AI for Emotional Human-Robot Interaction in Assistive Scenarios

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Abstract
To improve the acceptability of robots especially in assistance scenarios, where higher legibility and conformity to cognitive and emotional aspects of the social interaction are required, new human-robot interactive paradigms have to be modeled, in which the robot is humanized thanks to empowered AI-based social and cognitive abilities to recognize human users' emotions. Highlights on some works on AI approaches to emotion recognition in Assistive Robotics domains are presented.

Keywords
AI-powered Robotics, Assistive Robotics, Emotion Recognition, Brain-Computer-Interfaces

1. Introduction

The development of social robots interacting with humans is becoming an important focus of robotics research leading the EU commission to invest in social and cognitive robotics by boosting the view of trustworthy human-centric and Artificial Intelligence (AI) based technologies that can lead to high benefits for the entire society. In this regard, last years updates of the coordinated plan on AI put strategy in place concerning the adoption of a new generation of AI-Powered Robotics. Current advances in AI, in fact, enabled computers to have social capacities. AI-powered social robots, for example, provide psychological, social, and emotional support. Persons with cognitive disabilities may benefit from social robot help in daily duties since these systems allow them to preserve their freedom at home for long time [4]. The Potential of AI applied to Robotics has many advantages in Assistive Applications such as:

1 Cut costs, improve treatment, and bolster accessibility (decreasing costs for Health structures)
2 Transferring time-consuming human tasks to machines (improving QoL for Clinicians)
3 Enabling patients to self-service their care needs when possible (increasing QoL for patients/caregivers)

Furthermore, increasingly effective AI-powered social robots are expected to enter our daily lives as companions, instructors, coworkers, caregivers, or tutors for children. Most of the research projects in the Social and Assistive Robotics (SAR) are oriented towards the development of assistive technologies for the support, and improvement of the quality of life (QoL) of elderly and disabled people. Despite the promise of enormous improvement of QoL, robots are still far to be accepted, probably due to a lack of understanding and trustworthiness.

Most robotic applications are based on user static models and possible interaction contexts. This makes such systems incapable of adapting autonomously and proactively to changes in users' needs and preferences. More generally, assistive technology products do not take cognitive and personality characteristics into account (including an individual's specific deficits, emotional and behavioral problems, attitudes toward technology, and their physical and social environment) that can affect their acceptance, use and effectiveness. A valid robotic system with a high degree of acceptability must necessarily be based not only on the knowledge of potential users, through the integration of detailed information from clinicians and psychologists, but also on the knowledge of the users that the robot is able to reconstruct through the observation and interpretation of human users' overt and internal behavior (cognitive/emotional state and mental models), which provides essential elements for adaptive planning and customization of the interaction.

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This contribution aims at summarizing the main achievement of our Inter-University Research Group in this field.

2. AI-based technique for emotion recognition in SAR

It has been shown that in SAR the study of the emotional states of humans facilitates human-robot mutual affective understanding and, in turn, allows an empathetic interaction enhancing legibility and acceptability of robots. Thus, for a constructive and intelligent social human-robot interaction (HRI), robots should be endowed with the ability to detect and interpret humans' basic affective responses to adapt their behavior accordingly. This is especially desirable in the field of assistive robotics, where the interaction often takes place with disabled or vulnerable people (with diseases compromised the emotional response). Additionally, equipping robots with this kind of cognitive power may increase interlocutor engagement in complex social interactions [1, 2], and enables the understanding of the human partner's global state (needs, intentions, emotional state) relying on implicit communication cues [3].

Specifically, the robot's emotional system must be designed in terms of affective elicitation as well as sensing [4]. This can be done by developing robots capable of generating emotions through humanized social acts and perceiving human emotions similarly to a human partner. The elicitation capability can be achieved by letting the robot to imitate humans' affective behaviors and human-human social relationship. While perceiving human emotions can be achieved in several way. Typical approaches are able to assess humans' affective responses from the observation of overt behavior. However, there are cases in which the overt observable behaviors could not match with the internal states (e.g., people with diseases compromising normal emotional responses). In such cases, having an objective measure of the users' state from 'inside' is of paramount importance.

Recent studies showed that bio-signals analysis provides a valuable technique for affective state assessment since it guarantees repeatability and objectivity.

EEG devices have been widely used during last years in the robotics field particularly for robot automatic control [5].

Yet, there are a few studies that use BCI-based techniques and technologies in combination with robotic equipment to categorize human interior states. Additionally, it is worth noticing the potential of EEG signals analysis to detect time-varying changes in certain spectral bands in the brain activity that can be correlated to affective/cognitive states, such as increased anxiety, reduction of attentional focus, increasing of positive emotions, etc..

In the following subsections, we will summarize our research activities dealing with the use of diverse AI techniques to allow emotion recognition in HRI, especially in Assistive robotics contextes.

3. Applications

3.1. EEG-based Stress Assessment in HRI

While on the one hand, a robot can be used to help disabled people by providing cognitive rehabilitation exercises and assistance, on the other hand, its presence and actions could sometimes provoke negative emotions like stress or discomfort. This may cause serious difficulties by negatively impacting the users' health and, in turn, achieving a counter-productive result. In this context, robots could use the affect-sensing capability to adapt their behavior to be more comfortable for the person. In this direction we published a work [6] where we investigate how to incorporate implicit communication from a human to the robot so that the robot can *understand* the psychological state of the human whom it interacts with, with a particular focus on the stress state. To this aim, we implemented a Multi-Layer Perceptron (MLP) to identify common patterns in users' brain power spectrum, acquired from a non-invasive EEG device, while the subjects were exposed to different social robot interaction styles (friendly and authoritarian) which were hypothesized to provide different levels of stress. This research attempted to provide an objective measure of the human stress state by means of the analysis of the EEG activity useful to permit a robot to adapt its behaviour accordingly.

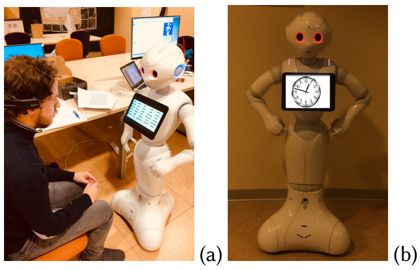


Figure 1: (a) HRI testing phase; (b) *Authoritarian* Pepper

HRI experiments were performed involving 10 participants, and EEG signals were recorded and analysed while these subjects underwent cognitive tests. Results showed the feasibility to assess affective states by using machine learning algorithms applied to EEG signals. Interestingly, results on cognitive tests scores suggested that an authoritarian interaction style can improve the performance,

(a) (b) (c)

Figure 2: HRI testing phase with (a) negative; (b) positive personality Pepper and (c) Confusion matrix of DNN.

although not significant differences have been observed between the friendly and authoritarian robots.

3.2. Enhancing Affective Robotics via Internal State Monitoring with AI

This work aims to demonstrate the effectiveness of EEG measurements in determining the emotional state in experimental subjects during the interaction with a robot. In particular, we investigate the correlation between the parameters of valence and arousal and the emotional state of users in correspondence with a particular personality profile of the robot, namely *positive* and *negative*, designed to induce greater positive responses (positive engagament) and lower negative responces (such as stress) during the interaction (see Fig.2-a and -Fig.2-b. Our hypothesis is that a positive personality aiming at creating a positive relationship with the users helps increasing the user engagement and in turn the success of the interaction, which, especially in the context of therapeutic and cognitive interventions, is one of the main objectives [7].

The results show a correlation between the extracted (and subsequently selected) features and the emotional state of the subject in the two experimental tests (See the Cconfusion matrix in Fig.2-c.

3.3. Global Optimization Model for Classifying Emotions in HRI

In general, studies on the use of EEG for emotion recognition in robotics applications are demonstrating the feasibility and effectiveness of this technology. However, there are still technical challenges to overcome, including the bias-variance trade-off, dimensionality, and noise in the input data space. The latter, in particular, may significantly impair the predictive quality of the tested models, and it is thus seen how an accurate phase of noise removal may improve overall performance. There are several neural network models or classifiers such as classical Support Vector Machine (SVM), Random Forest (RF) and Decision Tree (DT) but also new emerging techniques based on Deep Neural Networks (DNN) [8], that can address some of the issues listed above and combining them could significantly improve the performance of the algorithms. As a result, in this paper, we propose a Global Optimization Ensemble (GOE) Model based on a combination of feature selection and hyper-parameter optimization techniques that can improve the overall accuracy of various machine learning and deep learning models tested. In this work, we are interested in

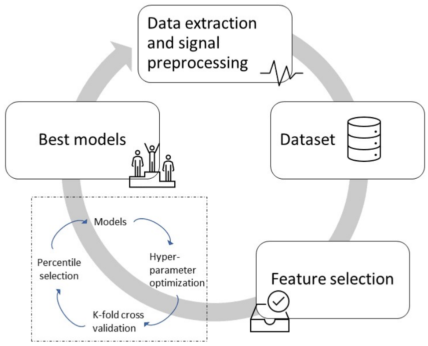


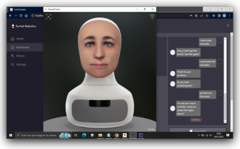
Figure 3: Global Optimization Workflow.

evaluating whether a different personality (positive or negative) of the robot could imply a different level of mental state of users who interact with it, which we plan to monitor through the analysis of human brain waves acquired through the use of EEG-helmet. The intent is to validate neuroscience theories that demonstrate that by observing particular relationships between alpha and beta waves in specific areas of the brain it is possible to detect a person's emotional state in terms of valence and arousal.

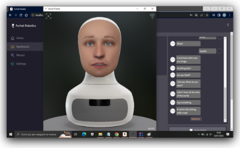
The tests are carried out with the aid of a humanoid robot which offers the dual advantage of being able to inspire its cognitive abilities to neuroscience (for example brain-inspired algorithms) and on the other hand to provide a means for assessing the human brain.

3.4. An alternative way to trait EEG-signals via topomaps

In this work (written with colleagues of this inter-university group and still under review), a digital version of Furhat was used, configured to simulate a bartender with or without identity: a) the robot with identity is endowed with social intelligence abilities such as irony and empathetic behavior b) the robot without identity shows an apathetic/not expressive behavior (See Fig.4).



(a) Ironic Furath.



(b) Apathetic Furath.

Figure 4: Furath's different role styles.

The acquisition phase was carried out using the Emotiv Epoc+ headset equipped with 16 sensors, including 14 EEG channels.The goal of this task is to use the EEG signal obtained from an interaction between a person and a robot to classify a positive or negative emotion. Unlike traditional approaches, this work doesn't apply classification to raw nor elaborated EEG-signals, but it transforms EEG into topomaps and adopts a CNN for the classification task (Fig. 5).

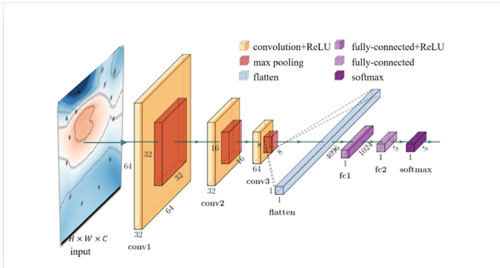


Figure 5: CNN trained on EEG-based topomaps.

3.5. Supporting diagnosis, monitoring and treatment of people with ASD

The number of autism spectrum disorder (ASD) individuals is dramatically increasing. For them, it is difficult to get an early diagnosis or to intervene for preventing challenging behaviors, which may be the cause of social isolation and economic loss for all their family. In [9] we conducted a systematic litterature review aiming at understanding and summarizing the current research work on the use of wearables for supporting detection and monitoring people with ASD and analyze the limitations and open challenges to address future work. Results revealed that the topic is very relevant, but there are many limitations in the considered studies, such as reduced number of participants, absence of datasets and experimentation in real contexts, need for considering privacy issues, and the adoption of appropriate validation approaches. The issues highlighted in this analysis may be useful for improving machine learning techniques and highlighting areas of interest in which experimenting with the use of different noninvasive sensors. Sensors may also be adopted for detecting challenging behavior of people with ASD [10].

3.6. Supporting Social Stories generation for people with ASD

Social stories have been introduced by Carol Gray and the use of this educational intervention methodology has been widely adopted, both by schools and at home, to help children with ASD to adapt to changes and face novel situations. Caregivers and therapists should be able to create customized digital social stories that take into account the ASD person's level of severity and his/her peculiarity. Gray provides guidelines for the construction of effective social stories , but this may not be an easy task for all caregivers who, in the majority of cases, are often relatives of the individual, and may not be experts in the use of digital devices and/or the creation of social stories. Thus, automatic or semi-automatic support may be helpful. In [11] we introduced an idea for the design of an intelligent editor of social stories. In [12], we desired to empower caregivers of people with ASD by providing an application with a multimodal interface that supports and facilitates the creation of social stories. Caregivers know the target user better than anyone else. Therefore they are the best proposers of an effective social story for the peculiarity of the person they care of. Thus, we proposed a multimodal conversational interface of a mobile application for creating social stories integrated with an intelligent editor and supported the application with innovative existing usability guidelines suitable for a multimodal conversational interface. Seven caregivers of people with ASD have participated in the evaluation. Usability results were encouraging.

3.7. Emotion recognition

In [13] we presented a user-centered design approach to develop an emotion detection system by using: i) non-invasive, wearable, low-cost sensors, ii) artificial intelligence models for classifying emotions and iii) affective analysis trough the Self-Assessment Manikin (SAM) questionnaire for assessing the impact of the system on the user affective state. We conducted an emotional analysis by using different ML and DL models. Emotion detection based on patient's speech and video analysis has been also adopted in [14] for supporting the clinician in the depression screening. In [15] we presented a patient-centered interaction project involving the Pepper humanoid robot for therapy applications for children with attention deficit. This new therapeutic methodology was created to support and make therapeutic work more attractive. The robot integrated with AI analyzes the child's expressions and recognizes his state of mind. This helps the therapist to build the right therapeutic path and the right behavioral measures to take.

3.8. Trust in Chatbot

Trust and reliability are essential components of human-AI interaction, particularly in scenarios where AI systems are designed to assist or augment human decision-making. AI-based systems are increasingly being employed in various fields such as healthcare, finance, and transportation, where accurate and reliable decisions are critical. In such cases, trust is necessary to ensure that humans accept the recommendations and decisions of the AI system. Furthermore, reliability is crucial to ensure that the AI system consistently provides accurate results that meet the users' expectations. Without trust and reliability, the effectiveness of AI systems is significantly reduced, leading to diminished user satisfaction and possibly negative outcomes. We investigated in [16] the impact of trust and reliability on the user experience and satisfaction towards one of the most recent and powerful AI tool, ChatGPT, a general-purpose language model, in providing accurate responses to a variety of questions. The study involved fifteen participants, all of whom had prior experience with ChatGPT, and were asked to provide a list of questions to be posed to the language model and highlighted that in many cases the tool produced fake info. These questions covered a range of topics, such as problem-solving, creativity, and search activities. The participants were asked to rate their satisfaction with ChatGPT both before and after the study, using a seven-point Likert scale. The results showed that while the participants' satisfaction decreased after using the language model, it was not as significant as expected. The median score passed from 6 before the experience to 5 after it. Examples of ChatGPT "hallucinations" were included in the paper, including a mathematical problem and a logic test, where ChatGPT provided incorrect solutions. Participants appreciated ChatGPT's ability to generate realistic and polite responses, even if they were not always accurate. The study revealed that participants should be aware of the realabilty of this kind of tool, otherwise they may decide to use it for "making homework, programming and any tasks". Often this very positive opinion and intention to use survive also when an incorrect content is provided.

4. Work in progress

We are currently investigating the possibility to use AI-empowered Robot to support clinicians in assessment and training activities. During last years, the use of social robots has been in fact explored to provide assistance to clinicians to the administration of pshycological/phsycometric assessment of patients with diverse disorders [1], and spcifically tailored for a personalized interaction, taking into account personality and emotional aspects of the involved patient, as a human doctor would do [7]. In collaboration with experts and clinicians, we are designing thw following activity:

Supporting schizophrenia PatiEnts' Care wiTh Robotics and Artificial Intelligence. At the present, we are investigating how robots and AI may be adopted to support the diagnosis of people suffering from schizophrenia who generally are characterized by speech disorders such as logorrea, dissociation of thought, or perseveration [17]. To subministrate diagnostic tests is a time consuming activity conducted by clinicians. We are developing an approach involving robots for subministrating the test and able to identify many speech disorders by exploiting NLP models and signal processing techniques.

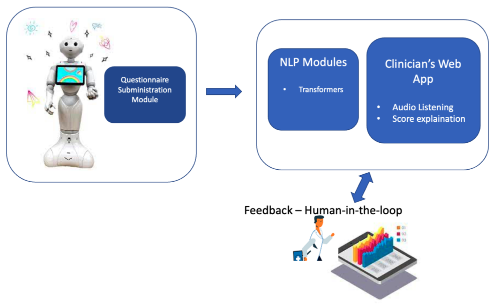


Figure 6: Main RoboTald modules.

We propose an approach named RoboTald in which a robot is used to formulating questions according to the Thought and Language Disorder (TALD) scale to patients and to record their answers. The audio files are then automatically transcripted and inputted to a deeplearning-based system aiming at assessing the speech disorders basing on the TALD classification. Faced with the need to improve and speed up the classification and quantification of disorders, various Artificial Intelligence (AI) models have been used. In this paper, we propose an approach in which Natural Language Processing (NLP) techniques are adopted to support the Clinicians in the classification of the SZ patients degree of speech disorders according to the TALD scale by examining the definition of each element of the scale and by providing an algorithm for scoring the single items. Additionally, to reduce the time spent by the Doctors to administer the interviews, a humanized social robot is used to formulate questions according to the TALD scale to patients. A human-in-the-loop approach will be used to permit the specialist to provide a direct feedback to the robot to correct sentences or suggest additional ones more suitable for the particular patient.

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