Health Monitoring System for Patients with Autism: with a Focus on Network Protocols

CMPE 457 – Data Communications & Networks II
Course Project, Group 7
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This project presents the development of a health monitoring system tailored for those with autism spectrum disorder (ASD) who suffer from sensory sensitivities, focusing on light and sound levels. The system is designed to alert caregivers promptly when potentially harmful levels are detected, utilizing a range of network protocols including SMTP, SNTP, MQTT, and HTTP. The primary goal is to offer an affordable, customizable, user-friendly, and accurate solution to assist caregivers in ensuring the safety and comfort of autistic individuals. The core hardware components employed in this system include the NodeMCU ESP32 Development Board, coupled with light and sound sensors. Data management and alert distribution are facilitated through Microsoft Azure IoT Hub, using Python scripts to enable integration for email and SMS notifications. The resulting product successfully achieves its objectives of real-time monitoring of light and sound levels, coupled with timely alerts via SMS. Additionally, it generates comprehensive weekly reports, sent via email, providing valuable insights into collected data trends. This innovative solution has the potential to revolutionize the landscape of products catering to individuals with autism, offering an accessible alternative to traditionally expensive (as seen in our project proposal) or challenging-to-access options. By leveraging cloud computing infrastructure and diverse network protocols, the system not only enhances the comfort and safety of autistic individuals but also provides invaluable support and peace of mind to their caregivers. With its multifaceted approach and emphasis on accessibility and effectiveness, this project exemplifies the intersection of technological innovation and social impact

I. Introduction & Contributions Of The Work

The upcoming literature review shows that the challenges posed by sensory sensitivities among individuals with ASD are well-documented, with hypersensitivity to bright lighting and loud noises often leading to distress and discomfort. These sensory issues not only impede daily activities, such as attending school or social events, making them difficult and stressful, but also exacerbate anxiety levels, impacting the quality of life for both autistic individuals and their caregivers. Despite extensive research highlighting these challenges, the market lacks comprehensive solutions addressing these specific needs, relying instead on rudimentary options such as sunglasses or earplugs, which underscore the importance of personalized approaches to accommodate varying levels of sensitivity, and fail to offer the requisite flexibility or insights into sensory stimuli, therefore, necessitating a paradigm shift towards innovative, tech-driven alternatives.

Considering this gap, this project endeavors to harness the power of modern technology to develop a cost-effective and readily accessible solution for managing sensory sensitivities in individuals with ASD. By leveraging the capabilities of the Internet of Things (IoT), cloud computing, and a diverse range of network protocols, the aim is to develop a customizable device prototype which empowers caregivers with the ability to monitor and respond to sensory triggers effectively.

The end-product facilitates real-time monitoring of light and sound levels to preemptively identify potential triggers and promptly take action. By adopting a comprehensive approach that interfaces cloud computing infrastructure and a suite of network protocols, the system not only alerts caregivers to threshold breaches but also generates comprehensive weekly reports, offering invaluable insights into trends and patterns.

II. Literature Review

This field of research known as the Internet of Medical Things (IoMT) has emerged with a clear aim: to enhance the well-being of individuals with autism, particularly those sensitive to excessive light and sound. This innovative project harnesses the power of Internet of Things (IoT) technology to ensure the safety of environments for individuals with autism. Leveraging cloud technology, ESP32 microcontrollers, and various networking protocols, the project integrates seamlessly with light and audio sensors to detect and mitigate potential hazards related to sensory stimuli. Through SMS notifications and detailed emails, caregivers are promptly alerted to any environmental triggers, enabling timely intervention and support. Importantly,the project's flexibility ensures its suitability for individuals across all age groups, with the capacity for customization to meet each patient's specific needs. Furthermore, its portability empowers caregivers to access support wherever they go, facilitating uninterrupted care and promoting independence for individuals with autism. By employing cutting-edge technology, this project not only improves the quality of life for individuals with autism but also enhances the efficacy of caregivers, underscoring the transformative potential of IoT in healthcare.

A. IoT Revolutionizing Healthcare: Trends, Challenges, and the Rise of Internet of Medical Things (IoMT)

The integration of IoT technology within the healthcare sector presents unparalleled opportunities for the monitoring and intervention of medical conditions. Within this realm, there exist distinct challenges, foremost among them being the assurance of data privacy, the attainment of real-time responsiveness, and the tailoring of interventions to suit individual requirements. Tunc et al. [1] conducted a thorough survey encompassing the IoT landscape in healthcare, which includes the exploration of various emerging technologies like blockchain and software-defined networking (SDN). Notably, the survey underscores the pivotal role of fog computing, wherein data processing occurs at the sensor-attached devices rather than at cloud servers or remote healthcare centers. The Internet of Medical Things (IoMT) has swiftly assimilated into the healthcare domain, concentrating on remote monitoring, personalized care, and streamlined data administration. As highlighted by Osama et al.[2], telemedicine stands out as a prime application of IoMT, facilitating the remote monitoring of patients and the provision of treatment from a distance. Additionally, the paper delves into the growing trend of leveraging cloud technology in the healthcare sector, recognizing its indispensability in fostering scalable, efficient, and accessible healthcare solutions.

B. Harnessing IoT Technology to Address Sensory Sensitivities in Autism: A Promising Approach for Personalized Interventionand Well-Being

Sensory sensitivities represent a significant challenge for individuals with autism, exerting a profound impact on their daily functioning and quality of life. Research studies, such as those conducted by Kanakri et al. [3] and Parmar et al. [4], have shed light on the pervasive effects of sensory sensitivities, particularly in relation to auditory and visual stimuli. Kanakri et al. delve into the intricacies of auditory sensitivities, revealing the heightened reactivity and discomfort experienced by individuals with autism in response to sound stimuli. Similarly, Parmar et al. elucidate the complexities of visual sensitivities, highlighting the adverse reactions and sensory overload triggered by light stimuli in this population. In individuals with autism spectrum disorder (ASD), an increased sensory response to rapid changes in the environment has been documented, including heightened sensitivity to sensory input such as visual stimuli. This hypersensitivity may manifest as aversion to bright or flickering lights, as well as difficulty filtering out irrelevant visual information from the surrounding environment. Consequently, individuals with ASD may exhibit exaggerated physiological responses, such as increased pupil dilation, in reaction to sudden changes in light intensity [8]. Individuals with autism often exhibit differences in auditory processing and sensitivity compared to neurotypical individuals. Research has shown that individuals with autism may experience hypersensitivity to auditory stimuli, reacting strongly to loud sounds and exhibiting behaviors such as covering their ears to avoid noise [10]. Studies have found that children with autism have lower loudness discomfort levels (LDLs) and a restricted dynamic range of perception compared to controls, indicating differences in their perception of sound intensity and ability to tolerate a wide range of sound intensities [10]. Furthermore, assessments of subjective loudness perception using categorical loudness scaling (CLS) have revealed that children with autism rate the intensity of pure tones as louder at lower intensities compared to neurotypical children, suggesting heightened perception of sound loudness [10]. These findings highlight the importance of understanding auditory processing and sensitivity in individuals with autism, as they may have implications for therapeutic interventions aimed at improving quality of life and learning outcomes. The emergence of IoT technology presents a promising avenue for addressing these challenges by leveraging smart sensors to monitor and regulate environmental stimuli. By deploying sophisticated IoT systems equipped with sensors capable of detecting variations in light and sound levels, interventions can be tailored to the specific sensory profiles of individuals with autism. These systems offer real-time monitoring and adjustment of environmental conditions, creating a dynamic and adaptive setting conducive to the well-being of individuals with autism. Moreover, IoT technology facilitates personalized interventions, allowing caregivers to fine-tune the ambient environment to meet the unique needs and preferences of an individual. Furthermore, the integration of IoT technology into the management of sensory sensitivities extends beyond mere mitigation efforts to encompass proactive strategies aimed at enhancing daily comfort and promoting overall well-being. Through continuous data collection and analysis, IoT systems can identify patterns and triggers associated with sensory sensitivities, enabling caregivers to implement targeted interventions and preemptively mitigate potential distress. Moreover, IoT-enabled environments can foster independence and empowerment for individuals with autism by providing them with greater control over their surroundings. By granting individuals the ability to adjust environmental stimuli according to their comfort levels, IoT technology promotes autonomy and self-regulation, empowering individuals with autism to navigate their environments with confidence and ease. In summary, the integration of IoT technology holds immense promise for addressing sensory sensitivities in individuals with autism. By harnessing the capabilities of smart sensors and adaptive systems, IoT interventions aim to create supportive environments tailored to the unique sensory needs of individuals with autism. Through personalized monitoring and intervention, IoT technology not only mitigates the adverse effects of sensory sensitivities but also promotes independence, comfort, and well-being for individuals with autism. When considering suitable lighting for individuals with autism, it's important to prioritize their unique sensory sensitivities. While preferences may vary, a recommended lux range falls between 300 to 500 lux, providing adequate illumination without overwhelming brightness that could trigger discomfort or sensory overload. Soft, diffused lighting sources should be utilized to minimize harsh glare and shadows, which can be distressing for individuals with autism. Collaborating with individuals with autism, their caregivers, or support professionals is crucial in determining the most appropriate lighting conditions for their specific needs and preferences. Taking this into account, our system will set the default lux value for individuals with autism to be 400 [9]. Furthermore, based on our research we found the upper threshold for the patients suffering ASD with regards to sound levels is 70 dB [11].

C. Optimizing Healthcare Solutions: The Crucial Role of IoT Protocols and Cloud Integration

The selection of appropriate IoT protocols and cloud platforms plays a pivotal role in ensuring the scalability, reliability, and efficiency of healthcare solutions. This critical decision-making process is underscored by a comparative study conducted by Yassein et al. [5], which sheds light on the significance of choosing the right IoT protocol for sensor-based applications. The study highlights the advantages of MQTT over CoAP, emphasizing its lightweight nature and efficient power usage. Given the inherent sensitivity and real-time nature of healthcare data collection, the lightweight and energy-efficient characteristics of MQTT make it an optimal choice for ensuring seamless communication between IoT devices and cloud servers. This selection is particularly crucial for our project, as it directly impacts the performance and responsiveness of the system in monitoring and managing sensory stimuli for individuals with autism. Furthermore, the integration of cloud services represents a fundamental aspect of IoT deployments in healthcare. An investigation by Pierleoni et al. [6] delves into the merits of various cloud platforms, ultimately identifying Microsoft Azure IoT Central as a standout choice. This selection is based on Azure's comprehensive support for WebSocket, a critical component for establishing real-time communication channels between IoT devices and cloud servers. Additionally, Azure's compatibility with popular programming languages such as C, Java, and Python provides flexibility and ease of development, aligning perfectly with the requirements of our project. The robust data management and analysis capabilities offered by Azure Central further solidify its suitability for our project's needs, ensuring seamless integration and efficient processing of sensory data collected from IoT devices. To conclude, the careful consideration of IoT protocols and cloud platforms is essential for the successful implementation of healthcare solutions, particularly in addressing sensory sensitivities in individuals with autism. The findings from comparative studies such as those by Yassein etal. [5] and Pierleoni et al. [6] guide our decision-making process, enabling us to select MQTT for efficient communication and Azure Central for robust data management and analysis. This strategic approach ensures the scalability, reliability, and effectiveness of our IoT-enabled solution, ultimately contributing to improved quality of life and well-being for individuals with autism.

D. Optimizing Healthcare Solutions: The Crucial Role of IoT Protocols and Cloud Integration

Selecting the appropriate microcontroller is a pivotal decision in any project, demanding a thorough evaluation and comparisonof available options to establish the one that aligns best with the project's unique demands. Our deliberation process involved a comprehensive analysis of various microcontrollers, weighing factors such as cost, power efficiency, quantity of I/O pins, and physical dimensions. Among the array of contenders, the ESP32 board emerged as a standout candidate. Its appeal stems from its effective equilibrium of functionality and affordability. The ESP32 not only highlights a compact form factor but also comes at a reasonable price point, making it an attractive option for economical projects. Furthermore, its integrated Wi-Fi capability enhances its utility, eliminating the need for additional components and simplifying connectivity requirements. Essential to our decision-making process was ensuring we had an abundant supply of I/O pins, a necessity that the ESP32 effectively fulfilled. This guarantees that our project's complex circuitry and interfaces are compatible, enabling smooth integration and operation. The combination of these qualities establishes the ESP32 as the best option for our application, aligning perfectly with themain goals and limitations of our project[7]. Expanding on this, it's worth noting that the ESP32's popularity originates not only from its technical capabilities but also from its extensive community support and wealth of resources available online. Finally, a decisive factor in our choice was the support for the ESP32 board by Microsoft through their Azure SDK for Clibrary. This support is crucial for integrating our IoT device with Azure IoT Hub, ensuring seamless connectivity and robust data handling capabilities.

III. SYSTEM DESIGN

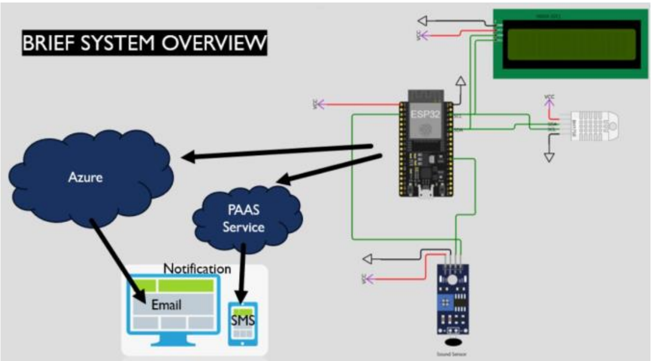

Fig. 1. System Overview

A. Hardware Implemetation

Our hardware implementation includes NodeMCU ESP32 development board as the microcontroller which governs the light and sound sensors. We have also attached a LCD screen to be able to view the readings of the light and sound sensors. These values are then transmitted to Azure and PaaS services.

B. Azure Services

Our project utilizes the IoT Hub, Blob Storage, and Azure Functions services of the Azure cloud. The data from the IoT hardware unit is transmitted hourly or if the threshold is exceeded to Azure IoT hub (which acts as a MQTT broker) using MQTT protocol, where the message is then routed to Azure Blob Storage (which is Storage as a Service (STaaS) module). Azure Functions has a python script deployed as a time trigger to generate a graph weekly based on data points from Azure Blob storage and to generate it as an image. Azure Functions, then, transmits the image as an email notification to the caretaker using SMTP protocol.

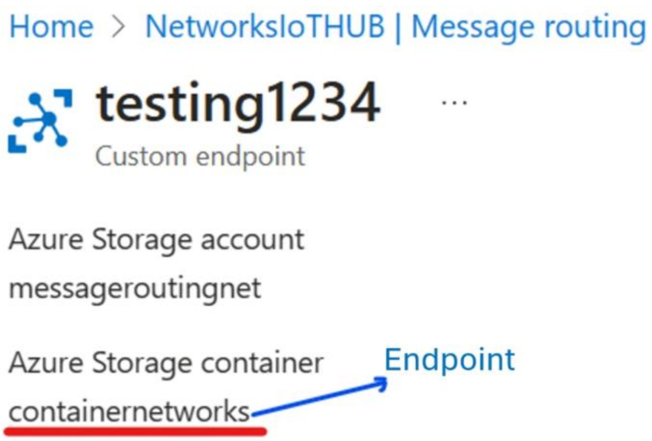

Fig. 2. Configuration of Message routing from IoT Hub to Blob Storage in Azure cloud services

C. PaaS Service

The IoT hardware unit, on being triggered due to an unsafe incident, sends a message to Heruko (which is a Platform as a Service (PaaS) based that enables developers to build, run and develop applications entirely on cloud) using HTTP POST request. This happens only in the case of an unsafe incident occurring to avoid wastage of resources.

A Python script is deployed on Heruko which utilizes Twilio (a cloud communications platform that provides software developers with tools to add various forms of communications to their applications) to send an SMS.

IV. Results

The system succeeds in sending SMS alerts, and email reports including data graphs, shown in the figures below. Fig. 2. shows immediate SMS alert to the caretaker on a trigger of unsafe environmental incident. Fig. 3. shows timely data analytics transmitted to monitor general activity of the patient. Fig. 4. shows the graph that gives the general idea of sound and light levels the patient is exposed to.

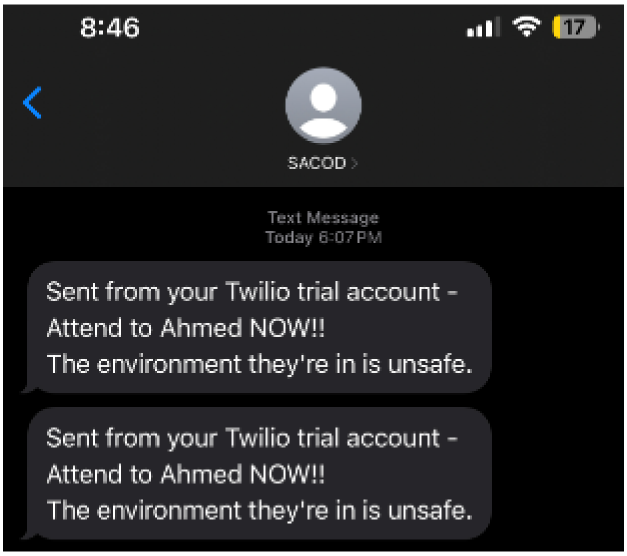

Fig. 3. Successful SMS transmission

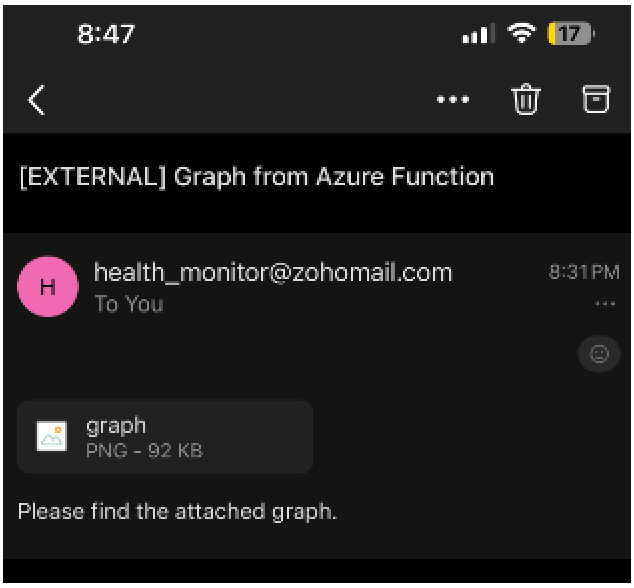

Fig. 4. Successful Email transmission

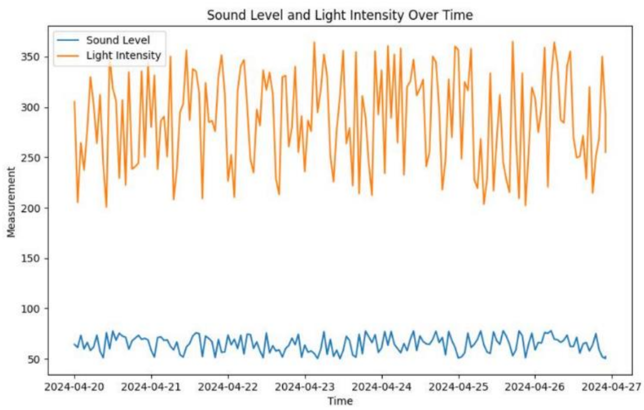

Fig. 5. Graph plot data provided to the caretaker attached in the email

V. TESTING

We performed a few tests by analyzing some parameters to ensure our product is reliable. First we measured the sensor accuracies by getting the values measured by the sensors at certain points and compared to the true values generated. The accuracies seem to be reasonable within the error limit and can be seen in the figures below.

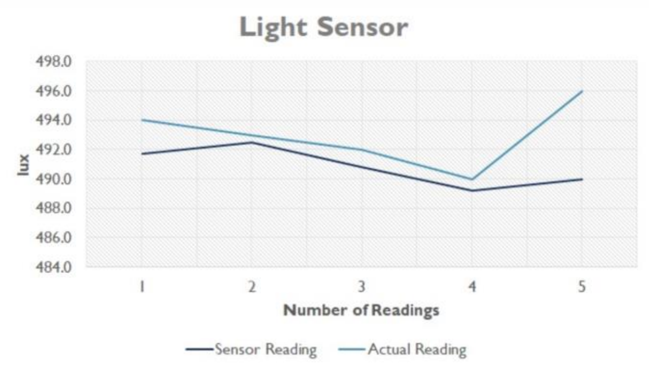

Fig. 6. Light Sensor accuracy measurements

Light Sensor Reading (lux)	Actual Reading (lux)	Error %
491.7	494	0.47
492.5	493	0.10
490.8	492	0.24
489.2	490	0.16
490.0	496	1.21
Average Error		0.44

Fig. 7. Error Calculation for Light Sensor

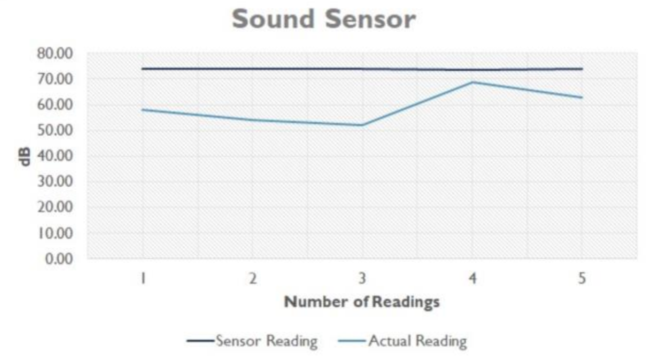

Fig. 8. Sound Sensor accuracy measurements

Sound Sensor Reading (dB)	Actual Reading (dB)	Error %
74.11	58	27.78
74.18	54	37.37
73.91	52	42.13
73.90	69	7.10
74.04	63	17.52
Average Error		26.38

Fig. 9. Error Calculation for Sound Sensor

Upon comparing the values obtained from the light and sound sensors with those measured usingthe Lux and Sound Meter mobile apps, it is observed that the BH1750 light sensor demonstrated remarkable accuracy, with an average error of merely 0.44%. Conversely, the sound sensor exhibited significant inconsistencies, yielding an error exceeding 25%. Despite this discrepancy, the system's functionality remains unaffected. The issue with the sound sensor's responsiveness can be rectified by upgrading to a sensor of superior quality.

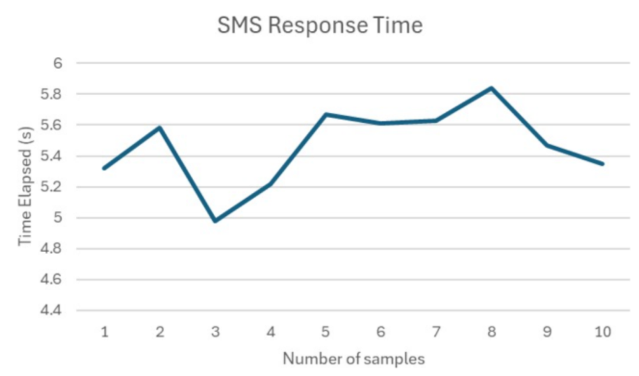

Fig. 10. SMS response time

Fig. 9. shows the duration between the moment an unsafe environment triggered the SMS to be sent and the time the SMS was received over a sample size of ten. It is safe to conclude that the duration was small, hence deeming our project's testing to be successful.

VI. CHALLENGES FACED

Throughout the course of our ambitious project, we encountered numerous challenges, each requiring unique solutions.These challenges included:

1. Difficulty sourcing references to establish appropriate light and sound thresholds for individuals with autism and sensory issues.

2. Initial limitations posed by the absence of Wi-Fi capability in the Arduino Uno microcontroller, resolved by transitioningto the NodeMCU ESP32 Development Board.

3. Choosing the optimal cloud communication platform proved challenging amidst a plethora of options.

4. Overcoming the complexity of the Azure cloud platform when writing cloud functions and processing data, ultimately resolved through consultation with technical support.

5. Configuring MQTT presented difficulties, which were mitigated by leveraging an SDK for streamlined implementation.

Despite these obstacles, our team persisted and successfully navigated each challenge, ultimately enhancing our project's resilience and effectiveness.

VII. Conclusion

Our project successfully achieved its primary objective of monitoring light and sound levels, issuing SMS alerts upon threshold exceedance, integrating cloud storage for data retention, and facilitating the dissemination of weekly data reports via email. However, there remains ample opportunity for enhancement. Potential improvements include - through further research and user feedback, optimizing the efficiency of SMS alert delivery, enhancing the accessibility and usability of cloud storage features, and implementing advanced data analysis techniques to extract deeper insights. Furthermore, the project could benefit from the integration of real-time monitoring capabilities and the incorporation of user-friendly interfaces for seamless interaction.

In short, the following steps, as future works, would benefit enhancing our project further:

1) Incorporating the monitoring of additional physiological parameters, such as heart rate, to provide a more comprehensive understanding of environmental stimuli's impact.

2) Implementing artificial intelligence algorithms to analyze collected data, identify patterns, and offer tailored solutions, thereby enhancing the system's adaptive capabilities.

3) Developing a dedicated mobile application to simplify user interaction and make the system more intuitive and accessible.

4) Enchancing data security by adopting a more secure communication protocol than SMTP for sending email reports.

5) Upgrading to a digital sound sensor to improve accuracy and reliability in sound level measurements.

Considering the points outlined in our informed judgement report and the additional improvements suggested integrated alongside the existing functionalities, the project is poised to significantly enhance the quality of life for individuals with ASD and sensory issues.

VIII. Individual Students' Contributions

The project was a collaborative endeavor, with tasks distributed among team members to ensure an equitable workload during the proposal phase. However, adjustments and improvisations were necessary throughout the process due to time constraints and varying levels of expertise in different domains. Mohamed and Zain led the research component, undertaking an exhaustive literature review and composing technical reports and assessments based on informed judgment. Aiman was responsible for the delivery of the final presentation. Additionally, Zain took on the task of refining the formatting of all deliverables.

On the hardware front, Aiman, with his prior knowledge on Arduino and microcontrollers, using Arduino IDE, along with Mahmoud, and Yusuf were pivotal in assembling the Arduino connections and interfacing the system with a PC. Originally, the project utilized an Arduino Uno R4 board; however, due to technical issues, a transition to the ESP32 board was made, with Mahmoud overseeing its setup. Furthermore, in terms of software development, Mohamed crafted the initial SMS-related code and configured the Twilio account, while Mahmoud was instrumental in developing the comprehensive codebase for the Arduino, employing MQTT and HTTP post protocols. Yusuf contributed to this effort as well. Furthermore, although the initial draft of the email communication code was written by Mohamed, Mahmoud enhanced and finalized it. Mahmoud also developed the code necessary to activate the HTTP trigger on Heroku. Yusuf was responsible for setting up the IoT Hub and collaborated with Mahmoud to establish the connection between the ESP32 MCU and the IoT Hub. Additionally, Yusuf configured the message routing to Azure Storage and created a blob storage. He experimented with various triggers in the Azure Functions App, ultimately opting for HTTP and timer triggers. Both Yusuf and Mahmoud engaged in extensive troubleshooting of the hardware connections, cloud communications, trigger configurations, and storage solutions.

Numerous improvisations were incorporated throughout the project's duration. A significant change was the switch to the ESP32 board. Another adaptation involved the use of an HTTP trigger hosted on Heroku, selected over an Azure event grid when complications arose. Further, the team moved away from authenticating with X.509 certificates towards generating a Shared Access Signature (SAS) token for connection purposes. Initially limited knowledge of cloud technologies led to several errors, underscoring the iterative nature of the learning and development process. Lastly, the technical report required a thorough revision of content and formatting with addition of a few sections and some other going through a complete revamp – all of which was undertaken by Aiman. Our plans of progressing through the stages of the project were modified to a significant changes based on the schedules of the team members due to which some other team members who were unoccupied took charge of the project in the meanwhile.

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