A Step towards Virtual Reality based Social Communication for Children with Autism

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Abstract—**Children with Autism Spectrum Disorder (ASD) are characterized by deficits in socialization, communication and imagination. In recent years several assistive technologies e.g., Virtual Reality (VR) are being investigated to promote social communication skills in these children. However these only report on performance and do not use physiological markers as predictors of one's affective states. In conventional techniques, a therapist adjusts the intervention paradigm by monitoring the affective states of these children. However, these children often demonstrate inability to explicitly express their affective states thereby inducing limitations on conventional techniques. Physiological signals being continuously available and not directly impacted by these communication difficulties can be used as markers of one's affective states. In India, research on technology-assisted intervention for children with ASD is rare. Here, the presented work seeks to address the challenge of maintaining the subtle Indian social aspects which still remains untouched in research, but are valuable contributors to social communication while developing VR based social conversation system. Additionally, we acquired physiological markers and correlated these with the affective state having implication on one's performance. A preliminary usability study indicates the potential of the system to improve social task performance and to induce variations in one's physiological markers.**

Keywords—**ASD, Virtual Reality, Physiology, Anxiety.**

I. Introduction

Autism is defined as a neurodevelopment disorder with prevalence rate being recorded as 1 in 250 in India [1]. It is typified by a triad of impairments in reciprocal social interaction, communication and imagination [2]. The severity of cognitive, language, social and adaptive skill impairments varies widely among children and thus, termed as Autism Spectrum Disorder (ASD) [3]. Autism remains as a behaviorally defined syndrome having no universally accepted treatment or cure. But there is an increasing consensus that intensive behavioral and educational intervention programs can significantly improve long term outcomes for individuals with autism [4]. Therefore researchers are looking forward in reforming the presently available intervention programs.

Realizing the inexpediency of the present treatment modes in terms of enormous cost [5], lack of trained professionals [5] and lack of generalization gained through behavioral intervention techniques, growing number of studies have been investigating the efficacy of using technology as an assistive therapeutic tool for children with ASD namely, computer technology [6], Virtual Reality (VR) environments [5] and robotic systems [7]. Among these alternative techniques, we chose VR because of its potential advantages which make it suitable for children with ASD. The strength of VR systems for ASD intervention includes malleability, controllability, modifiable sensory stimulation, individualized approach, safety and potential reduction of problematic aspects of human interaction particularly during initial skill training [5]. With no direct human to human interaction, the VR-based system provides a simplified but exploratory environment for children with ASD [5]. Since VR mimics real environments in terms of imagery and contexts, it may allow for efficient generalization of skills from the VR environment to the real world [5]. Thus VR based systems can serve as an effective complementary tool in the hands of the interventionist and thereby have the potential to make the application of treatment readily available and cost effective.

Despite these potential advantages of VR based system, current VR based studies as applied to assistive intervention for children with ASD [7], [8] report only on one's performance metrics with no mapping of one's performance to his affective states. This limits individualization of application. However, physiological signals can be used as markers of one's affective state such as, anxiety. Researchers have shown that physiological signals can be evoked by different amounts of presence in the virtual environment [9], [10] and the transition from one affective state to another is accompanied by dynamic shifts in indicators of Autonomic Nervous System (ANS) activity [11]. Although some studies [12], [13] have demonstrated this feasibility, however, research in Indian context is rare. Thus designing a VR based system that can elicit variations in one's affective states along with variations in physiological markers while maintaining the subtle Indian cultural social communication aspects would be critical. Subsequently, this will pave the way for understanding the feasibility of using the physiological markers as affective cues which in turn can make the Human Computer Interaction more effective and meaningful.

Using physiology based markers for predicting one's affective states is particularly relevant for children with ASD, because, these children exhibit deficits in expressing their affective state e.g., anxiety. This in turn places limits on the traditional conversational and observational methodologies. The physiological signals being continuously available and not necessarily directly impacted by these difficulties [3] can be used as markers of one's affective states. The affective state, e.g., anxiety forms the ground basis for the floor-time-therapy in conventional techniques where the therapist adapts her intervention strategy depending on the affective cues of these children. Anxiety is a common concern in clinical samples of children with autism and plays an important role in human-computer interaction tasks [12]. Research indicates that learning skills in communication and social domains show substantial gains if an individual works from his comfort zone with reduced anxiety [14].

Given the potential advantages of a VR based system, importance of physiological markers for identifying one's affective states during social communication, and limited investigation on this so far as social conversational issues in the Indian context are concerned, the research study presented in this paper aims at (i) developing a VR based social communication task module considering language and subtle social aspects specific to Indian context, (ii) interfacing the VR based system with physiological data acquisition module and (iii) designing a usability study to investigate the effect of interacting with our VR based system and to recognize the feasibility of mapping one's physiological signals to his affective states while participating in VR based social task.

In our research study presented in this paper, as an initial step to designing of the proof-of-concept application, we developed a VR based system that can monitor the physiological signals and measure one's performance while participating in a communication task. Subsequently, based on the performance measure, our system switched tasks of different difficulty levels along with physiological data acquisition for offline analysis. The rest of the paper is organized as follows: In section II we present system design. Section III discusses the method carried out for the study. Section IV presents the results obtained from the usability study. Section V summarizes the contribution of the present study and its scope for future research.

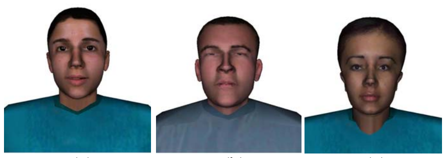
II. SYSTEM DESIGN

The system presented here comprises of the following sub-systems (i) VR based task module, (ii) Task Switching module and (iii) Physiological Data Acquisition module.

A. Design of VR based Social Communication Task Module

In our study, we used desktop Virtual Reality (VR) because this is affordable and less prone to cyber sickness [5]. The social communication task module consists of a task presentation module and a conversation module. The task presentation module consists of an avatar narrating social stories in first-person perspective with context-relevant backgrounds designed in the VR environment. The interactive VR environment is designed using the Vizard software from Worldviz. This software comes with limited number of avatars, virtual objects and scenes which can be modified and used to create a story in the virtual world. However, a number of enhancements were made on the VR platform to make it appropriate for intervention applications with children with ASD. In order to perform social communication tasks with children with ASD, we needed to develop more extensive social situations with custom-designed backgrounds and avatars whose age and appearance resembled those of the participants' peers without trying to achieve exact similarities.

We developed 24 social stories. These social stories are short stories written in specific style and format, and they describe what happens in a specific social situation and presents information in structured and consistent manner [15]. We chose social conversation in our study to help the participant become familiar with socially appropriate behavior and respond appropriately. In our study, the stories were chosen from a database [16] written specifically for these children and were based on topics of interest to teenagers, such as: memorable day in life, favorite sport, film, best friend, travel with family and field trip, etc. The avatar heads we worked with were taken from a data pool of different faces. For our study, in order to give our avatar an Indian look, we modified the complexion, hair and eyebrow colors of the avatars' faces by using GIMP software. In addition, the avatars were made to stand in the VR world at a decorum distance of 4.5 ft from the participant, so as to suit the cultural requirements for conversation [17]. We programmed our avatars to exhibit three different emotions, namely, happy, angry and neutral by morphing their facial expressions using the People-Maker software. The likely country of origin and emotions of the avatars were validated by conducting a survey among teenagers (age group of 14-21 years) to ensure that the participants can feel that the avatars are their classmates from their own country and interpret the emotion as intended by the designer. The avatar was rated based on valence-arousal scale (5 point scale) for three different sets of emotions, i.e., happy, angry and neutral [18]. The data was analyzed based on an approximated emotion model in the valence-arousal affective space. From the survey we selected eight avatars (four each for male and female). The Figure 1 shows three of the avatars demonstrating happy, angry and neutral faces.



(a) (b) (c)

Figure 1. Avatars displaying (a) Happy, (b) Angry and (c) Neutral faces

Our VR based task module also involved designing context-relevant backgrounds for the stories. For each story of the VR environment displayed three context-relevant backgrounds. The avatar moved in the virtual environment which displayed the different backgrounds with smooth transition of the background views relevant to the context being narrated by the avatar. The avatar also made gestures and moved dynamically in the VR world during the task presentation. The twenty four stories narrated by the avatars were recorded in a neutral tone in Hindi by teenagers from the neighborhood using Audacity software. For avatars to speak the content of the stories, these audio files were lip-synched using a Vizard-based speak module. An example for the task presentation module is shown in Figure 2 in which the avatar narrates his experience of his trip to a McDonald's outlet. He describes his experience using hand gestures while walking in the VR world displaying views from the McDonald's outlet. The first background (Figure 2a) displays the avatar standing infront of the McDonald's while the avatar narrates his trip to this outlet. While the avatar discusses his preference for burger, Figure 2b displays the advertisement with burger options in front of the outlet. The task presentation ends with the VR environment displaying the McDonald's restaurant (Figure 2c) when the avatar concludes his narration by sharing his experience on the taste and quality of the food items he had chosen and the cleanliness of the accompanying restaurant.

Figure 2. Screenshot of an example for avatar narrating a story with conversation menu appearing at the end of task presentation

This task presentation by the avatar was followed by participant's response options for questions asked by the avatar in which the participant's performance was evaluated. The conversation module followed a menu driven structure used by the interactive fiction community [19] in which the participant was required to converse with the avatar by choosing statements in response to avatar's questions. Specifically, at the end of each story narration, questions along with menu-driven response options (Figure 2d) were displayed and also spoken by the avatar. Then the participant was asked to select the correct response from the menu options provided by clicking on the accompanying radio buttons. The text box script was in Hindi and it was written using Devanagiri script to suit the local language requirements of our participants. For each task, the participant was provided with a set of five questions, whose content depended on the task's level of difficulty. At the end of each task, the participant's performance measure was evaluated and based on this performance measure, our system delivered visual feedback so as to encourage the participant for the next task. While the participant was interacting with the VR based task, our system acquired the physiological signals and extracted features, such as, heart rate and skin temperature. Vizard-triggered markers were used to synchronize each participant's physiological data with the beginning and end of each VR based task.

B. Task Switching Module

Our VR based system was adaptive to the participant's performance while using the conversation module. The VR based social conversation module consisted of tasks with four difficulty levels. The twenty four social stories were distributed among the four difficulty levels with six stories in each level. The difficulty level depended on the type of questions asked to the participants, such as, whether these were context relevant, projected contingent, emotion recognition based and/or reporting on one's own feeling. These questions were chosen in order to address the impairments in children with ASD related to realizing some of their perspectives on thoughts, emotions and behavior of others. The context-relevant questions are simple and direct questions aimed at addressing contexts that have been referred by the avatar during his narration. The projected contingent questions were designed so that one needs to do some deduction from facts mentioned in the narration before responding to the question. The emotion recognition questions were framed in such a way that a participant needed to recognize the emotions exhibited by the avatars during narration. Lastly, the personal feeling related questions were designed in order to understand the participant's own feeling while listening to the avatar. Specifically, the emotion recognition and reporting on one's personal feeling being some of the core deficits of the children with ASD were chosen by us as ingredients of conversation in tasks of higher difficulty levels. The tasks of difficulty Level I comprised of five context relevant questions; those of Level II consisted of three context relevant and two projected contingent questions; Level III comprised of two context relevant, two projected contingent and one emotion recognition question; and finally Level IV comprised of one context relevant, two projected contingent, one emotion recognition and one personal feeling related question. One's performance measure in a particular task was considered as 'Adequate' if the score was ≥70% of the total score (total score=70), otherwise this was considered as 'Inadequate' with the maximum achievable score remaining constant in each level. The weightage of the different questions in each level of task difficulty was assigned in a way such that in order to achieve an 'Adequate' score in each level, the participant

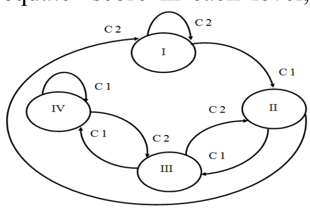


Figure 3. Switching Rationale

C1- Adequate Performance, C2 – Inadequate Performance

had to correctly respond to the more difficult question(s) specific to that difficulty level. Please note that we chose this criterion as a first approximation, and in fact with more data we can modify the criterion based on the intervention paradigm. The rationale of task switching is shown in Figure 3 designed as a finite state machine [20]. In our study, the tasks switched from a lower difficulty level to the next higher level (except at Level IV) if the participant's performance score was 'Adequate' (C1 in Figure 3). Otherwise, for 'Inadequate' (C2) performance score, the participant was offered a task of lesser challenge (except at Level I). This continued until tasks in a difficulty level were depleted.

C. Physiological Data Acquisition Module.

In this work, we acquired physiological signals mainly Pulseplethysmograph (PPG) and Skin Temperature (SKT). PPG is a non-invasive method based on the measurement of the intensity of a transmitted infrared-light beam, which depends on the blood flow at one's fingertip. From the PPG signal we extracted the average heart rate (in beats per minute) of an individual while participating in the VR based task. The SKT was used to measure one's surface body temperature (in deg. Fahrenheit) during the task. We chose these physiological indices because; these have been shown by different investigators as effective indicators of one's affective state, such as, anxiety [21]. Figure 4 shows the block diagram of the physiological data acquisition module. At this stage of research we have acquired one's physiological signals while interacting with the VR based tasks for offline analysis.

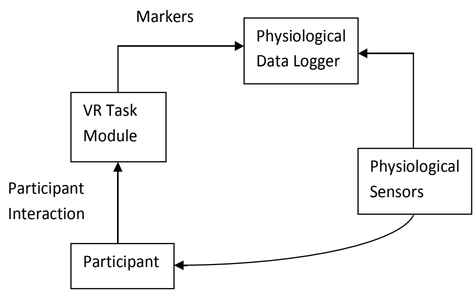


Figure 4. Block diagram of physiological data acquisition module

III. EXPERIMENTS AND METHODS

Before trying out our system with children with ASD, we carried out an initial feasibility study with typically developing (TD) teenagers (age group 13-19 years). Initially the experimenter briefed the participant about the study with the help of a visual schedule and then demonstrated the experimental setup. Also the experimenter told the participant that he could quit the study at any time if he feels uncomfortable interacting with our system. Next, the participant was asked to sit comfortably on a chair in front of the task computer for interacting with the VR based tasks. Then the PPG and the SKT sensors were placed on the tip of the participant's middle finger and the thumb of the non-dominant hand respectively. After the participant expressed his willingness to start interacting with our system, an introductory message scripted in Hindi accompanied by its oral presentation (recorded in a teenager's voice) appeared on the monitor of the task computer. This informed the participant that he would be first asked to listen to an avatar narrating his personal experience, think the avatar as his classmate and after the avatar's narration he would be asked to respond to the avatar's questions. The Figure 5 shows the snapshot of the introductory screen. This was followed by acquiring the participant's physiological signals for approximately 3 minutes as the baseline condition for the study.

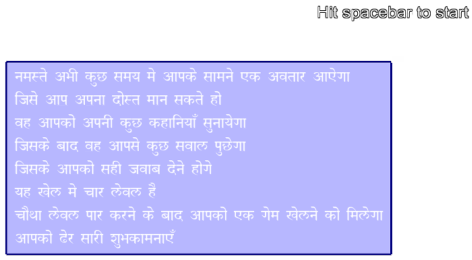


Figure 5. Snapshot of the Introductory Message

After this the participant was asked to press the spacebar (Figure 5) to start interacting with our system. The experiment started with an avatar narrating a story. The avatar exhibited a specific emotion depending on the content of the story. This presentation task was followed by the conversation task between the avatar and the participant.

At the end of the conversation task, the system provided feedback to the participant and based on the participant's performance score, our system used the task switching rationale to switch to the next task. This was accompanied with the acquisition of the participant's physiological signals for subsequent offline analysis.

IV. RESULTS AND DISCUSSIONS

To test the efficacy of our VR based system, we carried out a feasibility study with three typically developing (TD) teenagers (P1-P3). We analyzed the results of our study to investigate the effect of interacting with our VR based system that can adapt itself based on one's performance measure. Additionally, we collected and analyzed data on physiological signal features such as, Heart Rate (HR) and Skin Temperature (SKT), and tried to correlate these indices to one's performance in tasks of different difficult levels. Literature indicates that one's performance improves with decrease in anxiety [14] that is reflected from physiology [21]. We analyzed the data to see whether the participants' performance improved while interacting with our system. This might be due to decreased anxiety which can be interpreted from one's physiological data. This in turn will help us to understand the physiology based behavioral profiling of each participant.

A. Variation in the Participants' Performance while Interactingwith our VR based System

We analyzed the data to understand the effect of interacting with our VR based system so far as the performance of the participant was concerned. The Table 1 shows the participants' performance. The performance score of participant P1 improved as P1 moved from the level I to the Level II, but a drop in performance was observed in level III. This drop in performance in level III improved when the participant P1 moved to level IV. This can be attributed to reduced anxiety of P1 as is evident from his physiology (Section IVB). The participant P2 showed an improvement in performance from level I to level III. But compared to level I, level IV showed less improvement. This may be either due to the fact that the level IV task was too difficult for him or he might have been bored by the task by then.The participant P3 performed well for the first three levels of difficulty but performance at level IV was comparatively less compared to other levels which showed that the level IV was more challenging to the participant. Also P3 had a high anxiety indicated by reduction in his skin temperature (Section IVB).

Thus for all participants we find an improvement (less improvement for P2) in performance score at the fourth level of difficulty compared to the first level, except for participant P3. This might be due to the fact that the anxiety level of P3 was high.

TABLE I. PARTICIPANTS' PERCENTAGE PERFORMANCE SCORE

Participant	Number of Trials	Difficulty Level	Average Percentage Performance Score
P1	1	I	80
	2	II	100
	2	III	78
	6	IV	90.5
P2	1	I	80
	1	II	100
	2	III	100
	6	IV	81
P3	1	I	100
	1	II	100
	2	III	100
	6	IV	83.3

B. Variation in the Participants' Physiological Indices while interacting with our VR based system

At the start, during first trial of the feasibility study, majority of the participants showed a marked increase in quantitative measure of physiological data from the baseline condition. However, later during the study majority of the participants showed an increase in SKT (except P3) and decrease in HR as they moved through different tasks. This trend in SKT and HR can be attributed to the fact that majority of the participants were getting used to our VR based system and demonstrating less anxiety. However, the rate of increase or decrease of the quantitative measure of SKT and HR varied from person to person thereby demonstrating the need for an individualized system that adapts according to the affective state (e.g. anxiety) of each individual.

The Figures 6, 7, 8 show the Heart Rate (HR) and Skin Temperature (SKT) response of the participants (P1-P3) while they took part in the feasibility study. For all the three participants, the HR response showed a sudden increase from the baseline which can be associated to the high anxiety as the participant started interacting with the new system. As the participants interacted with the system and as the difficulty level increased, two of the participants showed increase in HR and towards the end of the communication task the HR decreased implying the participant was

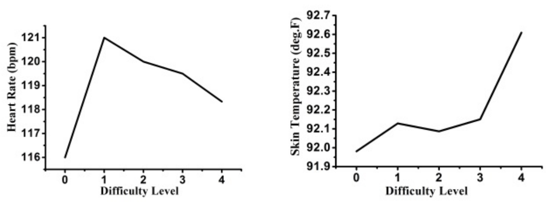


Figure 6. (a) Heart Rate (HR) and (b) Skin Temperature (SKT) responses of Participant P1

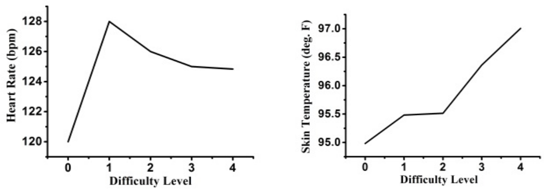


Figure 7. (a) Heart Rate (HR) and (b) Skin Temperature (SKT) responses of Participant P2

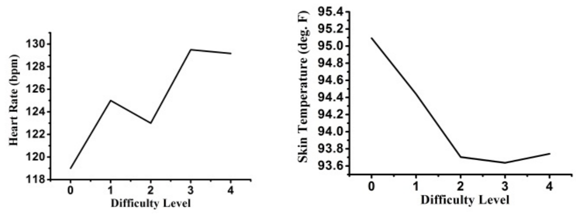


Figure 8. (a) Heart Rate (HR) and (b) Skin Temperature (SKT) responses of Participant P3

comfortable with our adaptive system. An exception in trend in HR response was observed for participant P3, in which the participant showed increase in HR which led to the decrease in performance at level IV as shown in Table 1. This can be attributed to the increase in anxiety for the participant.

The skin temperature (SKT) of a majority of participants while interacting with the first task showed increase from that at the baseline condition. We observed that two participants P1 and P2 showed increase in SKT which can be attributed to the decrease of anxiety while interacting with the system. However, a notable difference in both the HR and SKT patterns was observed for P3 (Figure 8) for the first task compared to the baseline. Specifically, there was a steeper decrease in SKT which again showed that P3 was more anxious while participating in the task.

V. CONCLUSION AND FUTURE SCOPE

In the work presented here, we have developed a VR based social communication task module that can adapt the task difficulty level with one's performance measure. Additionally, we investigated two physiological features namely, Heart Rate (HR) and Skin Temperature (SKT) that have been shown by different investigators to correlate with one's affective states. Our performance sensitive VR based adaptive system also reflects the efficacy of correlating some physiological features with one's affective states. Specifically, the preliminary offline analysis of physiological data could predict the affective state (e.g. anxiety) of the participant performing the VR based tasks.

Our preliminary results of the initial feasibility study while demonstrating the proof-of-concept application though encouraging, the system has some limitations. In our study, we used wired physiological sensors which limited the participant's freedom of movement that can itself introduce an additional anxiety factor. Also, the physiological features were observed to be varying from individual to individual. However, our system was only performance based and didn't harness the variations in one's anxiety by using physiological feedback in the task switching rationale. This would have provided increased individualization to the system. In our study the tasks were designed in such a fashion that every participant had to first interact with the task of difficulty level I without the option of choosing the task of his comfortable difficulty level. Additionally, our feasibility study had a limited sample size.

In future we aim to overcome these limitations by using wireless physiological data acquisition system and carryout feasibility study with an increased sample size. In addition, we plan to improve the performance sensitive system by providing the user flexibility to choose and start the interaction from the task difficulty that he is most comfortable with.

In this research presented here, the initial study was carried out for typically developing children to check the feasibility of the VR based system. In future we aim at carrying out this study with children with ASD. We further aim to study the physiological implications of affective states for children with ASD while interacting with our system. Finally, once the physiology based affect recognition rationale is established, we plan to develop the affective VR based adaptive social communication system. We believe that this psycho-physiological system will be intelligent enough to handle different communication and behavioral problems faced by these children with greater degree of individualization. In turn, the system will help these children to overcome some of their core communication deficits that can result in the development of various trades according to their abilities and help them lead a productive life.

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