test panel was composed of 6 male subjects: 4 ASDs with ages in the range 15-22 years and 2 controls with ages in the range 15-17 years. Due to the very low number of subjects involved in this preliminary test and to the wide range in ages, a parameter known to influence HR values, a statistical analysis of the subject samples was impossible and these data have to be considered as proof of the platform's ability to perform HRI studies on ASDs subject.

The ECG analysis of HR time-domain parameters has shown that the mean HR values decreased in ASDs subjects with respect to controls during the entire session, showing that patients were not disturbed by the presence of the android. HRV data did'nt show any statistically significant differences although in every phase of the session it was increased in ASDs.

The ECG analysis of HRV frequency-domain parameters revealed differences in VLF (calculated for the entire session) and LF (calculated for each phase); in both cases values were increased in ASD subjects with respect to controls, while no significant differences were found in HF. However it was interesting to notice that the highest HF value, that is the highest para-sympathetic activity, corresponded to the phase in which the subject engages in a conversation with the android.

This indicates, as postulated by Porges in the Polyvagal Theory [22], that social interaction tasks seem to activate the parasympathetic system.

Moreover the comparison between the values of LF/HF (Figure 3) of the two groups showed a trend of higher LF values in ASD subjects as the ratio was much higher than one for every phase. These results are consistent with those reported in Ming et al[23], in which an increased cardiac sympathetic activity was observed in ASDs.

While these results have little clinical relevance they do confirm that FACET can be used as innovative tool for HRI studies on ASD subjects and that the FACET therapeutic protocol is able to involve the active participation of ASD subjects, despite their well known difficulties in attention focusing and performing relationship oriented tasks.

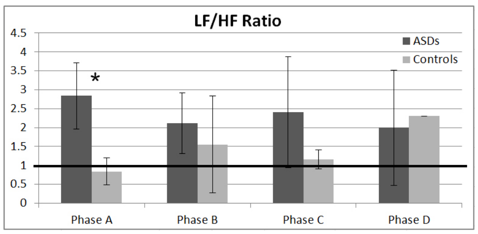

Fig. 3. LF/HF ratio during the various protocol phases (Not statistically significant, $p < 0.05$ only in Phase A*).

IV. CONCLUSIONS AND FUTURE WORKS

In this paper we describe how FACET is being used to help ASD subjects to learn empathy. This application of a customizable HRI assessment platform (HIPOP) can become an innovative therapeutic approach aimed to gradually increase social cognitive skills of autistic subjects.

One of the main innovations of this platform will be the FACE adaptive control algorithm. This algorithm will allow the robot's "mood/behavior" to change smoothly modulating its social behavior and consequently not only its autonomous movements, as already implemented in this paper, but also its facial expression intensity, its head position during gaze, and its voice tone. With this emotion modulation algorithm the robot's behaviors will be finely adapted to the therapeutic scenarios and also to the subject's inferred state, allowing a better representation of the social context that this form of therapy tries to recapitulate.

In the future, through the GUI, the therapist could also use the subject's inferred state as positive or negative feedback for the robot mood calculator. The inferred state, expressed by the real-time algorithms [10] as ECS values, can be used as feedback to finely adjust the robot's behavior. This semi-closed loop adaptive algorithm will allow a better representation of social interaction scenarios and increased involvement of ASD subjects as well as the robot's capability to convey emotions.

REFERENCES

[1] S. Baron-Cohen, *Mindblindness: An Essay on Autism and Theory of Mind*. The MIT Press, Feb. 1997. [Online]. Available: http://www.worldcat.org/isbn/026252225X

[2] J. Scholtz, "Theory and evaluation of human robot interactions," in *Proc. 36th Annual Hawaii Int System Sciences Conf*, 2003.

[3] C. Plaisant, A. Druin, C. Lathan, K. Dakhane, K. Edwards, J. M. Vice, and J. Montemayor, "A storytelling robot for pediatric rehabilitation," in *Proc. ASSETS '00*. ACM, 2000, pp. 50–55.

[4] K. Dautenhahn and A. Billard, "Games children with autism can play with robota, a humanoid robotic doll," in *in In Proceedings of the 1st Cambridge Workshop on Universal Access and Assistive Technology*. Springer-Verlag, 2002, pp. 179–190.

[5] H. Kozima and C. Nakagawa, "A robot in a playroom with preschool children: Longitudinal field practice," in *Proc. 16th IEEE Int. Symp. Robot and Human interactive Communication RO-MAN 2007*, 2007, pp. 1058–1059.

[6] J. T. D J Moore, P McGrath, "Computer aided learning for people with autism - a framework for research and development," *Innovations in Education and Training International*, vol. 37/3, pp. 218–28, 2000.

[7] C. L. Bethel, J. L. Burke, R. R. Murphy, and K. Salomon, "Psychophysiological experimental design for use in human-robot interaction studies," in *Proc. Int. Symp. Collaborative Technologies and Systems CTS 2007*, 2007, pp. 99–105.

[8] D. Mazzei, L. Billeci, A. Armato, N. Lazzeri, A. Cisternino, G. Pioggia, R. Igliozzi, F. Muratori, A. Ahluwalia, and D. De Rossi, "The face of autism," in *Proc. IEEE RO-MAN*, 2010, pp. 791–796.

[9] G. Pioggia, R. Igliozzi, M. Ferro, A. Ahluwalia, F. Muratori, and D. De Rossi, "An android for enhancing social skills and emotion recognition in people with autism," *IEEE T Neur Sys Reh*, vol. 13, no. 4, pp. 507–515, 2005.

[10] G. Valenza, A. Lanata, E. P. Scilingo, and D. De Rossi, "Towards a smart glove: Arousal recognition based on textile electrodermal response," in *Proc. Annual Int Engineering in Medicine and Biology Society (EMBC) Conf. of the IEEE*, 2010, pp. 3598–3601.

[11] G. Loriga, N. Taccini, D. De Rossi, and R. Paradiso, "Textile sensing interfaces for cardiopulmonary signs monitoring," in *Proc. 27th Annual Int. Conf. of the Engineering in Medicine and Biology Society IEEE-EMBS 2005*, 2005, pp. 7349–7352.

[12] D. Alie, M. H. Mahoor, W. I. Mattson, D. R. Anderson, and D. S. Messinger, "Analysis of eye gaze pattern of infants at risk of autism spectrum disorder using markov models," in *Proc. IEEE Workshop Applications of Computer Vision (WACV)*, 2011, pp. 282–287.

[13] A. Armato, "Implementation of new assistive technologies for people affected by autistic spectrum disorders (asds)," Ph.D. dissertation, PhD course on Automatic Robotic and Bioengineering, University of Pisa, 2011.

[14] N. Mavridis and D. Hanson, "The ibnsina center: An augmented reality theater with intelligent robotic and virtual characters," in *Proc. 18th IEEE Int. Symp. Robot and Human Interactive Communication RO-MAN 2009*, 2009, pp. 681–686.

[15] A. Cisternino, D. Colombo, G. Ennas, and D. Picciaia, "Robotics4.net: software body for controlling robots," *IEE Proceedings - Software*, vol. 152, no. 5, pp. 215–222, October 2005.

[16] J. Saldien, K. Goris, S. Yilmazyildiz, W. Verhelst, and D. Lefeber, "On the design of the huggable robot probo," *Journal of Physical Agents*, vol. 2, no. 2, 2008. [Online]. Available: http://www.jopha.net/index.php/jopha/article/view/26

[17] C. Breazeal, *Designing Sociable Robots*. Cambridge, MA, USA: MIT Press, 2002.

[18] J. A. Russell, "A circumplex model of affect," *Journal of Personality and Social Psychology*, vol. 39, pp. 1161–1178, 1980. [Online]. Available: http://dx.doi.org/doi/10.1037/h0077714

[19] D. B. Percival and A. T. Walden, *Wavelet Methods for Time Series Analysis*. Cambridge University Press, 2000.

[20] S. Marple, *Digital Spectral Analysis*. Prentice-Hall International, 1987.

[21] N. Montano, T. G. Ruscone, A. Porta, F. Lombardi, M. Pagani, and A. Malliani, "Power spectrum analysis of heart rate variability to assess the changes in sympathovagal balance during graded orthostatic tilt." *Circulation*, vol. 90, no. 4, pp. 1826–1831, Oct 1994.

[22] S. W. Porges, "The polyvagal perspective." *Biol Psychol*, vol. 74, no. 2, pp. 116–143, Feb 2007. [Online]. Available: http://dx.doi.org/10.1016/j.biopsycho.2006.06.009

[23] X. Ming, P. O. O. Julu, M. Brimacombe, S. Connor, and M. L. Daniels, "Reduced cardiac parasympathetic activity in children with autism." *Brain Dev*, vol. 27, no. 7, pp. 509–516, Oct 2005. [Online]. Available: http://dx.doi.org/10.1016/j.braindev.2005.01.003