Socially Assistive Robotics combined with Artificial Intelligence for ADHD

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***Abstract*—This paper presents a patient-centered interaction project of Pepper humanoid robotic therapy applications for children with attention deficit. This new therapeutic methodology was created to support and make therapeutic work more attractive. Pepper comes with a tablet and two identical cameras. The tablet is used to make the patients interact with the application, while the cameras are used to capture their emotions in real-time to understand the degree of attention and any difficulties they may have. The interaction with the tablet takes place through some exercises in the form of games. The exercises performed by the patients are analyzed and combined with the data acquired by the cameras. The combination of these data is elaborated to propose adequate levels of therapeutic activity. This process leads to the digitization of the patients' therapeutic path so that any improvement (or worsening) is monitored and makes Pepper a reliable and predictable technological intermediary for the child. The work was developed in collaboration with a diagnostic and therapeutic center, where it is being tested. By interacting with a humanoid robot, children show greater involvement, which can be explained, according to psychologists, by the fact that a robot is emotionally less rich than humans and the patients feel less fearful.**

Keywords—Behavioral Disorder; Emotion recognition; Socially Assistive Robotics.

I. INTRODUCTION (*HEADING 1*)

Socially Assistive Robotics (SAR) [1] aims to address critical areas of medical care by automating the supervision, coaching, motivation, and companionship aspects of interactions with vulnerable individuals from various large and growing populations, such as stroke survivors, individuals with dementia, and/or Alzheimer's disease, children with autism spectrum disorders (ASD) and others. The goal of SAR is to improve the quality of life of these individuals by providing services for daily use, therapeutic support, and a way for individual diagnosis through constant monitoring and interaction. This will allow a continuous longitudinal objective observation, with analysis and evaluation. In the field of education and childcare, SAR has been successfully applied to help children with diabetes [2], to help teachers with storytelling [3], or parents in home education [4]. In the clinical setting, Beran et al. [5] introduced a small humanoid robot for influenza vaccination. In another study [6], it was shown how human-robot interaction could be used as a means of pediatric care. Robots also have the advantage of overcoming concerns related to physical inactivity and isolation of children, typically associated with the use of computers [7] because they involve them in interactions and encourage movement [8]. Recent studies also show that a humanoid robot can be successfully used in physical rehabilitation. Indeed, it is essential to motivate children during rehabilitation, as physical therapy sessions include repetitive tasks [9]. Monotonous actions cause a reduction in the performance of children's behavior due to reduced attention. Additionally, repetition decreases focus on current activity and the motivation for repetitive exercise. Play is, therefore, a concrete way for children to communicate and express themselves in a more natural way [10] and children's motivation to participate in activities can improve if the child perceives the robot as a playmate. One of the main fields of application of current SAR research is in the clinical setting for children with behavioral disabilities. Usually, the problems of behavioral disorders concern isolated episodes or delicate and temporary evolutionary phases. However, in some cases, they can represent the prelude to subsequent psychopathological disorders. It is essential to investigate the psychological and relational aspects of the child to prevent the onset of major problems. Behavioral disorders may include attention / hyperactivity disorder (ADHD), opposition disorder (OD), or conduct disorder (CD) [16]. In particular, attention deficit hyperactivity disorder (ADHD), a neurodevelopmental disorder characterized by inattention, hyperactivity and impulsivity, has recently attracted significant research attention [21, 22]. Furthermore, working memory deficits are known to be a major factor in ADHD [22]. ADHD is one of the most common childhood behavioral disorders [23]. To develop effective intervention strategies, careful observation of this behavior is necessary in order to fully understand its causes and identify the most suitable resources to deploy. In connection with their deficits in social and communication skills, children with attention deficit often have difficulty managing their emotions. It often happens that therapists struggle to communicate with these children, as the human being is very expressive, and also the tone of voice, never constant, affects the child's perception of feeling at ease. Also, in play scenarios, ordinary toys are often unable to stimulate responses and involvement in those children. The contextual analysis carried out by us in collaboration with a diagnostic and therapeutic center led us to deepen the adoption of SAR solutions to improve the clinical contexts in which children undertake a therapeutic path. In this research, we design and develop SAR technology to support children's psychologists in therapeutic activities related to behavioral disorders, in particular ADHD. We use a toy/game robotic approach thanks to the use of Pepper. It is a humanoid robot designed by SoftBank Robotics [20] to interact with humans. This will provide the therapist with a new tool to achieve predefined therapeutic goals through social robotic interaction. Furthermore, we want to exploit the ability of artificial intelligence algorithms to derive facets, such as emotions, that we humans can escape. The Pepper-based prototype system we have developed has undergone an initial experimental study before the COVID-19 events of February 2020 at the Diagnostic and Therapeutic Center. The results of the initial study are reported here and indicate that the system is a useful tool when a therapist is trying to help, teach, communicate, or interact with patients with behavioral disorders. Related work will be presented in section 2. The contextual investigation performed will be illustrated in section 3. In section 4, we illustrate the system and its architecture. How artificial intelligence can support therapy is explained in section 5, which describes the use of neural networks for emotion recognition. The experiment is presented in section 6 and finally the conclusions are presented in section 7.

II. Related Work

Assistive Robotics (AR) is a broad class of robots whose function is to provide assistance to users, ranging from getting out of bed, brushing teeth, locomotion, and rehabilitation. Socially Assistive Robotics (SAR) is the class of robots that provide diverse assistance to different vulnerable populations through social interaction. The application of robotics in the treatment of children with behavioral disorders should aim to teach children basic social skills, communication, and interaction. Currently, researchers have focused on achieving these goals primarily in the area of the autistic disorder [17] [18]. Scassellati [11] indicates that robotic devices can provide quantitative data that could be useful to clinicians in diagnosing, monitoring patient progress, and comparing patients. Robots have been shown to generate a high degree of motivation and involvement in subjects, including those with difficulty or unwilling to interact socially with human therapists [12]. Some individuals with behavioral disorders even prefer robots to humans [13]. Robins et al. have shown this preference in children with autism spectrum disorder (ASD) and limited verbal skills [14]. Fridin, Angel and Azery [10] in their research studied the acceptance, interaction, and authority of robots over children in kindergarten, or in other words, they studied assisted robotics in kindergarten. They conducted their research on 19 children between the ages of 4 and 8. In their experiments, the researchers measured eye contact, face, body, expression of vocal emotions, and proxemics. After the experiment, the researchers concluded that the children accept the robot's presence, even if the robot intrudes into their personal space. Furthermore, children like to interact with the robot and can even follow the robot's instructions and accept its authority. It is also worth mentioning that although their study was conducted with typically developing children, their proposed technology was intended to be implemented for children with ADHD. Humanoid robots, which look like a human but are much less complicated than humans, could allow a child with behavioral disorders to relate better. Prins et al [24] in their research on the impact of play elements on child motivation conducted an experiment with 51 children with ADHD, aged from 7 to 12 years. All subjects were divided into two randomly selected groups and exposed to three weekly memory courses. One group had a play version of the training, while the other had a normal one. The results suggest that the children, who were assigned a game version of memory training, showed greater motivation and better performance, making fewer errors on tests. The main objective of this work is to use humanoid robotic technology together with psychological and engineering sciences, combining it with play elements, to improve the social skills of children with behavioral disorders. The designed system focuses on different aspects, such as the recognition of facial expression, patient's attention, and the emotion aroused. In addition to the beneficial effects deriving from the interaction with a humanoid robot, the data collected during the therapeutic sessions can be used to monitor the progress of the patients suffering from behavioral disorders.

III. Contextual Investigation

An empowerment-based analysis method was adopted to achieve user experience (UX) requirements, as illustrated in [19]. The method illustrated in Fig. 1 is a transformative process that starts with a contextual investigation aimed at understanding users, their behaviors, and skills within a given community and identifying potential improvements in their quality of life, which are expressed in terms of human needs.

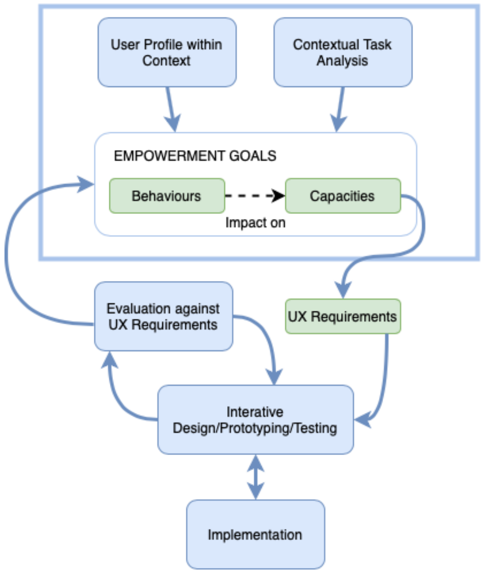

Fig. 1. Empowerment-driven Requirements Engineering process.

The key factors that can contribute to the empowerment of the target users with respect to the identified needs are taken into consideration in order to formulate clear user empowerment goals. The goals involve a number of UX requirements that can be iteratively modified/extended and ultimately guide usability designers. The contextual analysis started in September 2019 and allowed us to have a vision of the most common questions regarding the problems related to people with ADHD. Our work was carried out in collaboration with a diagnostic and therapeutic center in Senigallia, which allowed us to meet and interview a developmental psychiatrist and a psychologist. During the interview, we focused on analyzing the domain of ADHD and, in particular, on understanding the associated therapeutic process. An Mp3 file was generated for each interview in order to keep only the information deemed useful for the analysis. Finally, the properly analyzed information was reported on a document so that it could be easily shared with the design team. The therapists explained that the therapeutic pathways for children with ADHD must be determined based on the specific patient, as each subject can present different symptomatology. Surely, the protagonist is never just the patient but the whole context and the people around which a multilateral path is necessary.

Stimulus control is a fundamental part of therapy, as these children often get distracted, precisely because they are constantly looking for stimuli. They reported that for a child with attention deficit predictability is a watchword, these children need to predict what happens. They agreed that the humanoid robot could become a reliable and predictable technological middleman for the child. Among the therapeutic activities for which greater attention is expected, the personalization of the therapeutic path has proven to be the innovative element of our system.

Following the analysis phase, the following functional requirements were established:

- Recognition of facial expression,
- Personalization of the therapeutic path,
- Data acquisition in real-time,
- Data processing,
- Monitoring of the therapeutic progress.

The research work we carried out capitalizing the results of the contextual inquiry aimed to provide therapists with a complete tool, capable of simplifying the collection and analysis of data thanks to an ad hoc structure, but above all, we wished to give them the possibility to experience a new approach to cognitive behavioral therapies with the help of artificial intelligence. Our goal was to demonstrate that the use of artificial intelligence and the use of innovative technologies can positively affect what therapy for ADHD is today.

IV. The System

Our system was conceived to provide support to therapists in the treatment of ADHD patients by making the therapy less boring and more attractive, by fully capturing patients' attention. It is perfectly integrated with a humanoid robot equipped with a touchscreen that allows interaction with patients through our application. The system is connected to a remote server, and the patient receives customized exercises in the form of games for therapeutic purposes. The humanoid robot used is Pepper. The system, through one of the two cameras integrated on Pepper (one on the forehead and one on the mouth), observes the child interacting with the application and uses emotion recognition algorithms to capture and understand the patient's degree of attention and any difficulties. Analyzing the child's expressions and recognizing his state of mind, through artificial intelligence, helps the therapist build the right therapeutic path and the right behavioral measures to take. The data collected by the camera are combined with the results of the exercise. This combination is subsequently analyzed through evaluation metrics with automatic data analysis algorithms to propose adequate levels of therapeutic activity, and above all to provide the therapist with the degree of patient participation. This process leads to the digitization of the patients' healing path so that any improvement (or worsening) is monitored. Children perceive the presence of a robot as a game. Therefore, children are aware that they are facing therapy but do not perceive stress. Pepper becomes a reliable and predictable technological intermediary for the child, making the patient active, protagonist, and autonomous during a therapeutic session.

A. Architecture

As mentioned in the previous paragraph, Pepper is equipped with a touch screen and video camera. The architecture of the system is presented in Fig 2.

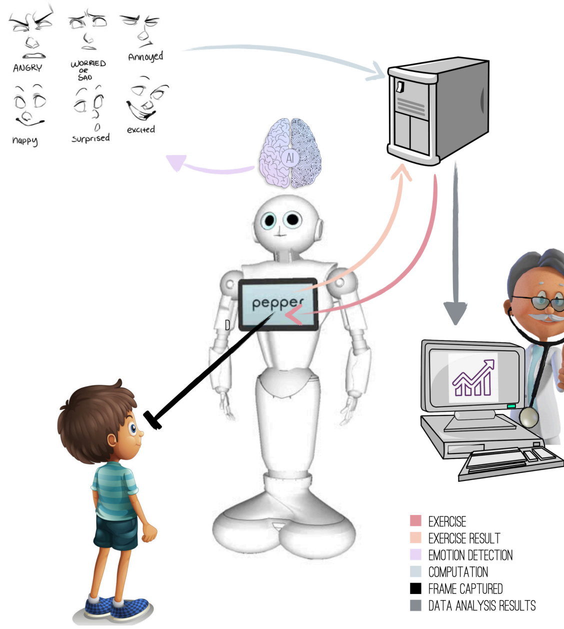

Fig. 2. System Workflow.

During the therapy session, the therapist starts the system via their PC so that the application is launched on Pepper's touchscreen and the child can face the first exercise in terms of play. During therapy, the child will (unknowingly) be supervised by the humanoid robot's video camera, which will periodically capture frames. It was decided to carry out a sampling in order to reduce the computational load of the system. The captured frames are analyzed by an emotion classification model so that an estimate of the child's emotionality can be made. After the exercise, the results and frames are sent to the remote server which, through ad hoc metrics and algorithms, generates the next level of therapeutic activity. The combination of data is fundamental as we cannot rely solely on the outcome of the exercise but also on the patient's specific emotional state, which can be influenced by various factors (such as boredom, hyperactivity, anger). With the acquisition of the frames, we can understand the degree of attention and this allows us to analyze the session efficiently. Once the data has been analyzed, the therapist can view the patient's progress on his PC and thus understand in real-time how to continue the exercise session. Each therapy session will be recorded and will provide an estimate of the patient's progress.

V. Artificial Intelligence in the System

This section will show how artificial intelligence can support the therapist on this path. As illustrated in the previous section, during the therapy session the child will be monitored by the humanoid robot's webcams to analyze his emotions. The classification of emotions has been carried out using convolutional neural networks (CNN or ConvNet). CNNs are machine learning algorithms that have been incredibly successful in handling a variety of tasks related to video and image processing. The captured images, therefore, pass through these algorithms which first detect a face and then recognize the emotion of that face. Finally, the trend of the captured data will be analyzed in order to obtain a qualitative measure, which will be used both to understand the progress of the therapy and to let Pepper give a message of encouragement to the child. Fig. 3 shows a schematic representation of the various parts that make up the recognition of emotions in the system.

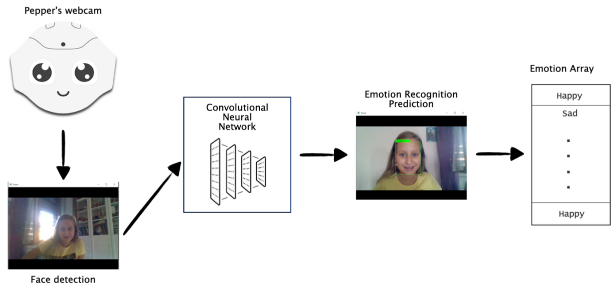

Fig. 3. Emotion Recognition Workflow.

A. Face Detection

A Multi-task Cascaded Convolutional Network (MTCNN) was used to perform the face detection. The MTCNN uses three convolutional networks in cascade, capable of recognizing the faces and positions of the five points of reference, namely:

- 2 reference points in the center of the eyes;
- 1 reference point on the tip of the nose;
- reference points at the end of the mouth.

The three phases of face detection are divided in this way:

1. in the first phase a shallow CNN is used in order to quickly capture the candidate faces;

2. in the second phase a selection of the candidate faces is made, or false positives are eliminated, through a more complex CNN;

3. in the third phase, another CNN fine-tunes the previous results, also identifying the reference points of the face.

Let's analyze in detail the three phases listed above.

1) Proposal Network (P-Net): This network is used to obtain the bounding boxes relating to faces, through a technique called “bounding box regression”, which has the purpose of locating the bounding boxes relating to the objects sought, in this case the faces. Finally, refinements are made to combine the overlapping bounding boxes.

2) Refine Network (R-Net): The output of the P-Net goes to the R-Net input. R-Net reduces the number of candidates by performing bounding box regression calibration and non-max suppression to merge overlapping candidates. For each candidate, R-Net establishes whether it is a face or not and outputs a 4-element vector representing the bounding box and a 10-element vector for locating the facial reference points.

3) Output Network (O-Net): The last step is similar to R-Net, but O-Net aims to describe the face in more detail and visualize the positions of the five facial reference points for the eyes, nose, and mouth.

B. Emotion Recognition

For the classification of emotions, we use a CNN which takes as input the faces returned in output by the MTCNN. The network is structured as follows:

1. convolutional layer: 32 output features, 3x3 kernel, stride 1, batch normalization, and ReLu;
2. convolutional layer: 64 output features, 3x3 kernel, stride 2, batch normalization, and ReLu;
3. convolutional layer: 128 output features, 3x3 kernel, stride 2, batch normalization, and ReLu;
4. convolutional layer: 256 output features, 3x3 kernel, stride 2, batch normalization, and ReLu;
5. fully connected layer:
   a) 256 features 6x6 in input, 256 neurons, ReLu;
   b) 256 input connections, one output neuron for each emotion to be classified (7), sigmoid function.

The output of this CNN will be the emotion classified for the input image; the bounding box around the identified face and a label bearing the classified emotion will be visible on the video stream.

C. Dataset

The network illustrated above was trained on the Toronto Face Database dataset [26]. This dataset comes from a subset of images present in the data set called Facial Expression Recognition 2013 (FER-2013) [27]. FER-2013 was created by Pierre Luc Carrier and Aaron Courville using the Google Image Search API to search for face images that match a set of 184 emotion-related keywords such as "happy", "angry" and so on. Toronto Face Database was then created on the basis of FER-2013 by Mehdi Mirza and Ian Goodfellow. The latter prepared a subset of 35887 images and mapped the keywords of the emotions in order to obtain seven broad categories:

- 4953 images for "Anger",
- 547 images for "Disgust",
- 5121 images for "Fear",
- 8989 images for "Happy",
- 6077 images for "Sad",
- 4002 images for "Surprise",
- 6198 images for "Neutral".

D. Capture of the predominant emotion

Analyzing Fig. 4 it can be seen that the emotions captured during the therapy session are inserted into an array and then processed. The therapy session is divided into several established time intervals and for each interval the various emotions are captured. To carry out this operation, the underlying algorithm relies on a support array where all the emotions relating to an interval of therapy are first saved. After the interval, the array is analyzed. Since emotion is a qualitative measure, the mode is extrapolated, corresponding to the most frequent value in the observed distribution. We can have either unimodal or bimodal distributions. The mode is saved in another array and the support array is emptied to be ready for the next interval. Carrying out the analysis of emotions during the therapy phase is very important as it allows us to observe the subject's moods. In fact, the therapist can understand if the child is able to keep attention during the session (as if he/she looks away, the "distracted" label will be marked) or if he/she is getting bored and therefore some new strategy must be adopted. At the same time, Pepper uses the latest mode value to provide appropriate feedback to the little patient, pronouncing an encouraging message to the subject. To achieve that, a dictionary of encouragement phrases has been designed and created for each emotion so that Pepper may randomly "choose" what to say in order to properly encourage the child, considering the latest captured emotion.

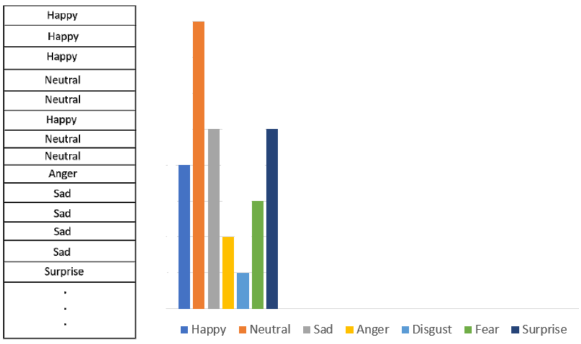

Fig. 4. Example of a support array with related emotions Humanoid

VI. Prototype Evaluation

Our system has been designed to provide children with a playful way to approach therapy, giving the traditional work of therapists an extra boost. The prototype was tested within a therapeutic session of a group of children to assess the degree of acceptance of the humanoid robot therapist. At the outset, a laboratory experiment was conducted with a child with ADHD to make sure that adequate therapeutic stimuli came from Pepper at any time.

A. Preliminary experiment

The preliminary experiment happened in January 2020 and was conducted in the HCI-UsE laboratory of the University of Salerno. During the child-robot interaction, the child was accompanied by his therapist. The participant in the preliminary experiment is an eight-year-old boy named Francesco who is in the third year of primary school. From an early age, he showed difficulty managing his emotions. After several tests it emerged that Francesco has behavioral disorders; in particular, he has difficulty in staying focused even during mundane activities. Plus, he has a hard time dealing with frustrations. Initially, Francesco was afraid to face the therapies with the therapist and appeared extremely introverted. The therapist also found it difficult to attract his attention and let him do the exercises. With the introduction of the Pepper based application, Francesco was able to carry out the therapy in a fun way. During the experimental session, Francesco started playing a game, which aimed to train him to stay focused. Pepper told and illustrated a story through his display and, in real-time, captured the child's expressions. Francesco was initially distracted from discovering the origin of the sound but was intrigued by the story he observed on the display. When Pepper finished illustrating the story, he asked Francesco to answer the questions in order to analyze the little patient's degree of understanding. The data acquired from the responses plus the frames were processed to obtain the percentage of attention received. The result was displayed on the therapist's terminal. The next game was then chosen based on the information gathered and was submitted to Francesco. After the session, the therapist, thanks the data processed by the system, was able to obtain a quote on the progress of Francesco's therapy.

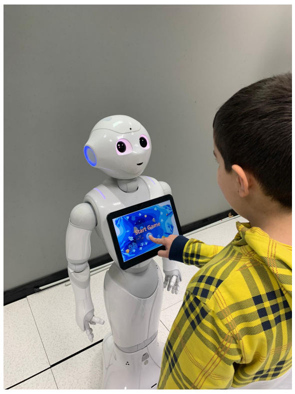

Fig. 5. The child while experimenting with the system.

B. Assessment of the degree of acceptance

The first experimental phase continued through the observation of group therapy activities, that occurred in the center, after gaining consensus by parents. The goal was to evaluate the degree of acceptance of the introduced technological support. The group therapy allows children to manage their emotions through social relationships while collaborating with other children [15]. A group of children (N = 5), aged between 7 and 10 years, was followed by the therapist, who interacted with them through games and exercises. The observation spread over three subsequent sessions lasting an average of 50 minutes for three weeks. During the first session, the therapist introduced Pepper to the children and explained how to interact with the humanoid robot. Children immediately accepted the presence of the humanoid robot, starting to collaborate and showing a high degree of attention regarding the exercise they had to perform. After the end of the third session, a set of 10 questions extracted from the UTAUT questionnaire [25] was submitted to individual children to measure their acceptance of the system. Children could indicate their level of agreement on a five-point smiley face scale, selecting the appropriate smiley face corresponding to totally disagree (1) - disagree (2) - neither agree nor disagree (3) - agree (4) - totally agree (5). Although a rigorous assessment of the degree of acceptance, based on the UTAUT model is part of our current work, the feedback gained by the initial experiment was encouraging, promising a good acceptance and intention of using a humanoid robot for therapeutic use in children with behavioral disorders. This was also confirmed by the therapist who reported a favorable reaction to this playful Pepper-based therapy.

VII. Conclusion and Future Work

In conclusion, the idea to rely on a humanoid robot in the therapeutic context has proven very attractive for both therapists and children, who are better motivated in their therapeutic path. The prototype we have described allows to build personalized therapeutic paths based on the profile of the patients with ADHD, also thanks to the support of artificial intelligence. The next step in this research will be a rigorous longitudinal experimental study, involving a significant number of patients, meant to assess the degree of acceptance of the proposed assistive robot-based system. Unfortunately, this phase has been temporarily stopped due to the Coronavirus disease pandemic. In the future, we also plan to employ the system to support activities within the school environment. Indeed, we are confident that, thanks to the logic of group therapy, Pepper could help children affected by ADHD socialize with their classmates. This could be the fundamental component to increase peer inclusiveness towards children with ADHD, this being a factor of fundamental importance [28]

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