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Smart shirt and carpet for annotating child behaviour in autism research

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Abstract

This study presents a developmental solution for annotating events, eye-contact, in live interaction scenarios, such as autism research. The approach involves prototyping infrared light emitting diodes (IR LEDs) integrated into both a smart shirt and smart carpets. Leveraging the imperceptibility of IR LEDs to the human eye ensures minimal disturbance to the individuals under surveillance. During video analysis, researchers can identify instances of eye-contact through the activation of IR LEDs, aiding in the recognition of corresponding events. The prototyped smart shirt features a necklace-type design with embedded IR LEDs, while two distinct designs of smart carpets incorporate IR LEDs at varying vision angles and positions.

Validation of the prototypes includes laboratory testing and real-world evaluations with the researchers. The assessment encompasses the observation of IR LEDs on the smart shirt and carpets from diverse perspectives, evaluating their light intensity, and assessing their operational synchronization. The findings contribute to the advancement of technology-assisted methodologies in capturing and analyzing interpersonal interactions, particularly in the context of autism research.

Keywords: participatory planning, autism spectrum disorder, smart textiles, research

Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental condition characterized of difficulties in social communication and restricted, repetitive behavioral patterns. Young children with ASD typically orient towards another person's face and initiate eye contact less than their typically developing peers. Detecting developmental concerns of ASD are essential for starting the early interventive support. The ASD diagnosis is based on behavioral observations and parental reports of the child, although there is increasing evidence of face and gaze-sensitive neuroimaging findings in ASD. In [1], the researchers utilized clinical imaging. This research undertakes neuroimaging investigations on young children affected by ASD. The study aims to longitudinally gather brain imaging data and conduct analyses to examine the progression of ASD across various developmental stages in young children. Moreover, in eye reconnaissance study [2], they examined frontal electroencephalography (EEG) asymmetry in response to direct and downcast gaze in 3- to 6-year-old individuals with ASD, typically developing (TD) children, and those with intellectual disability (ID). The goal was to understand how these groups differed in approach-related brain activity when encountering different gaze conditions. The study found that young children with ASD lacked normative approach-related neural activity to direct gaze. However, the study of facial responses [3], elucidates differences in automatic emotion processing in boys with ASD compared to typically developing controls. The researchers implemented eye tracking and facial mimicry data during an emotion recognition task, the research found that while both groups performed similarly behaviorally, boys with ASD exhibited smaller saccadic amplitudes, indicating a less exploratory face processing strategy. However, facial mimicry responses were similar in both groups, suggesting comparable reactions to emotional faces. The methodologies outlined in [1-3] delineate the manifestation of ASD and provide a comparative analysis of its developmental trajectory across various life stages. These approaches involve the utilization of brain imaging techniques, exploration of diverse approach-related brain activities through reconnaissance studies, and examination of distinctions in automatic facial responses to emotions. While these studies are grounded in data analysis with the involvement of advanced technologies i.e., brain imaging, EEG etc. there remains a need for research to elucidate methods for early detection of ASD in children with less complicated methodologies and subsequently address developmental challenges.

Wearable smart jackets were implemented on individuals for outdoor activities that observes, realizes, and respond to numerous protective measures in various environments like the heart rate and ultraviolet monitoring, temperature-responsive warming to hold body heat for endurance etc. [4]. The combination of fashion and wearable products innovation produces numerous R&D designs in the shape of smart watches [5], smart clothing [6,7], smart textiles [8], and smart shoes [9]. Contrasted with other design things, clothing has numerous extraordinary qualities that make it especially reasonable as a wearable stage [4]. Innovation can be incorporated into clothing to expand its essential usefulness, transforming it into a portable stage supporting detecting and a connection point with setting mindful figuring [4].

Monitoring eye-contact is one of the key factors in diagnosing ASD. In this study, the researchers need to annotate and track the eye-contact of a child, while physically interacting with them, to detect ASD in its early stage. Coding eye-contact from videos is time-consuming and rather unreliable, as it is often impossible to see whether another person is looking at the eyes or only orienting towards the face. Eye-contact might also be a short glance, which makes it difficult to spot from the videos. In addition, when interacting with small children who are constantly moving, the camera might not always capture the face of the child. The researchers stipulated the following areas in the current practice.

- Prototype of a smart shirt and carpet that can be utilized during child surveillance.
- The smart shirt and carpet must contain invisible electronic indicators on all sides which provide the indications of each eye-contact made.
- The indicators must be synchronized while providing eye-contact indications on all sides of the smart shirt and carpet.
- The switches of textile electronics must be easily operated during interaction.

The textile electronics contains integrated IR LEDs which were executed as indicators on each eye-contact made by the child. The smart shirt is worn by the researchers during a surveillance session with the child, who is being recorded in the camera. In addition to eye-contact annotating, the IR LEDs on the smart carpet were embedded to indicate session beginning with the child. The principal goal of prototyping the smart shirt and smart carpet was to gather the results of eye-contact surveillance i.e., frequency and duration and examine the effectiveness of the method. The benefits of using this methodology are.

- The technology will assist the researchers to detect ASD in its early stages.
- Provides real-time monitoring of eye contact, enabling continuous data collection.
- Implementing smart shirts and carpets is a more cost-effective solution compared to other advance technologies.
- The Childrens will find comfort of interacting with a psychologist wearing a smart shirt than undergoing brain imaging or EEG procedures.
- Smart shirts and carpets are potentially more accessible and portable, making them applicable in diverse settings beyond clinical environments.
- Smart shirts and carpets will allow for long-term, continuous monitoring over extended periods, providing a more comprehensive understanding of eye contact patterns and potential developmental changes.

Material and methods

The researchers selected the shirt and the carpet. The embedding of electronics on the textile material was carried out using the cotton yarn and sewing needle on the shirt whereas the hot silicon gun was executed to place and hold the semiconductor electronics on the carpet. Surface mount IR LEDs carrying the wavelength of 940 nm were employed as an indicator, to each eye-contact made with the researchers, on all sides of the shirt and the carpet. Moreover, the functioning of the smart shirt was synchronized with the smart carpet via wireless radio frequency (RF) switching sensor operating at 433.92 MHz frequency. The RF transmitter was integrating into the smart shirt while the RF receiver was placed on the smart carpet. In addition to eye-contact surveillance, the IR LEDs on the smart carpet indicates session beginning with the child.

The manufacturing of the smart shirt i.e., necklace type design and two different prototypes of smart carpets were effectuated as presented in Figure 1. The front and back view of necklace type design smart shirt with embedded smart textile switch can be seen in Figure 1 a) & b). However, the smart carpet 1-design 1 with IR LEDs placed at 00 degrees flat angle and the smart carpet 1-design 2 with IR LEDs placed at 800 degrees can be seen in Figure 1 c) & d) respectively. The later design is employed with a black textile material for increasing IR light visualization. The different number of IR LEDs placement on the smart carpet designs helped us to compare and chose the best prototype.

To drive IR LEDs effectively and efficiently, LED driver module was integrated which provided constant regulated voltages and eliminated the implementation of traditional resistors. The integrated circuit (IC) AL8805 helps the driver module to regulate the direct current (DC) voltages to the required level with minimum current draw rating. Moreover, for the operation of IR LEDs as indications during an interaction session with the child, a switch was required which can turn on and off the IR LEDs when needed. To execute the required purpose, a smart textile-based switch was prototyped consisting of three layers to make it operational for the intended usage, possessing two conductive layers of smart textile material and a non-conductive layer of flexible textile material. The non-conductive layer, having a circular opening in its centre, was placed in the middle of the conductive layers. While pressing the conductive layer from one or the other side, the conductive layers meet, through the opening, which permit the progression of current through the switch, in other case it stays in the off condition. The switch was then embedded in the smart shirt, and it appeared as a part of the shirt. Moreover, the resistance of the switch was tested using the digital multimeter. While pressing the switch, the resistance meter displayed the value of 0.5 ohms however, on a slitter touch it appeared to be varying between 0.9 – 1.2 ohms. The results depict the lesser resistance of the smart textile switch which illustrates that it is good material to conduct the flow of current.

The indication system on the smart shirt and carpet requires power source for the uninterruptible operation. The forward voltage ratings and current draw ratios of IR LEDs were evaluated for all the designs carrying different numbers of IR LEDs. These evaluations defined that the power source rating of nine volts was sufficient for the indication system on the smart shirt whereas for the smart carpet twelve volts were found appropriate. While selecting the befitting power source for the system, it was kept in mind that the power source should be portable, compact, and easily embedded on the smart shirt and carpet. In the study, a PP3 type non-rechargeable alkaline nine volts battery and a coin cell type non-rechargeable three volts battery were executed. It is highlighted that to deliver required voltages to the smart carpet, PP3 and coin cell type batteries were connected in series to sum-up the voltages and deliver twelve volts from source to destination.

On the other hand, the embedded electronics were connected and traced with other electronics through conductive yarns, smart textiles, and electrical wires on the smart shirt. The smart textiles were effectuated using the iron machine to trace the circuitry in between the electronic components in the smart shirt whereas conductive yarns were utilized to sew the traced connections with the electronic components to conclude the contacts. However, the electrical wires, with 1.6 mm diameter, were executed on the smart carpet using soldering iron machine to provide conductive connections. The electrical wire tracing was carried out on the back side of the carpet and to avoid meshed circuitry each wiring connection was fixed with the carpet using the hot silicon gun. However, the placement of IR LEDs on the smart shirt was important to visualize them from all directions and monitor the operation of IR LEDs presenting different angles.

Figure 1. Prototypes of the smart shirt and the smart carpets. a) front view of the smart shirt. b) back view of the smart shirt. c) smart carpet 1-design 1. d) smart carpet 1-design 2.

Results and discussion

Laboratory testing

The visualization of light intensity of IR LEDs varies under different cameras. In the research work, initially it analyses and monitor IR LEDs under different cameras i.e., Lenovo X390 laptop camera, Sony HDR-CX240E camera, and iPhone 12 pro camera to pick the befitting hardware for the actual testing in eye-contact monitoring. Then the smart shirt was tested within 1 meter distance from the cameras under differing room environments i.e., all room lights off, all room lights on, and overhead light off. The outcomes were quite revelation, IR LEDs were only visible with Lenovo X390 laptop camera under all room conditions whereas IR LEDs were invisible while visualizing them under the rest of the cameras. This happened because of the presence of IR filters in the camera systems of Sony HDR-CX240E and iPhone 12 pro cameras which removed the IR wavelength to be viewed while such filter was not available in Lenovo X390 laptop camera and thus, further monitoring of IR LEDs was carried out using the same camera.

In the laboratory testing, all the prototypes of the smart shirt and smart carpets were analysed with varying distance dependent measurements within 1 – 3 meters and the testing were completed under full bright room lights. The IR LEDs were embedded on the prototype of the smart shirt and their operation was monitored from the front, back and side view angles. The analyses illustrated the performance of IR LED light intensity which differ when the distance varies. The IR LED light intensity increases when the camera gets closer to the smart shirt i.e., 1 meter while the IR LED light intensity starts to decrease at 3 meters of the smart shirt. This depicts that the smart shirt operates accurately at 1 meter distance. Whereas the performance testing of smart carpets was completed under the similar room conditions. The IR LEDs on carpet 1 – design 1 were embedded at 00 degrees i.e., flat on the carpet. Due to bright colour scheme of the carpet 1, the IR LEDs light intensity were not visible at 3 meters distance while the light intensity starts to appear in the camera at 1 meter distance. On the other hand, IR LEDs on carpet 1 – design 2 were placed at 800 degree which supported visualizing the light intensity much better at 3 meters distance and the light intensity increases as the distance reduces as described in Table 1 as well.

User testing experience

After meticulous laboratory testing, the smart shirt and smart carpet prototypes were tested in a real time environment with the users i.e., autism researchers, as can be seen in Figure 2. The testing was organized in a child friendly monitoring room under full bright room lights which involves an attending acting child, the researchers, and a moving recording camera i.e., Lenovo X390 for eye-contact observation. The chosen prototype of the smart carpet and smart shirt were tested with the users and the behaviour of IR LEDs light intensity from various angles and positions was recorded in the camera. The indication states of IR LEDs on the smart shirt were controlled with the smart textile switch and on the smart carpet with the RF control switch.

Before the session beginning, the researchers wear the smart shirt and, the acting child was asked to sit on the smart carpet as can be seen in Figure 2a. The researcher initiates the session with the acting child by turning on the IR LEDs of the smart carpet, by pressing the RF switch integrated on the smart shirt, stating that the session has begun as evident in Figure 2b. In addition, of providing the indications of monitoring session beginning, the IR LEDs on the smart carpet were also executed during the parent-child session to monitor their eye-contact while they were sitting on the carpet. To grab child attention, boxes of toys were placed on the smart carpet to perform various activities and gather rigorous eye-contact monitoring during the session. However, during this state the IR LEDs on the smart shirt remains OFF as can be observed in Figure 2c. The IR LEDs of the smart shirt turns on, using smart textile switch, whenever the child makes an eye-contact with the researchers, the IR LEDs on the smart shirt remains illuminated till the eye-contact breaks as can be seen in Figure 2d. However, in other states, the IR LEDs stays off. Table 2 briefly illustrates the relation between different testing states of IR LEDs.

Table 1. Performance testing of the smart carpets.

Prototypes of smart carpets	Placement of infrared LEDs on the smart carpet	IR LEDs visualization testing from all directions, measurements at 3 m	IR LEDs visualization testing from all directions, measurements at 1 m
Carpet 1 – design 1	0^{o} angle	Not functional	Low intensity
Carpet 1 – design 2	80^{o} angle	Low intensity	High intensity

Table 2. Real time testing states of IR LEDs.

Indication conditions of IR LEDs	IR LEDs controlling method	Status of IR LEDs on smart shirt	Status of IR LEDs on the smart carpet
When the session is not started	Not applicable in this state	The IR LEDs remains OFF	The IR LEDs remains OFF
When the session started with the child	RF control switch	The IR LEDs remains OFF	The IR LEDs are turned ON
During the session when the eye-contact is not made	Not applicable in this state	The IR LEDs remains OFF	The IR LEDs remains OFF
During the session when the eye-contact is made	Smart textile switch	The IR LEDs are turned ON	The IR LEDs remains OFF

The results attained with user testing are stated below.

- The electronics embedded on the smart shirt and carpet needs to be scaled down to enhance productivity and reduced product weight.
- The miniaturized IR LEDs and improved design of their placement could be executed to hide IR LEDs and visualize them only when seen from the camera.
- IR LEDs on the smart carpet can be protected using a transparent cover to improve the robustness and applicability.
- The control switches of IR LEDs i.e., smart textile and RF, could be embedded on the same side of the smart shirt with significant difference while sensing and pressing each switch without looking them.
- To construct accuracy and transparent monitoring, a live clock can be implemented on the smart shirt or carpet to match eye-contact frequencies and the durations with the recording camera.

Nevertheless, certain limitations and problems in the methodology surfaced during this research.

- The performance of cameras employed in this study face challenges in detecting IR LEDs. It is imperative to utilize a specialized camera capable of distinctly detecting indications from IR LEDs. Subsequent research endeavors will incorporate a camera designed to align with the specific wavelength properties associated with IR LEDs.
- The IR LEDs employed in this study are observable from external sources, revealing the electrical connections on the LED surface. In subsequent investigations, we intend to explore tailored IR LEDs that seamlessly integrate within both the shirt and carpets. This approach aims to conceal the electronics, presenting a cohesive appearance as an integral part of the smart shirt and carpets.
- The researchers encountered challenges when employing capacitive touch switch to activate IR LEDs. The rapid and brief nature of some eye-contact instances made it

impractical to first locate and then press the switch. In subsequent studies, we plan to incorporate a smart glove alongside the smart shirt, equipped with a capacitive touch sensor for controlling the IR LEDs. This approach eliminates the need for researchers to visually engage with the switch, allowing them to simply close and open their fist to indicate eye contact.

- To safeguard the IR LEDs integrated into smart carpets from potential damage caused by individuals sitting on them, it is imperative to introduce a material, in future studies, that provides protection without compromising the functionality of the LEDs. This material should allow for seamless observation of the LEDs as they switch between the on and off states in dynamic environments.

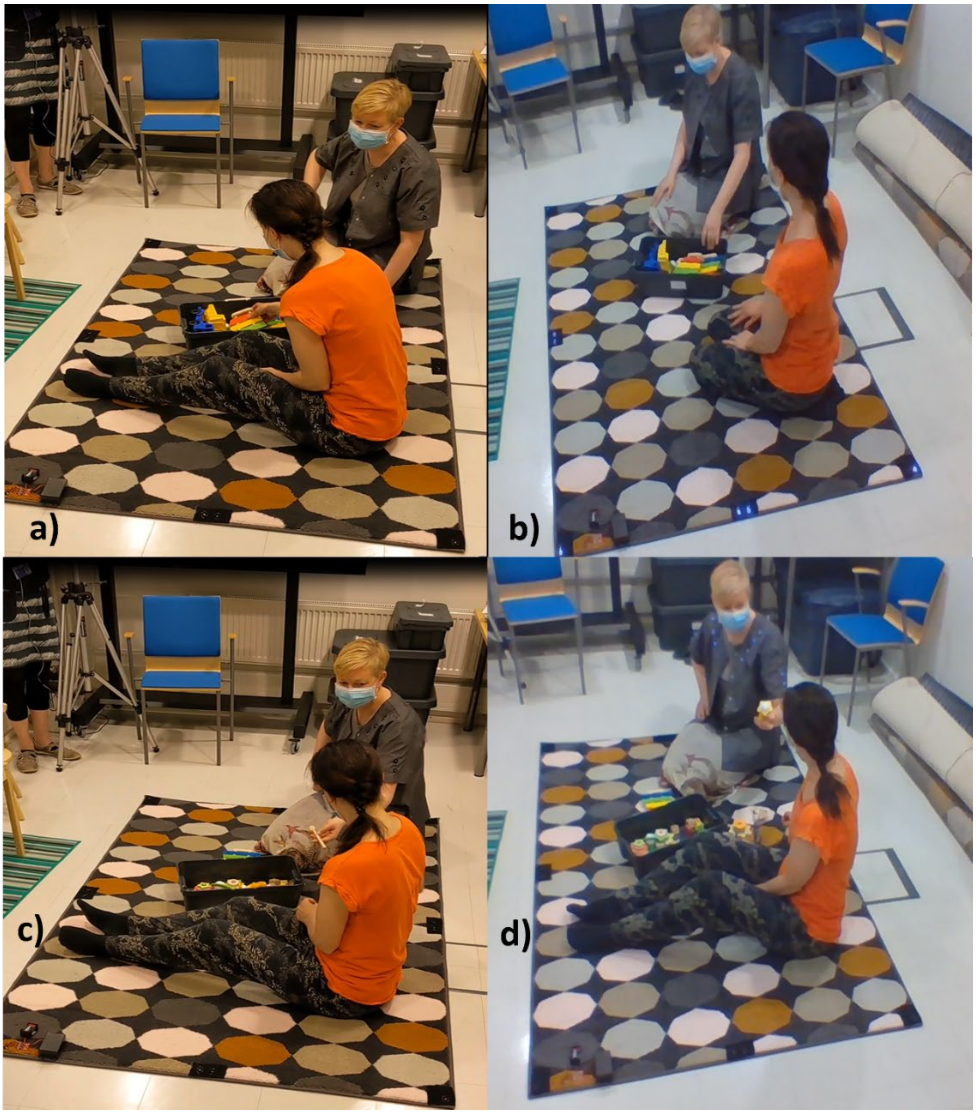

Figure 2. Real time environment testing. a) session not started. b) session started with smart carpet IR LEDs state on. c) no eye-contact between the individuals. d) smart shirt IR LEDs state on when eye-contact establishes.

Discussion

While the previous neuroimaging studies [1-3] of face and gaze processing in ASD are rooted in thorough data analysis leveraging advanced technologies, there persists a necessity for research aimed at clarifying approaches to detect ASD at an early stage in children, employing less complex methodologies. The present investigation has addressed the identified issue and presented an additional method for early ASD research, devoid of intricate methods. The findings highlight the efficacy of smart clothing in facilitating this research. Utilizing IR LEDs integrated into the smart shirt, the study recorded and analyzed the surveillance of eye contact, including its frequency and duration, with the various states of infrared LEDs detailed in Table 2.

The main aim of the study was to annotate the behaviour i.e., eye-contact of the child for ASD using effective smart clothing. Nonetheless, there is a need for further improvement and experimentation on both the smart shirt and carpet design to enhance their usability and detection capabilities. In future studies, we will streamline the technology to make it more user-friendly and accessible, keeping the pace with the evolution of wearable technology to incorporate new features and capabilities, ensuring the project remains cutting-edge and relevant and conducting more user experience research and incorporating feedback to refine the design.

Conclusions

Individuals with neurodevelopmental condition like autism spectrum disorder face significant socialization and communication challenges that rise for example from reduced orienting towards other peoples' faces and lessened used of eye-contact. To investigate the child's social behaviour, the researchers screen the recurrence and length of the eye-contacts made with the ASD child to concentrate on their way of behaving during various sessions. The observation could assist the early analysis of the child's social behaviour and following the effects of early interventions.

The study incorporates the prototype and design of the smart shirt and carpet observing the eye-to-eye connection of an ASD child. Various designs for the arrangement of infrared LEDs were proposed and executed on the smart shirt and the carpet to record recurrence and the span of the eye-contacts during a researcher's session through IR LED pointers. In any case, smart textiles were the best and oversimplified ways of coordinating electronics into the smart shirt. The integration of the smart textiles uses the adaptability, wearability, the cost adequacy, and dependability of the proposed solution. Whereas various IR LEDs with changing power evaluations and vision points were tried for the best result befitting the application testing requests. Nevertheless, the induction of the smart shirt and carpet could provide more reliable results in terms of accuracy and efficiency from live observations with the individuals and can save the time spent in analysis, repeatable sessions, and cost.

The outcomes portray the effective integration of infrared LEDs on the smart shirt and on the carpet, and they can altogether improve the working productivity of researchers during a session. Nonetheless, for real time testing with the child, the incorporated electronics can be downsized on the smart shirt and carpet to improve the convenience. Similarly, a straightforward transparent defensive layer can be executed on the infrared LEDs of the smart carpet to work on the vigour of the proposed arrangement. Essentially, the driving circuit and the battery could be scaled down and put on a solitary board to guarantee less minimization of the electronic circuitry.

In the future, the events will be integrated with the psychophysiological signals recorded during observations, and this would markedly help in investigating psychophysiological responses in live settings.

Conflict of interest

The authors declare that there are no conflicts of interest.

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