Imitation and Learning of the Emotional Behaviour: Towards an Android-based Treatment for People with Autism

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Abstract

Biological believability and how to design machines which can perceive, learn and make choices are currently being addressed in human-machine interfaces. Once these ambitious targets have been reached, dynamic human-machine interactions will have to be studied focusing in particular on possible changes in the interactive structure and thus on any manifestations of emerging behaviours. The FACE (Facial Automaton for Conveying Emotions) project addresses both issues. FACE is a life-like artifact intended as a believable human-machine interface that is able to engage in non verbal communication by imitating and learning the emotional behaviour of an interlocutor. At present, the immediate objective is focused upon exploring its use in social skills and emotional therapy in individuals with autism. It will enable us to verify if the system can help children with autism to learn, identify, interpret, and use emotional information and to extend these skills in a socially appropriate, flexible, and adaptive context.

1. Introduction

The efforts of the science fiction to enable believability often convey the ambition of the bio-inspired engineering in literary terms. How could we realise a biologically-inspired artifact able to keep a believable interaction with human beings? Scientists are exploring new approaches for robotics in order to "understanding biology to build robots and building robots to understand biology" (Webb, 2001). This aim can be achieved studying man-machine dynamic interactions, in order to make it possible for innovative emotional and rational behaviours to emerge. The FACE (Facial Automaton for Conveying Emotions) project (Pioggia et al., 2004a) under development at the Interdepartmental Research Center "E. Piaggio", is aimed by the above mentioned premises. FACE design approach is founded on the simulation of biological behaviour using materials, structures and control algorithms that can replicate some of the functions and responses of living systems, in order to realise a social believable artifact able to operate in a minimum environment.

It is an android able to interact with the external environment, interpreting and conveying emotions through a non verbal communication. FACE captures from its interlocutor expressive and psychophysical correlates and actuates behaviours following two communicative modalities of semeiology. FACE interacts with kinesics, a non verbal communication conveyed by body part movements, facial expressions, and so on, taking into account the proxemic space. FACE's goals are double: to define and to test a therapeutic protocol for autism in order to enhance social and emotive abilities in children with autism (Facial Automaton for Conveying Emotions as a Therapeutic tool, FACET) (Pioggia et al., 2004a, 2005); to investigate emerging behaviours during the interaction between the child and FACE in order to pave the way to the development of an interactive present machine as the basis of artificial intelligent agents.

2. Emerging behaviours

The intersection between biology and engineering needs a context which enables the conditions for the development of adapting dynamics. Instruments in the field of artificial intelligence research for a phenomenological believability and a natural or virtual environment in which the machine is situated should be designed. However, the natural evolutive dynamics cannot be interpreted of on the basis of an optimization method. Biological organisms live in an evolutionary environment where optimal features should be dangerous in a modified environment. Most biological matter saves archetypal functions, structures and margins of adaptability. Artifacts should possess such a strategy enabling the learning of unexpected situations. In order to let innovative controlled behaviours to emerge, the control system should enable volition in the prediction task, i.e. the ability to interpret its own conative intentions and to process suitable sensory-motor responses.

As a first step towards enabling innovative behaviours, we are working on an artificial neural structure capable of creating its own representation of the surrounding environment. It is an associative memory through which it may be possible to navigate within a behavioural space. These characteristics are typical of some areas of the central nervous system like the hippocampus, upon which the architecture of the neurocontroller of FACE will be based. The current hippocampus models make use of a preformed topology of artificial neurons with different levels of complexity, like *Integrate And Fire* or *Leabra* (O'Reilly and Munakata, 2000), interconnected between themselves, whose learning process depends on parameters linked to the epochs of presentation of the training data set. This method creates a dichotomy between learning and acting, with different stages and procedures which impede a continuous learning process. This led us to leave the idea of realising a neurocontroller based solely on a group of neurons in various states of connection. Furthermore, preformism impedes the topological and geometrical structure from developing in an adaptive manner. Moreover, the current neural models do not include the role of glia cells and in particular those of the astrocytes. As has been recently demonstrated, the glia modulates the neural communication achieving a two-dimensional continuum in which calcium ion waves influence synaptic communication (Zonta and Carmignoto, 2002). The glia cells are the centre of spontaneous activity induced by the continuous rhythm of the oscillations of ion waves at specific frequencies which influence the coordination and the control of neural cells. The complex and dense branching which extends from each astrocyte cell defines a three-dimensional space, thereby defining an anatomical domain of influence. It is our intention to consider the group of the domains of influence as a single continuous domain, as first suggested by Beurle (Buerle, 1956). We propose therefore to develop a neurocontroller made up of a group of neuro-entities placed inside a continuous volume of connected astrocyte cells using an epigenetic topology.

3. Umwelt

The realisation of a social interactive machine entails critical requirements for the body, the sensory perception system, the mobility and the ability to perform tasks. The human mind responds and modifies itself in respect to the real world making the body to be able to perceive, to act and to survive; the human intelligence primarily rises from the interpretation of the body needs. For this reason it is preferred to follow a mind-body monism, i.e. an embodied mind able to perform the elaboration processes taking into account the domain of experiences where the machine is placed; such processes influence and are influenced by its own *presence*.

Dynamic interaction mechanisms are needed in order to place the robot inside its environment: FACE must be provided with extrinsic perception in order to interiorize the external world and to be able to suitably react. FACE must own body structures as a support to the intrinsic perception (proprioception) and motor activity. The rising of a relationship domain close to a human context underlies the need of a high degree of believability in the FACE robot. FACE must possess a time-space capability for both egocentricity and allocentricity, taking into account the actuation of preprogrammed behaviours as well as an imitative learning strategy.

The concept of umwelt (Von Uexküll, 1921) rises from the above considerations. Umwelt is a time-space reality where the machine is placed and where it has the ability to receive stimuli, to interact, to learn and to act.

4. Imitation and learning

The real environment is complex as well as the whole human cognitive processes. Obviously the internal representation of the external world rebuilt by a machine may result strongly incomplete. We should provide the robotic brain with the greatest possible external information and with the rules to correlate them, or we should allow the robot to learn. The former is unfeasible; the latter is difficult but possible through a process of imitation-based learning.

As pointed out by Jaqueline Nadel (Nadel et al., 2004a), the process of imitation is innate to humans, and place a crucial role in distinguishing between actions arising from within or actions induced by others (Rizzolati et al., 1999). Imitation paves the way to the comprehension of the intentions of others establishing a reciprocal non verbal communication process in which the roles of the imitator and of the model are continuously exchanged. Moreover, in the early years of the life, imitation plays a fundamental role for the emerging of the proprioception, of the perception of the external world and of the ability to act our own actions.

The learning process in FACE will be based on imitating predefined stereotypical behaviours which can be represented in terms of FAPs (Fixed Action Patterns) (Linas, 2001) followed by a continuous interaction with its umwelt, the epigenetic evolution of the machine. FAPs can be classified as belonging to action schemes, partly fixed on the basis of physical constraints and sensory-motor reflexes, partly subjected to a specialization on the basis of the experience. FACE will therefore be able to continually learn, to adapt and evolve within a simplified behavioural space in function of the umwelt and to maintain spontaneous activity open to any innovative and intelligible behaviours arising which may then be interpreted.

5. FACE

FACE consists of a passive articulated body equipped with a believable facial display system based on biomimetic engineering principles. The latest prototype of the FACE robot is shown in figure 1. Although in Japan and USA, android faces equipped with elastomeric skins overlying a mechanical skull are being developed in order to produce a range of expressions (Hanson website, Android world website), our project is the first in EU. The above mentioned projects however do not have direct relationship with our study on neural dynamics of social interactions and on an innovative treatment approach for autism.
FACE's head consists of an artificial skull covered by an artificial skin which is a thin silicone-based mask equipped with sensory and actuating system. It is fabricated by means of life-casting techniques and it aesthetically represents a copy of the head of a human subject, both in shape and texture. FACE can express and modulate the six basic emotions (happiness, sadness, surprise, anger, disgust, fear) in a repeatable and flexible way via an artificial muscular architecture and servomotors. This process can be controlled thanks to an artificial skin consisting of a 3D latex foam equipped with a biomimetic system of proprioceptive mapping. The sensing layer responds to simultaneous deformations in different directions by means of a piezoresistive network which consists of a carbon rubber mixture screen printed onto a cotton lycra fabric. These sensors are elastic and do not modify the mechanical behaviour of the fabric. This structure allows the expression required to be achieved by means of a trial and error process. The artificial skin covers an artificial skull which is equipped with an actuating system. The head is fabricated by means of life-casting techniques and aesthetically represents a copy of the head of a human subject, both in shape and texture. The artificial muscular architecture permits movement of the skin and confers human-like dynamics to it.

Figure 1 – The latest prototype of FACE

FACE can enable a real-time acquisition of both physiological and behavioural information by means of an unobtrusive sensorized wearable interface from the interlocutor.
FACE is able to analyse the emotional reactions of individuals through optical analyses of facial expressions, to track a human face over time and to automatically store all data (Pioggia et al., 2004b). FACE's eyes are realised using animatronic techniques and their expressiveness is achieved through an artificial muscular structure surrounding the orbital region. It "sees" differently from man, using stereoscopic vision over frequency rather than over space. A three-dimensional contouring apparatus, equipped with a section for data analysis, rebuilds an internal representation of a portion of the world before it. Currently FACE surveys the curvature of the three dimensional scene once per second. We adopted a neural approach to allow FACE to recognize the expression of a subject (figure 2). A dedicated process detects a number of points (markers), which are used to divide the human face into four main areas (left eye, right eye, nose and mouth). The data of each area are processed by a Hierarchical Neural-Network (HNN) architecture based on Kohonen Self Organizing Maps (KSOMs) and Multi-layer Perceptron (MLP). Data of a zone is input to only one map; in this way, each KSOM is trained (unsupervised learning) with the purpose of clustering data coming from the respective zones into crisp classes (pre-classification). The outputs of the KSOMs are used to form the input pattern for the MLP, which defines the group to which the facial expression belongs.

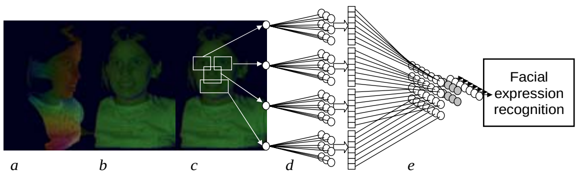

Figure 2 – FACE: facial tracking and expression recognition system

6. Biomimetic proprioception

The FACE artificial sensing skin is a 3D latex foam, under which lies a sensing layer. The sensing layer responds to simultaneous deformations in different directions by means of a piezoresistive network which consists of a Conductive Elastomers (CEs) composites rubber screen printed onto a cotton lycra fabric. CE composites show piezoresistive properties when a deformation is applied and can be easily integrated into fabric or other flexible substrate to be employed as strain sensors (figure 3). They are elastic and do not modify the mechanical behaviour of the fabric. CEs consist in a mixture containing graphite and silicon rubber. In the production process of sensing fabrics, a solution of CE and trichloroethylene is smeared on a lycra substrate previously covered by an adhesive mask. The mask is designed according to the desired topology of the sensor network and cut by a laser milling machine. After the deposition, the cross-linking process of the mixture is obtained at a temperature of 130°C. Furthermore, by using this technology, both sensors and interconnection wires can be smeared by using the same material in a single printing and manufacturing process.

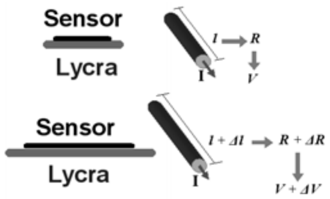

Figure 3 – Transduction principle of the strain sensor

From the technical viewpoint, a piezoresistive sensing fabric is a system whose local resistivity is a function of the local strain. In a discrete way, it can be thought of as a two dimensional resistive network where single resistors have a non-linear characteristic that depends on the local strain.
Our strategy to evenly cover the artificial skin of FACE was to realise distributed several 12 channels single sensor arrays. In each sensor array, sensors are serially connected. A current is superimposed in the circuit and high impedance differential voltages are acquired from each sensor. The block scheme of the acquisition hardware for a single sensor array is presented in figure 4. Two multiplexers allow a sensor to be selected and the relative signal is acquired by a differential amplifier. A microprocessor drives the acquisition block, performs the analogous/digital conversion for all the signals coming from the array and exchanges data packets via USB interface with a scan rate equal to 100 packets/sec. The device is provided with an automatic calibration subsystem which allows gain and offset to be tailored to each sensor.

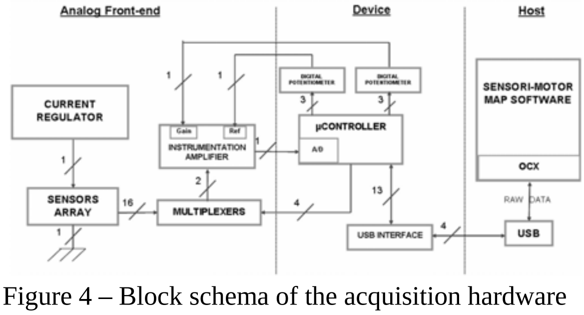

Figure 4 – Block schema of the acquisition hardware

A software framework for the management and synchronization of data and processes has been developed. The framework core and the application processes are interfaced to the sensor array through a framework I/O interface. The framework I/O interface has been developed in order to act as a buffer for the flow of information from the sensors to the application processes. Signals that will be coming from different sensor arrays are gathered in parallel and are encoded following a standard protocol. The encoded information is received by a dedicated filter for each sensor array, which then sorts them to framework I/O interface.
The integral impedance pattern of the two dimensional resistive sensor network is a function of the overall shape of the sensorized fabric and allows mapping between the electrical space and the shape space. The shape space is coded in real-time by a two-dimensional artificial neural network (ANN).

7. Acquisition of physiological signals

A wearable interface (e-shirt) for the acquisition of physiological signals from human subjects has been developed at our research labs. The e-shirt approach consists in the integration of smart sensors in a handy garments, whose arrangement, together with the integrated electronic devices and with the on-body elaboration of the acquired signals, lead us to the realisation of Intelligent Biomedical Clothes (IBC). From a general point of view, the main innovation of this technology lies in the combination of the wearable technologies (sensorized garments, electronic sensors, tailored algorithms, on-body computing) together with the user feedback.
The e-shirt collects heterogeneous physiological signals from the human interlocutor of FACE. Acquired signals are transmitted to a server workstation which performs the processing tasks. The e-shirt is based upon three key points: a network of smart sensors, i.e. electrodes and connections embedded on fabric; a wearable acquisition and processing framework equipped with wireless communication systems; a model for data classification, correlation and prediction.
Electrodes and connections are woven in the garment, using natural or synthetic fibers containing conductive yarns. A suitable positioning of the electrodes allows physiological signals such as the ECG and the skin electric conductance to be acquired. CE composites rubber screen printed onto fabric have been used to transducer the respiration rhythm.

8. Application: Autism

It is well documented that people with autism have impairments in processing of social and emotional information. Typically developing infants show preferential attention to social rather than inanimate stimuli; in contrast, individuals with autism seem to lack these early social predispositions. This hypothesis was recently substantiated in a neurofunctional study of face perception in autism, in which adequate task performance was accompanied by abnormal ventral temporal cortical activities, which in turn suggested that participants had treated faces as objects. Klin et al. (2002) created an experimental paradigm to measure social functioning in natural situations, in which they used eye-tracking technology to measure visual fixations of cognitively able individuals with autism. When viewing naturalistic social situations, people with autism demonstrate abnormal patterns of social visual pursuit consistent with reduced salience of eyes and increased salience of mouth, bodies and objects. In addition, individuals with autism use atypical strategies when performing such tasks, relying on individual pieces of the face rather than on the overall configuration. Alongside these perceptual anomalies, individuals with autism have deficits in conceiving other peoples mental states. The cognitive theory of mindblindness suggests that individuals with autism have difficulty in conceiving of people as mental agents (Baron-Cohen et al., 2000 ; Baron-Cohen, 1997). Mindblindness is thus the inability to perceive another person's mental state.

Recent studies have shown that individuals, particularly those with high functioning autism, can learn to cope with common social situations if they are made to enact possible scenarios they may encounter. By recalling appropriate modes of behaviour and expressions in specific situations, they are able to react appropriately. As reported by Nadel (Nadel, 2004b), during social situations preverbal children with autism show spontaneous imitation of normal developing children and adults. In this case imitation is a simple correlation of gestures or actions, which could be improved by repeated experimental sessions. Moreover, experimental sessions could improve the ability to become aware of imitation and of the non verbal communication. Thus, the engage of people with autism in social situations could improve their action-perception task and increase the amount of autonomous action a child with autism can learn.

At present there are a number of highly structured therapeutic approaches based on emotion recognition and social skill training using photographs, drawings, videos or DVD-ROMs. Their aim is to enable individuals with autism to interpret meanings and intentions of people and to anticipate their emotional reactions to typical situations they may encounter during the course of their daily lives.

These treatment approaches suggested the development of robotic systems to become engaged with people with autism within the reconstruction of social situation. This approach is close to an environment that people with autism could consider to be social, helping them to accept the human interlocutor and to learn through imitation. First robotic experimenters are AURORA (AUtonomous RObotic platform as a Remedial tool for children with Autism) (Dautenhahn et al., 2002a; Dautenhahn et al., 2002b; Robins et al., 2004b) and the Mobile Robotic Toys as Therapeutic Tools for Autism projects (Michaud et al., 2002, 2003). However these robots are not capable of any biomimetic or emotional representation and they do not include any three dimensional facial display. In our approach FACE can act as an interface between the patient and a trained therapist in a dedicated umwelt. Robins et al. (2004a) found that children with autism's initial response is much more positive towards a "robot looking" humanoid robot, rather than a robot with a detailed face. This could be seen as their predisposition towards objects. Our biomimetic approach instead is more close to an environment that people with autism could consider to be social, helping them to accept the human interlocutor and to learn through imitation. FACET allows the real-time acquisition of both physiological and behavioural information by means of an unobtrusive sensorized wearable interface from a patient during the treatment. Figure 5 shows the experimental set-up.

8.1 Treatment

Two distinct modalities are employed: the first is based on a repertoire of pre-selected social situations and the second allows the therapist to realise new situations as a consequence of the real time interaction between FACE and the child. A series of initial sessions are devoted to the familiarisation of the child with the robot, and to observe spontaneous reactions of the child when placed in front of FACE. During the familiarisation phase it will be possible to identify verbal and non verbal expressions of the child which can be used to ascertain the degree of social attention towards the robot. This will be done by hidden raters through an original Grid for the Assessment of Social Attention derived from previous study on early autism (Maestro et al. 2001; Maestro et al. 2002).

The first element evaluated during the treatment is the ability of the child to imitate the movements of FACE. Factors such as spontaneous imitation, or imitation upon presses by the therapist will be considered, as well as the "goodness" of imitation. It is also possible to increase the degree of a given emotion on FACE to induce or potentiate imitation if necessary.

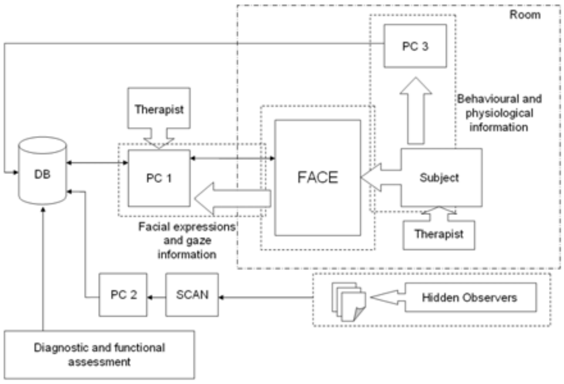

Figure 5 – FACET experimental set-up

When exposing the child to the collection of social situations a series of lessons are prepared based on selected emotions to enable the child to develop abilities in two particular spheres:

- Non verbal expression association: this is the ability of the child to associate an emotion with that expressed by FACE.
- Emotion contextualization: this is the contextualization of an emotion by presenting the child with different social situations and then asking him/her to select an appropriate response for FACE.

After the initial training phase, patients are encouraged to engage in a social interaction and to learn through a trial and error approach. The therapist modifies her/his behaviour, and thus the FACE one, in response to the patient behaviour. Hidden raters will assign scores based on the above mentioned Grid for the Assessment of Social Attention during the training sessions.

8.2 Preliminary results

Initial experiments on the familiarisation phase were performed. Results have shown that the android has a high visual impact and suggested that children with autism can be led to interact proactively in a positive manner with FACE. In particular, we monitored the children's attention towards FACE and then we checked if the android remains a restricted and repetitive interest or an object to share with the therapist. A preliminary study involved an experimental group, composed by 4 children with autism with a mean age equal to 9 years. During twenty minutes sessions, we observed both spontaneous behavior of the participants and their reactions to therapist's presses in correlation with the time course of the physiological and behavioural data. The participants showed a spontaneous ability of imitation of the head and face parts movements of the android. Moreover we observed that the children with autism focused their attention towards FACE's eyes movements as a result of verbal suggestions of the therapist. We observed also that children with autism can sometimes show clear attempts to draw another person's attention to the android integrating eye contact with pointing and/or vocalization. They can sometimes also request different activities using more than one communicative strategy.

9. CONCLUSIONS

We have described FACE, an ongoing project at the Interdepartmental Research Center "E. Piaggio" of the University of Pisa devoted to develop a believable android both in appearance and behaviour. The aim of the android is to act as a human-machine interface for non verbal communication within an umwelt. The learning process in FACE will be based on imitating predefined stereotypical behaviours which can be represented in terms of FAPs followed by a continuous interaction with the umwelt, the epigenetic evolution of the machine. At present FACE is applied to enhance social and emotive abilities in children with autism and to investigate emerging behaviours in the interaction between the child and FACE in order to pave the way to the development of an interactive present machine. Our hypothesis is that this method will diminish social impairment and increase expressiveness, facial mimicry, and shared attention.

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