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Neuro-Symbolic Approach for Tantrum Monitoring and Prevention in Individuals with Autism Spectrum Disorder: A Protocol for Virtual Agents

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Abstract. Autism Spectrum Disorder (ASD) poses unique challenges, with individuals often experiencing difficulties in emotional regulation, leading to disruptive behaviors such as tantrums. This research protocol outlines the development of an innovative system designed to monitor and prevent tantrums in individuals with ASD, employing a neuro-symbolic approach. The proposed system integrates neural networks and symbolic reasoning to improve understanding and prediction of tantrum episodes. Leveraging real-time physiological and behavioral data, collected through wearable devices and user input, the system employs machine learning algorithms to detect patterns indicative of imminent tantrum events. Furthermore, a symbolic reasoning system interprets these patterns, taking into account individualized factors. The outcomes of this study are anticipated to contribute valuable insights to the growing field of technology-assisted interventions for neurodevelopmental disorders.

Keywords. Autism, Human-AI interaction and collaboration, User modeling and personalisation, Integration of learning and reasoning, Biosensing techniques

1. Context

1.1. Clinical problem

Autism remains an etiological mystery, its treatment has attracted the attention of many researchers who have used different techniques and technologies to improve the quality of life of ASD subjects.

In this regard, recent methodological advancements have focused on measuring emotions as organized patterns that emerge within interactions with others which may aid in better understanding the developmental mechanisms that underlie the nature, causes, and consequences of emotions—including tantrum. Machine learning is one of

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the above-mentioned advances in computer science that can process data to highlight meaningful patterns. When artificial intelligence is used to investigate affective states of the human being, we enter the field of affective computing, defined as “computing that relates to, arises from, or deliberately influences emotion or other affective phenomena” and use “affect” and “emotion” interchangeably [16].

1.2. Related Literature

Most of the literature found with the keywords ”ASD” and ”Machine learning” refers to the diagnosis of the disorder itself, however the use of machine learning in tantrum detection in ASD children has been studied and applied in many researches (for a complete review: [10]), but only a few of these used biometric data: most used data related to facial expression, kinetics and motor movements ([15], [9], [8], [17]).

Studies that specifically deal with the detection of tantrums in ASD patients through the use of wearable devices and biometric data are now presented.

The first study [13] aims to examine the feasibility of detecting agitated behaviors in children with autism spectrum disorder (ASD) using data from wearable devices. Data were collected on a 9-year-old autistic child using the Empatica E4 device, which records electrodermal activity (EDA), pulsating blood volume (BVP), and acceleration (ACC). The study demonstrated the possibility of using data from wearable devices to detect the agitated behaviors of children with ASD during their daily activities. This could improve the quality of life of ASD patients and their caregivers by providing timely notification of such behaviors and preventing harmful consequences.

The second study [11] proposes and implements a non-invasive real-time deep learning-based Meltdown / Tantrum Detection System (MTDS) for ASD individuals. The system uses a prototype hardware in the form of a wearable bracelet, which records the heart rate, skin temperature, and galvanic skin response of individuals with ASD, and transmits the data to a server connected to the internet, where it is analyzed by deep learning models such as CNN, LSTM, and CNN-LSTM. The system can detect the state of anger or panic crisis in real-time and generate an email alert to caregivers or clinicians, and it also offers a graphical interface to monitor and analyze data and results. The size and sociodemographic and clinical characteristics of the sample are not specified. The results show that the CNN-LSTM-based system achieved higher accuracy (98) and lower absolute mean error (0.04) than the other algorithms.

The aim of the third study [19] is to create a device that can detect and prevent meltdowns in autistic children using stress sensors and machine learning algorithms. An optical sensor was used to measure heart rate and an electrodermal sensor to measure the galvanic response of the skin. An STM32-F446RE microcontroller converted analog signals to digital and transmitted them via bluetooth to an Android application. The logistic regression model showed promising results with an accuracy score of 0.82 and a recall score of 0.83. The decision tree model showed a lower accuracy score of 0.76 and a recall score of 0.62. These results depend on the only child tested for this thesis and could change for other users depending on how their body reacts to stressful situations. The study has shown that meltdowns can be predicted using simple machine learning algorithms that don’t require large data to give generally good accuracy scores.

The aim of the latest study [7] was to evaluate whether physiological and movement data collected by a wearable biosensor can be used to predict aggression toward others in young people with autism spectrum disorder (ASD). Cardiovascular, electrodermal and accelerometric activity was recorded from a biosensor worn by 20 young people with ASD (ages 6-17 years) during 69 nature observation sessions in a specialized psychiatric unit. The results indicate that aggression towards others can be predicted 1 minute before it occurs using 3 minutes of previous data from the biosensor with an average area under the curve of 0.71 for a global model and 0.84. The biosensor was well tolerated, usable data were obtained in all cases, and no users withdrew from the study. These findings lay the groundwork for the future development of real-time adaptive intervention systems to prevent or mitigate the emergence, occurrence, and impact of aggression in ASD.

As far as patient intervention is concerned, research so far has focused on robotic agents in the field of social robotics: social robots, also known as Socially Assistive Robots [5], have been designed to leverage their social and affective attributes to sustain people's engagement as well as to motivate, coach, educate, facilitate communication, monitor performance, improve adherence to health regimen, and provide social support to people [14]. Researchers have found that if a robot communicates using the same sorts of non-verbal cues that people use, then people subconsciously interpret, form social judgments, and respond to robots much as they do when these cues are used by people [1].

2. Research Question

The research question is as follows: how does the integration of affective computing with physiological signal processing, and a symbolic reasoning framework with Answer Set Programming (ASP) contribute to the development of a virtual agent for tantrum monitoring and prevention in individuals with ASD?

It is hypothesized that the virtual agent, incorporating advanced affective computing techniques and a dynamic symbolic reasoning framework through ASP, will significantly prevents or reduce the severity of tantrum episodes in individuals with ASD. Additionally, it is anticipated that the personalized interventions generated by the virtual agent, based on real-time emotional data and individualized factors, will enhance emotional regulation and well-being, contributing to an improved quality of life for both individuals with ASD and their caregivers. Through iterative testing and refinement informed by user feedback, it is anticipated continuous improvements in the virtual agent's effectiveness and user satisfaction over the course of the study. One of the possible explanations for this clinical pattern is that individuals with ASD experience extreme difficulty filtering sensory and social inputs, a fundamental process to discriminate important information from irrelevant information when interacting with their environment (physical and social) [20].

To talk about the novelty of this research, it is good to underline, starting from the prevalence of robotic agents compared to virtual ones as therapeutic and educational tools for autism, a particular phenomenon: the practices of the of the use of the robot in the field of ASD, often considered best practices, are determined by the mainly from manufacturers or professionals in the robotics sector who take little into the consideration of clinical aspects [21]. The following research will be carried out with the collaboration of a strongly multidisciplinary team that will ensure rigor both from a computer science point of view and from that of social sciences and clinics. The second fundamental element of novelty is the use of a Neuro-Symbolic approach, which represents a convergence of symbolic reasoning and neural network based learning. This hybrid methodology leverages the strengths of both symbolic AI, which excels in rule-based reasoning and logical inference, and neural networks, which excel in learning complex patterns from data [6]. In the context of the presented research, the neuro-symbolic approach is particularly advantageous. It facilitates the integration of symbolic reasoning, crucial for modeling individualized factors influencing emotional states in ASD, with the adaptability and learning capabilities of neural networks. This synthesis enables the virtual agent to dynamically interpret and respond to complex emotional cues, evolving its interventions based on real-time data.

3. Methodology

3.1. Design

The design of this research is a cross-sectional study with quantitative and qualitative methodologies to investigate the development and impact of a virtual agent. This mixed-methods approach allows capturing both quantitative effectiveness metrics and the qualitative richness of user experiences. On the quantitative front, a pre-post intervention design will be implemented through a structured set of outcome measures, including frequency and severity of tantrums and identify the system's effectiveness. Additionally, physiological data, collected through wearable devices, will be subject to statistical analysis to provide objective insights into emotional regulation changes. Complementing this quantitative foundation, a qualitative research strand will employ in-depth interviews and usability testing sessions. These qualitative components aim to uncover subjective experiences and perceptions of individuals with ASD and their caregivers regarding the virtual agent. Thematic analysis will be applied to extract rich narratives, providing a deeper understanding of how the virtual agent influences emotional well-being and daily life.

To develop a comprehensive understanding of the ASD population, a specific sampling strategy will be implemented. The sample will ideally be formed by subjects with a confirmed diagnosis of level 2 ASD between the ages of 18 and 30: by tailoring interventions to the specific needs and strengths of young adults, the effectiveness and long-term impact can be maximized. In tandem, caregivers closely associated with the daily lives of these individuals will also be invited to participate, providing a holistic perspective on the efficacy of the virtual agent proposed. To initiate participant recruitment, collaborative efforts will be made with the DISCAB Neuropsychology Clinic and the Abruzzo Regional Autism Reference Center. This collaborative approach, involving healthcare professionals and advocacy groups, will facilitate the identification and invitation of potential participants who meet the specific inclusion criteria. Informed consent will be obtained to confirm a clear and voluntary understanding of the purpose of the study. Finally, the determination of sample size will be guided by a balance between practical considerations and statistical power. Given the unique nature of the ASD population, an approach that prioritizes a smaller sample size with in-depth qualitative data collection will be adopted, ensuring a comprehensive exploration of the impact of the virtual agent on diverse individuals.

3.2. Neural network

In this section, we will explain how you intend to develop the ML system that will process the input data.

Physiological Signal Processing Integration: The biosignals that will be measured in the research have been chosen after the evidence highlighted previously in the review paragraph. Heart Rate Variability (HRV) is defined as the variations between consecutive RR intervals or heartbeats. HRV components are regarded as significant dependent measurements in psychophysiology and behavioral medicine, and they have attracted interest in both fields [2]. Galvanic Skin Response (GSR), also called Electrodermal Activity (EDA), is considered to be one of the most robust physiological indices of stress and it is widely used [12]. The aim is develop algorithms for HRV and GSR analysis to extract patterns associated with varying emotional states in individuals with ASD. It will be necessary to develop signal processing techniques to discern subtle changes indicative of heightened arousal or emotional distress.

Real-time Emotional State Inference: The system will integrate HRV and GSR signal processing components into a system for real-time emotional state inference. The aim is to provide the virtual agent with accurate and timely information regarding the user's emotional state. Cognitive empathy is the capacity to understand and identify the feelings of another individual; it makes us better communicators because it helps us relay information in a way that best reaches the other person. It involves having the ability to comprehend the mental condition of others and what they might be thinking in response to the situation. This is associated with the concept known to psychologists as the ''Theory of Mind,'' or the capacity to consider the thoughts of others. Although they are far from the formalization of artificial empathy, several studies have highlighted how necessary it is for an agent to be able to intercept the emotional states of the user and respond in a relevant way [4].

3.3. Automated Reasoning

On the other side, this research will develop a comprehensive symbolic reasoning system that includes a broad understanding of individualized factors influencing emotional states in individuals with ASD. Automated reasoning is more complex than just analysing users' behaviours since it requires problem solving based on numerous processes. The aim is to establish a knowledge base that incorporates symbolic representations of various contextual factors; this base will serve as the foundation for the virtual agent's decision-making process, allowing it to interpret emotional cues within a rich and personalized context. To accomplish this, we plan to use ASP. This programming paradigm is widely used and has also been applied to the development of logical agents [3]: the reason is that, unlike neural networks, it allows for reliability, transparency, and trustworthiness. In addition, the absence of a black box makes it possible to intervene in a targeted manner to modify, if necessary, the system and ensure maximum customization. Using ASP's expressive syntax will represent complex relationships and dependencies within the knowledge base, allowing for flexible and efficient reasoning. Another application of automatic reasoning within this research could be relative for mobility and transportation, as the cognitive profile of people with ASD can lead to some difficulties during their journey. This can involve difficulties with communication, the incapacity to utilize public transportation securely, and frequently the requirement to be accompanied by a caretaker [18]. The problem of connecting two places as quickly as possible is a classic example used in ASP, which seems to have been created specifically to solve this type of problem. This element of the research will serve to provide ASD subjects with greater autonomy and reduce dependence on caretakers, providing overall a significant improvement in their quality of life.

4. Discussion and future works

The presented research poses several ethical considerations. Some potential ethical problems include:

1. Privacy and Informed Consent: Collecting sensitive data, including facial expressions, physiological signals, and behavioral patterns, raises concerns about privacy. Ensuring informed consent, especially considering the vulnerability of the ASD population, is crucial. In this regard, implement informed consent procedures is in plane: clearly explaining the purpose of data collection, how the data will be used, and measures in place to protect participant privacy.
2. Stigmatization and Bias: A virtual agent designed specifically for ASD individuals may unintentionally reinforce stereotypes or stigmatize participants if not developed and implemented carefully. To avoid this, in this research they will be kept as a reference of inclusive and person-centered design principles, ensuring that the virtual agent's responses and interventions are respectful and unbiased.
3. Equity and Accessibility: Ensuring equitable access to the virtual agent from diverse backgrounds is essential. Socioeconomic factors or limited access to technology could create disparities in the benefits of the intervention. For this reason, it is expected that the development of the agent and the affective computing system will be carried out through tools within everyone's reach, such as common smartwatches or EMPATICA's devices and monitoring platform.

By merging neural network and symbolic reasoning, this research aims to provide a novel and effective tool for supporting individuals with ASD in emotional regulation, fostering improved quality of life for both individuals and their caregivers. At present, the research is in the neural network development phase. Until now, the design of the agent has been based on data from the literature. The user's interaction with the agent has not been specified in this paper because, for a design that is maximally user-oriented and context-specific, a survey is being completed to map the needs and expectations of young ASD subjects and their caregivers. These phases, carried out in parallel, are expected to be completed by July 2024; subsequently, with the data collected, we will move on to the development of the symbolic component: The idea behind this choice is the belief that similar interventions designed a priori have limited effectiveness. In conclusion, beyond the interdisciplinary synergy within IT science, this research underscores the imperative collaboration with psychology. It is in the confluence of IT science methodologies and psychology's deep understanding of human behavior that we find the transformative potential to improve interventions in ASD.

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