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## AutiSense: Smart Assistant System for Children with Autism Spectrum Disorder

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*To fulfill the requirements for a bachelor's degree in Computer Systems  
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# Abstract

Children with Autism Spectrum Disorder (ASD) may experience sudden emotional stress that is difficult to communicate verbally, which can interrupt daily routines and make task transitions challenging. This project presents AutoSense, an assistive system that uses a wearable system to notice signs of stress early and helps the caregiver with appropriate interventions at the right time. The wearable is built around an ESP32 and integrates a MAX30102 heart-rate sensor, a galvanic skin response (GSR) sensor, and an MPU6050 motion sensor for continuous monitoring. Stress detection follows a baseline-based threshold method. The system first measures a personal baseline for each child, then filters GSR noise, uses an average heart-rate value, and checks motion to separate stress from normal movement or repetitive behavior. When moderate or high stress is detected, the caregiver is alerted through a mobile application and uses it to start an LED-based timer to help the child transition. Prototype testing confirmed reliable real-time sensing and end-to-end operation of the monitoring, decision, and feedback workflow, indicating that AutoSense is a practical, low-complexity solution for supportive ASD care settings.

**Keywords:** ASD, Real-Time Alert System, Wearable Device, Stress Detection, Task Transition, GSR Sensor, Heart Rate Monitoring.

## الملخص

قد يعاني الأطفال المصابون باضطراب طيف التوحد (ASD) من نوبات مفاجئة من التوتر العاطفي يصعب التعبير عنها لفظياً، مما قد يعيق الروتين اليومي ويجعل الانتقال بين المهام أكثر صعوبة. يقدم هذا المشروع نظام AutiSense، وهو نظام مساعد يستخدم نظاماً قابلاً للارتداد لرصد مؤشرات التوتر مبكراً ومساعدة مقدم الرعاية على تنفيذ تدخلات مناسبة في الوقت المناسب. يعتمد الجهاز القابل للارتداد على المتحكم ESP32 ويضم مستشعر MAX30102 لقياس معدل ضربات القلب، ومستشعر الاستجابة الجلدية الجلفانية (GSR)، ومستشعر الحركة MPU6050 للمراقبة المستمرة. يعتمد كشف التوتر على طريقة عتبات مبنية على خط الأساس. يبدأ النظام بقياس خط أساس شخصي لكل طفل، ثم يرشح ضوضاء إشارة GSR، ويستخدم متوسطاً لمعدل ضربات القلب، ويتحقق من الحركة للتمييز بين التوتر وبين الحركة الطبيعية أو السلوك التكراري. عند اكتشاف توتر متوسط أو مرتفع، يتم تنبيه مقدم الرعاية عبر تطبيق للهاتف المحمول، ويستخدمه لبدء مؤقت يعتمد على مصابيح LED لمساعدة الطفل على الانتقال بين المهام. أكدت اختبارات النموذج الأولي موثوقية الاستشعار في الزمن الحقيقي وعمل النظام بشكل متكامل من المراقبة واتخاذ القرار حتى تقديم التغذية الراجعة، مما يشير إلى أن AutiSense حل عملي منخفض التعقيد لدعم بيئات رعاية الأطفال المصابين باضطراب طيف التوحد.

**الكلمات المفتاحية:** اضطراب طيف التوحد، نظام التنبيه في الوقت الحقيقي، جهاز يمكن ارتداؤه، اكتشاف الإجهاد، انتقال المهام، استجابة الجلد الجلفانية، مراقبة معدل ضربات القلب.

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# List of Acronyms

ADXL335	Analog Devices Acceleromete
ASD	Autism Spectrum Disorder
BLE	Bluetooth Low Energy
BPM	heartbeats per minute
DMP	Digital Motion Processor
DSM	Diagnostic and Statistical Manual of Mental Disorders
EBD	Emotional Behavior Disorder
EDA	Electrodermal activity
EMA	Exponential Moving Average
GPU	Graphics Processing Unit
GSR	Galvanic Skin Response
HDMI	High-Definition Multimedia Interface
HR	Heart Rate
HRV	Heart Rate Variability
HTTP	Hypertext Transfer Protocol
I2C	Inter-Integrated Circuit
IDEA	Individuals with Disabilities Education Act
LCD	Liquid Crystal Display
MPU	Motion Processing Unit
PPG	Photoplethysmography
PWM	Pulse Width Modulation

RMS	Root Mean Square
SCL	Serial Clock Line
SDA	Serial data Line
SPI	Serial Peripheral Interface
TFT LCD	Thin-Film Transistor Liquid Crystal Display
Wi-Fi	Wireless Networking Technology

# Chapter 1

## Introduction

### 1.1 Preface

The intelligent stress management for children with Autism Spectrum Disorder (ASD) is basically on the spot personalized support, helping children through their emotional challenges and smoother task transitions. Autistic children become anxious and sometimes disengaged when facing some unexpected change or overwhelming situation, traditional methods like verbal cues or static routines just cannot suffice to meet the need at that very moment.

This system improves emotional well-being by recognizing early signs of stress and providing personalized support to help children stay calm and focused. Advanced monitoring and intervention methods assist children in developing improved adjustment skills that improve their daily social interactions and life quality. In addition, the use of structured visual instruction integration facilitates task execution and reducing anxiety and confusion. At the end, this project is an intriguing this is a tangible way to increase autonomy and build a more leveled, engaging community for autistic children.

### 1.2 Problem Statement

Children with ASD need support tailored to their needs, helping them express emotion and adjust to stress and transitions between activities. They should receive an immediate personalized intervention according to their needs so that they may be able to lead through activities in a calm transition and supportive environment.

Currently, most support systems use a static approach, bringing in elements such as verbal prompts, picture schedules, or set routines, which can sometimes fail to help when there is a sudden mood change. These negative changes often go unnoticed at first, gradually contributing to stress, frustration, or disengagement in emotions. Without visual cues for changes, transitions from one task to another can be so adversarial that it makes adjustments all the harder.

To overcome these difficulties, the proposed solution helps a smart system to identify early distress signs and intervene with customized real-time responses. Through the means of auditory

prompting, sensory feedback, and interactive visual cues, the system stimulates an ambience that helps kids to regulate emotions, lower anxiety, and walk through everyday activities with more confidence and ease.

## 1.3 Project Aims and Objectives

In this project, we propose a system that aims to provide the following features:

1. The system aims to provide real-time emotional support for children with ASD to stress management and emotional self-regulation. In order to complete this aim, the following objectives should be achieved:
  - (a) Develop a system that continuously monitors the child's emotional and physiological status.
  - (b) Integrate feedback mechanisms (auditory, sensory, and visual) to provide immediate interventions based on detected stress levels.
  - (c) Ensuring seamless system component level communication for real-time data exchange.
2. The system aims to support timely and appropriate calming interventions based on the child's detected emotional and physiological state. In order to achieve this aim, the following objectives should be accomplished:
  - (a) Perform real-time stress detection using physiological signals and threshold-based decision logic.
3. The system aims to improve task transitions and time management for children with ASD using visual and auditory tools. In order to complete this aim, the following objectives should be achieved:
  - (a) Create a visual system that provides transition cues between activities to help children expect changes.
  - (b) Provide calming auditory and visual cues during transitions. These cues are activated in response to the child's stress level and are managed by a specialist through a mobile application to ensure personalized and timely support during routine changes.

## 1.4 Requirements

To specify the system requirements, the following functional and non-functional requirements are considered:

### 1.4.1 Functional Requirements

The system must be able to:

1. Identify and track signs of emotional discomfort in autistic children.
2. Respond immediately through a variety of feedback mechanisms when stress is detected.
3. Include a structured method to help children transition between activities.
4. Collect and process physiological sensor data using predefined thresholds to determine stress levels.
5. Enable specialists to receive stress alerts and remotely activate personalized interventions via a mobile application.
6. Operate in real-time, ensuring timely responses to events causing stress.

### 1.4.2 Non-Functional Requirements

1. **Reliability:** To minimize false positives and ensure correct actions, the system aims to achieve an accuracy of up to 90%.
2. **Response Time:** To provide immediate assistance, the system aims to respond within about 5 seconds.
3. **Usability:** Specialists should be able to easily navigate and use the system interface.

## 1.5 System Description

Our system is a wearable device can be worn on the child's hand. It is designed to help children with Autism Spectrum Disorder (ASD) regulate their emotions and manage transitions between tasks. The system consists of sensors and interactional components intended to detect early cues that something is troubling them and provide timely support.

The system consists of three subsystems, a wearable device, an Interactive screen, and mobile application. The wearable device has a heart rate monitor for sensing heart pulse rate and the system can determines heart rate change, a skin conductance sensor to sense the amount of sweat, which is considered an index of stress, and movement sensors that track abnormal movement patterns. All the sensors are reading data in real time, and this is being processed to recognize signs of emotional disturbance. When stress is detected, the system sends an alert that is sent out via a mobile application to the specialist or teacher in real time. Based on the child's current emotional state and needs, the specialist selects the appropriate calming intervention, such as guided breathing exercises with audio instructions,relaxing videos, or interactive coloring activities displayed on the screen. This collaboration provides more specific and individualized regulation strategies, ensuring that assistance is tailored to the child's condition in real time.

To assist in transitioning between activities like transitioning between classes, daily tasks in the classroom, and individual activities to group or reverse activities. the wearable has an LED based countdown timer, which the specialist can configure remotely to help the child prepare for transitions between tasks. This is supplemented by an external interactive screen that can offer calming visual and auditory stimuli, including relaxing videos, or visually stimulating content to help with emotional regulation. With ongoing monitoring, adaptive feedback, and guided task based instruction, the device demands to impact emotional regulation and daily management routines for children with autism.

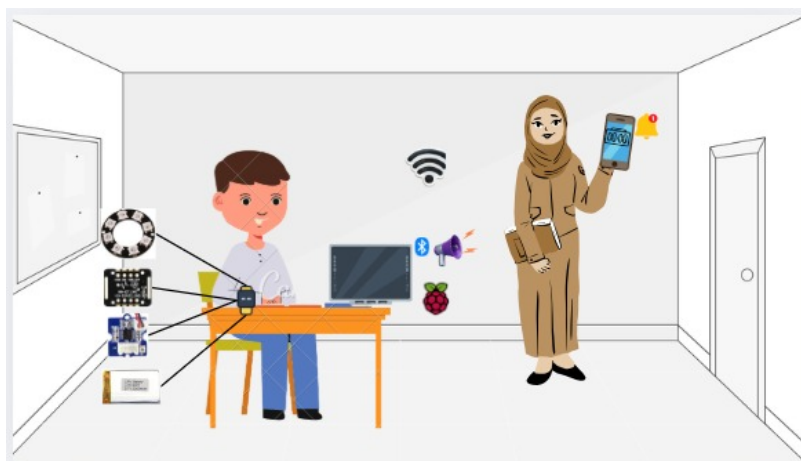


Figure 1.1: System's Expected Structure

## 1.6 Project Limitations/Constraints

1. **Wireless Connectivity and Detection Range:** Communication among the wearable device, the mobile application used by specialists, and the interactive screen is conducted over a Wi-Fi network. Network instability, limited coverage, or temporary disconnections may interrupt real-time data transmission and control commands. Such interruptions can lead to delayed stress alerts or calming interventions, potentially reducing the effectiveness of timely emotional regulation.
2. **Power Limitations:** Since the wearable device runs on battery power, it needs regular recharging. If it isn't charged in time, the system could temporarily stop monitoring.
3. **Environmental Factors:** Environmental factors may affect sensor accuracy, including temperature, humidity, or background noise, which may lessen the reliability of stress detection in some situations.
4. **Adaptation Time:** The system requires time to adapt and personalize its responses. For autistic children, adaptation is crucial since they have to get used to wearing the system on their wrist.

## 1.7 Schedule

The tasks of the system implementation and operation are distributed along the first semester, summarized in Table 1.1.

Table 1.1: Project Timeline

	The first semester			The second semester			
Week	1 - 4	5 - 10	16 - 20	1 - 5	6 - 9	10 - 14	15
Selection of project Idea							
Collecting the Data							
System Design							
System Implementation							
System testing							
system operation							
Documentation							

## 1.8 Report Outline

This report is organized as follows: Chapter 2: Provides an overview of definition and classifications for Autism, and sensory processing difficulties in Autistic children, along with a literature review that compares our project to similar ones. Chapter 3: Outlines the project's design, including both hardware and software aspects. It discusses design choices, the conceptual background of the software, the sequence diagram and presents a schematic diagram. Chapter 4: explains the system implementation and implementation challenges. Chapter 5: explains the test process of the system components. Finally, chapter 6: concludes the results of the work and recommendations of improvements.

# Chapter 2

## THEORETICAL BACKGROUND

### 2.1 Preface

This chapter introduces the theoretical foundation essential to our project. Following this, we will conduct a literature review, comparing our project with previous works related to our work. This comparison will help highlight the unique aspects and innovations our project introduces. In summary, this chapter provides the necessary background to understand the origins of our project and its position within existing research.

### 2.2 Theoretical Background

This section provides an overview of definition and classifications for Autism, and sensory processing difficulties in Autistic children.

#### 2.2.1 Autism Spectrum Disorder (ASD): Definition and Classifications

##### 2.2.1.1 Definition

Autism is defined according to the Individuals with Disabilities Education Act (IDEA) as a developmental disability having a substantial effect on verbal and nonverbal communication and social interaction, with onset generally before age three, and which adversely affects a child's educational performance. It is often associated with repetitive behaviors, resistance to change, and unusual sensory responses. If a child shows these traits after age three but meets the criteria, they may still be diagnosed. Qualified professionals, such as psychiatrists or pediatricians, make the diagnosis [1].

##### 2.2.1.2 Classifications

According to the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5), ASD is classified as a single diagnosis without subcategories (as opposed to DSM-4), and is further divided into three levels based on the level of support required [2].

### **Level 1: Requiring Support**

The diagnosis of an individual with Level 1 Autism Spectrum Disorder (ASD) indicates the mildest form of autism. Individuals are typically verbal, able to form sentences, and engage in simple conversations. However, they could not be expected to prompt or sustain social interaction, and could be expected to have difficulty with understanding social cues or engaging in small talk. They may not find it easy to initiate or sustain close friendships. They may be uncomfortable or anxious because of a change of routine or transition from one task to another. Although they are mostly independent in many places, they still require support, especially in social situations, to manage their interactions and adapt to changes effectively [2].

### **Level 2: Requiring Substantial Support**

The diagnosis of an individual with Level 2 Autism Spectrum Disorder (ASD) has much more severe communication and social deficits than Level 1. Individuals at this level often have problems with both verbal and non-verbal communication, and show much more repetitive behaviors such as flapping, rocking, and skin picking. These behaviors can affect daily work or social operations. Such individuals also have difficulties in adjusting to changes in routine and thus require intensive support in many life areas, including academic, occupational, and social contexts. A principle applied to these behaviors has to be in the best interests of the individual with autism [2].

### **Level 3: Requiring Very Substantial Support**

The diagnosis of an individual with Level 3 Autism Spectrum Disorder (ASD) require very substantial support, as they tend to be the most affected by the condition. They tend to have severe communication difficulties, with limited or no verbal skills and little tendency to respond to social cues or others attempts at making contact. People at this level tend to engage in strong and repetitive behaviors and have extreme difficulty handling changes or alterations in routine; they may exhibit meltdowns, aggression, or self-injury at times and require almost constant supervision and interventions. Because of the immediacy of the effect experienced in nearly all areas of life, people with Level 3 autism need broad and comprehensive support throughout life-in-home, school, health care, and the community [2].

Table 2.1: Levels Of Support In Autism Spectrum Disorder

<b>Feature</b>	<b>Level 1</b> (Requires Support)	<b>Level 2</b> (Requires Substantial Support)	<b>Level 3</b> (Requires Very Substantial Support)
Support Needed	Some support	Substantial support	Very substantial support
Language & Communication	Can speak, mild difficulties	Noticeable challenges	May be nonverbal or limited verbal communication
Social Interaction	Difficulty with casual conversation and friendships	Difficulty with understanding social cues	Severe impairment in social engagement
Repetitive Behaviors	Present but less intense	Frequent, may disrupt daily functioning	Intense, persistent, may be harmful
Independence	Largely independent	Needs regular assistance	Requires constant supervision
Response to Change	Discomfort with change	Resistance to change	Strong resistance and distress

### 2.2.2 Sensory Processing Difficulties In Autistic Children

Children with Autism Spectrum Disorder (ASD) tend to have Sensory Processing Difficulty (SPD), which influences how they perceive and react to sensory input. Their challenges will be different from one child to another but typically emerge as one or more of the following:

#### 1. Tactile Defensiveness (Hypersensitivity to Touch)

Some children with autism are hypersensitive to touch, and even slight contact—such as seams in clothes, wristbands, or nubby fabrics—can be uncomfortable, irritating, or even painful. This sensitivity, known as tactile defensiveness, is one of the most critical considerations in wearable system design.

To address this challenge, it is essential to employ soft, breathable, hypoallergenic materials in any wearable component, and to render the device light, pliable, and easy to adjust. However, comfort may not suffice to guarantee effective adoption.

Kientz et al. (2020) investigated how autistic children perceive wearing a smartwatch. Some children tolerated the smartwatch after receiving simple verbal guidance, but others initially refused it due to discomfort. Interestingly, the study demonstrated the effectiveness of their method, which was based on visual schedules with video modeling that visually broke down the process of wearing the watch into small, manageable steps. This gradually increased

tolerance: 62.5% of the participants (5 out of 8) later wore the smartwatch comfortably while also engaging in related activities [3].

This suggests that gradual, structured exposure can reduce tactile defensiveness, improving acceptance of wearables in children with ASD. Moreover, material selection and introduction strategies significantly influence successful adoption, emphasizing their impact on intervention approaches.

## 2. Hypo-responsiveness (Under-Responsiveness)

Some ASD children do not react much to physical stimulation. They will not notice a watch on their wrist, may not register important notifications (e.g., vibrations), or will not sense discomfort due to an incorrectly fitting device. In these cases, it is helpful to add multi-sensory feedback (e.g., visual notification, light vibration, or audio notification) to make the device more noticeable and effective.

## 3. Sensory Seeking Behaviors

Unlike defensiveness, other children actively seek out sensory input. They might like to make physical contact, touch, or move and might even find the watch soothing or stimulating. For these children, wearables can be developed with self-regulating calming sensory feedback, such as vibrations, smooth texture, or visual animations.

Table 2.2: Comparison of Sensory Processing Difficulties in Autistic Children [4].

Category	Common Behaviors	Real-life Examples	Support Strategies
<b>Over-Responsiveness</b>	<ul style="list-style-type: none"> <li>• Pain from light touch.</li> <li>• Dislike of certain fabrics.</li> <li>• Hair washing difficulties.</li> <li>• Food texture sensitivity.</li> </ul>	<ul style="list-style-type: none"> <li>• Refuses tight clothing.</li> <li>• Cries when head is touched.</li> <li>• Eats limited foods.</li> </ul>	<ul style="list-style-type: none"> <li>• Warn before touching</li> <li>• Remove clothing labels</li> <li>• Gradual texture exposure using soft tools</li> </ul>
<b>Under-Responsiveness</b>	<ul style="list-style-type: none"> <li>• High pain threshold</li> <li>• Doesn't notice food in mouth</li> <li>• Chews on non-food items</li> <li>• Seeks deep pressure</li> </ul>	<ul style="list-style-type: none"> <li>• Hugs too tightly</li> <li>• Bites or hits self</li> <li>• Loves heavy blankets</li> </ul>	<ul style="list-style-type: none"> <li>• Provide safe chew alternatives</li> <li>• Use weighted items</li> <li>• Offer structured sensory activities</li> </ul>
<b>Sensory Seeking</b>	<ul style="list-style-type: none"> <li>• Rubs textures</li> <li>• Seeks vibrations</li> <li>• Enjoys spinning or movement</li> </ul>	<ul style="list-style-type: none"> <li>• Touches walls frequently</li> <li>• Jumps or spins constantly</li> <li>• Craves tight hugs</li> </ul>	<ul style="list-style-type: none"> <li>• Provide sensory-rich toys</li> <li>• Integrate vibration safely</li> <li>• Include sensory input in routines</li> </ul>

## 2.3 Literature Review

Recent projects have explored wearable and assistive technologies to support autistic children, focusing on stress detection, communication, and behavior management. This section reviews key examples from past work to compare their features and limitations with our proposed system.

### 2.3.1 Preventing, Anticipating and Mitigating Off-Task Behavior in Special Needs Students

Authors in this work [5] focus on supporting children with Autism Spectrum Disorder (ASD) or Emotional Behavior Disorder (EBD) by reducing off-task behavior during activity transitions, which aligns closely with the objectives of our proposed system. Similar to our project, it relies on a wearable sensing approach to monitor physiological indicators of stress, including heart rate, temperature, and sweating, in order to detect stress-related states.

The system integrates a wearable device based on the Atmega328P microcontroller for data acquisition, combined with an external interactive screen that provides calming activities and visual countdowns to prepare children for upcoming transitions. This concept of combining wearable sensing with visual feedback is directly related to our approach of using a wristband together with an interactive screen to support emotional regulation.

However, the authors reported limitations related to sensor sensitivity to environmental factors and the risk of the interactive screen becoming a source of distraction rather than support. These challenges highlight the importance of robust signal processing and carefully designed feedback mechanisms, which our project addresses by focusing on real-time stress detection and smoother, less intrusive task transitions.

### 2.3.2 Empatica E4 Wristband

The authors in [6] describe the Empatica E4 wristband as a medical-grade wearable device designed for continuous physiological monitoring, making it highly relevant to stress-detection-based systems such as our project. It measures key signals that overlap with our design, including electrodermal activity (EDA), heart-related metrics (HR/HRV), skin temperature, and motion, which are commonly used indicators of stress and emotional arousal.

The E4 demonstrates the feasibility of accurate, real-time physiological stress monitoring using a wrist-worn device, reinforcing the scientific validity of using EDA and heart-related signals as stress markers. This aligns directly with our choice of sensors for detecting emotional stress in children with ASD.

Despite its strong sensing capabilities, the Empatica E4 presents several limitations when considered for practical assistive use with autistic children. These include very high cost, short battery life, and the fact that it has been discontinued. Additionally, it is primarily designed for research and clinical settings rather than child-centered, everyday support. These limitations motivate the need for a more affordable, child-friendly, and application-specific wearable solution, which our project aims to provide.

### **2.3.3 New Tool for Kids & People with Autism: The Gizmo Watch 3 - Adventure**

The authors in [7] describe the Gizmo Watch 3 as a smartwatch designed for children, including those with Autism, and focuses on promoting independence and safety. While it is not a medical or stress-monitoring device, it overlaps with our project in terms of being a wearable wristband used by autistic children and supporting daily routines.

The device includes basic motion sensing and programmable timers that help structure activities and transitions, which indirectly relates to our goal of easing task transitions. However, unlike our system, the Gizmo Watch 3 does not measure physiological stress indicators such as heart rate or electrodermal activity, and therefore cannot detect emotional stress in real time.

Furthermore, the watch may cause discomfort for sensory-sensitive children and offers limited adaptability for emotional regulation. These limitations emphasize the gap between general-purpose smartwatches and specialized assistive systems. Our project addresses this gap by combining wearable sensing with real-time emotional stress detection and adaptive calming feedback, tailored specifically to the needs of children with Autism Spectrum Disorder.

A summary of the comparison is presented in Table 2.3 .

Table 2.3: Comparison With Other Projects

<b>Feature</b>	<b>Preventing Anticipating &amp; Mitigating Off-Task Behavior in Special Needs Students</b>	<b>Empatica E4 Wristband</b>	<b>The Gizmo Watch 3 - Adventure</b>	<b>Our Project</b>
<b>Device Type</b>	Wearable + Interactive Screen	Medical-grade wristband	Smartwatch for kids	Wearable wristband + external interactive screen
<b>Target Group</b>	Children with ASD or EBD	Patients, research subjects	Children with Autism	Children with Autism Spectrum Disorder
<b>Main Goals</b>	Reduce off-task behaviors and ease activity transitions	Continuous physiological monitoring for stress and health	Promote independence, safety, and communication	Provide real-time emotional support and smoother task transitions
<b>Sensor Types</b>	Heart rate, temperature, sweat (stress indicators)	EDA, HRV, temperature, accelerometer	Basic motion sensor	Heart rate, sweat (EDA), motion sensors
<b>Limitations</b>	Environmental sensor sensitivity, possible distraction	Very high cost, short battery life, discontinued	Not a medical device, limited texting, may irritate sensory-sensitive kids	Cost, Bluetooth range, battery, environment, adaptation time
<b>Cost</b>	\$40–80 (prototype-based)	\$1,690	\$150 (device only)	about 1500 NIS

Unlike past projects concentrating on monitoring or basic alerts, Our system integrates real-time emotional detection with guided professional support. It includes a wearable wristband equipped with GSR and heart rate sensors to monitor stress indicators, and an external interactive screen where the specialist can display calming visuals and auditory cues relevant to the child’s current emotional state.

The system involves the specialist in interpreting information and giving the most appropriate response, rendering the support sensitive to the sensory profile of every child. A visual countdown through an LED ring helps to facilitate transitions between tasks, with the system being cost effective, school friendly, and easily adaptable to the specific needs of autistic children. This adaptive integration of feedback, real time data, and human intervention distinctly separates our project from existing solutions.

## 2.4 Summary

In this chapter, we presented the theoretical background that provides an overview of definition and classifications for Autism, and sensory processing difficulties in Autistic children. We also conducted a literature review where we compared our system with similar existing projects. The comparison outlines how our project stands out by merging real-time emotional detection with interactive, personalized support through both a wearable device and an external screen, especially for children with autism.

# Chapter 3

## SYSTEM DESIGN

### 3.1 Preface

This chapter provides an overview of the necessary hardware and software components intended for our project. It explores various options for each component, presents a conceptual description of the system, and launches a general block diagram. Additionally, the chapter delves into system algorithms and methodologies through the use of flowcharts. Schematic diagrams depict the interactions and interfaces between components.

### 3.2 System Components and Design Alternatives

This part describes the hardware and software components and their design alternatives.

#### 3.2.1 Hardware Components

##### 3.2.1.1 Wearable Device

The wearable unit is responsible for detecting physiological stress signs from the child, processing them, and providing sensory feedback.

##### 3.2.1.1.1 Microcontroller

The microcontroller is a main component in the wearable device, which collects physiological data from sensors. There are two available options for the microcontroller ESP32 3C ZERO, LilyPad Arduino, to choose from shown in Table 3.1.

Table 3.1: Comparison of ESP32 3C ZERO and LilyPad Arduino

Characteristic	ESP32 3C ZERO [8]	LilyPad Arduino [9]
Image		
RAM	400KB SRAM	1KB SRAM
Clock Speed	Up to 160MHz	8 MHz
Storage	4MB Flash	16 KB
Dimensions (L x W x H) mm	(18mm × 25mm × 3mm)	approximately 50mm diameter, height 4.5mm
Connectivity	WiFi, Bluetooth	No built-in WiFi/Bluetooth
Price	starts from around \$4	starts from \$1 – \$3 [10]
Operating Voltage	3.0V–3.3V	2.7V–5.5V



The ESP32-C3 Zero was chosen because its size, speed, large memory and built-in WiFi/Bluetooth, making it ideal for real-time sensor data processing and wireless communication in the wearable system.

### 3.2.1.1.2 Skin Conductance Sensors

Skin conductance is a standard psychophysiological measurement procedure, often referred to as Electrodermal Activity (EDA). It is used as an index of the activity of the sympathetic nervous system, whose role is to generate the body's response, a physiological response triggered by emotionally arousing or stressful stimuli.

This response increases sweat gland activity, particularly in areas with a high density of sweat glands, such as the fingers and palms. As emotional or psychological arousal rises, such as during stress or anxiety, the skin's ability to conduct electricity improves due to the increased sweat production [11]. During stress, the resistance of the skin drops due to increased secretion in the sweating glands [12]. There are two available options for skin conductance sensors to choose from shown in Table 3.2.

Table 3.2: Comparison of Grove Galvanic Skin Response (GSR) Sensor and Galvanic Skin Response (GSR) Shimmer3 Sensor

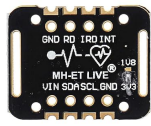

Characteristic	Grove GSR [13]	GSR Shimmer3 [14]
Image		
Price	≈ \$60–\$70	≈ \$570
Power Supply	Operates at 3.3V / 5V	Rechargeable 450mAh Li-ion battery + Bluetooth
Connectivity	Wired (analog output)	Wireless via Bluetooth / USB / SD card
Size & Weight	Very small and lightweight	Small size, lightweight (28g)

The Grove GSR sensor was chosen due to its affordable price, simple integration process, and compatibility with low-power wearable systems. While premium options like the Shimmer3 GSR offer advanced features and medical-grade precision, the Grove GSR provides enough data resolution for detecting stress related physiological changes, which is the main requirement of the system. Additionally, its compact size and minimal energy requirements make it ideal for embedding within a lightweight wearable device.

### 3.2.1.1.3 Heart Rate Sensor

A heart rate sensor is used to monitor the number of heartbeats per minute (BPM). It provides valuable data into a person's physiological and emotional state, especially in response to stress, anxiety, or physical activity. In wearable health devices, heart rate monitoring helps in detecting abnormal patterns, and assessing stress levels. There are two available options for heart rate sensors to choose from shown in Table 3.3.

Table 3.3: Comparison of MAX30102 Sensor and Pulse Sensor

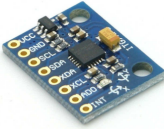

Characteristic	MAX30102 [15]	Pulse Sensor [16]
Image		
Price	Starts from \$7	Starts from \$1
Output Type	Digital signal (data stream over I2C)	Analog voltage (pulse waveform)
Type of Measurement	Digital biosensor with SpO <sub>2</sub> + HR detection	Analog optical heart rate sensor
Detection Method	Optical reflection (PPG) with dual-wavelength absorption	Optical reflection (PPG) with single wavelength
Power Control	Software-controllable (can be turned off)	Always on when powered
Pin Count	7 pins (VIN, GND, SCL, SDA, INT, RD, IRD)	3 pins (VCC, GND, A0)
Weight	1.1g	9g

The MAX30102 sensor module was chosen for this project due to its high accuracy and ability to capture both heart rates and blood Oxygen saturation (SpO<sub>2</sub>). The physiological signals formed by these parameters are among the prime indicators of stress and emotional states, which correspond directly to the goal of the system, that is, to monitor emotional response in children. MAX30102 differs from other ordinary pulse sensors in having superior noise rejection and ambient light suppression, thus being qualified for wearable applications where reliability and accuracy are crucial.

#### 3.2.1.1.4 Motion Sensor ((MPU6050), (ADXL335))

A motion sensor can be used to track the movement, position, or rotation of the body. It is important in monitoring systems such as wearables because it tracks the level of activity, identifies normal and abnormal repetitive motions, as well as differentiates between stress and usual physical responses. There are two available options for motion sensors to choose from shown in Table 3.4.

Table 3.4: Comparison Of MPU6050 Sensor and ADXL335 Sensor

Characteristic	MPU6050 [17]	ADXL335 [18]
Image		
Price	Starts from \$3–5	Starts from \$4–6
Sensor Type	Digital Accelerometer + Gyroscope	Analog Accelerometer
Axis	6 (Accel + Gyro)	3 (X, Y, Z)

The MPU6050 was chosen for this project because it combines a 3-axis accelerometer, 3-axis gyroscope, and an embedded Digital Motion Processor (DMP) in a compact, low-power module. This sensor provides acceleration, orientation, and angular velocity data in all dimensions, making it highly accurate in motion tracking. These motion parameters are essential for detecting physical behaviors and movement patterns that are often stressed in fragile groups of non-aggressive children with autism, such as repeated motions or certain unusual postures of the body.



### 3.2.1.1.5 LED Strip

An addressable LED strip is used as a visual countdown timer to support emotional self-regulation for children with autism.

The LED strip is a non-verbal and intuitive method to indicate time duration, such as for breaks and transitions.

The LED strip offers both flexibility in visual design and a strong sensory impact, which can help reduce anxiety during routine changes. There are two available options for LED strips to choose from shown in Table 3.5.

Table 3.5: Comparison Of WS2812 NeoPixel Ring and APA102 [19]

Characteristic	WS2812 NeoPixel Ring [19]	APA102 [19]
Image		
PWM Resolution	8-bit (256 levels)	8-bit (256 levels)
PWM Frequency	400 Hz	20 KHz
Type	RGB 5050 Pixel	RGB 5050 or 2020 (Dotstar Micro) Pixel
Data Rate	800 Kbps	less than 4 Mbps

The WS2812 NeoPixel Ring was chosen for this project because of its simple integration and for being easily suited for visual feedback applications. It requires only one data line, fully complies with the ESP32 C3 ZERO microcontroller, which is going to be used in the project, and prompts bright, individually addressable RGB LEDs [19].

### 3.2.1.1.6 Battery

For this project, a Lithium-Ion (Li-ion) battery was selected due to its superior energy density, safety profile, and it is rechargeable, which are critical for wearable and healthcare-related applications.



### 3.2.1.2 Interactive Screen

Interactive screen is used to present calming audio and visual content to the child under stressful emotional conditions. The screen is also used as a feedback system associated with the wearable device, and it processes incoming data received and responds accordingly.

#### 3.2.1.2.1 Microcontroller

The microcontroller of the interactive screen takes input in the form of processed physiological data from the wearable device and displays appropriate visual, auditory, or multimedia data depending upon the emotional state of the child. There are two available options for microcontrollers to choose from shown in Table 3.6.

Table 3.6: Comparison of Raspberry Pi 3 Model B and NVIDIA Jetson Nano



Characteristic	Raspberry Pi 3 model B	NVIDIA Jetson Nano [20]
Image		
RAM	1GB	4GB
Clock Speed	1.5GHz	1.43GHz
Connectivity	Built-in WiFi / Bluetooth / Ethernet	Ethernet only
Dimensions (mm)	85.6 x 56.5	100 x 80
GPU	Broadcom VideoCore VI	128-core Maxwell GPU
Price	about 250 NIS [21]	about 2500 NIS [22]

Raspberry Pi 3 Model B is selected as the main microcontroller of the interactive screen because of the community support it has gathered, multimedia capabilities, and built-in wireless connectivity. Compared to Jetson Nano, it already comes autonomous with WiFi and Bluetooth, thus simplifying communication with the wearable device. The Raspberry Pi 3 Model B also features sufficient processing power and RAM to support real-time video and multimedia content required to calm down the child. Its compact nature, lowered price, and ease to develop render it ideal for use in assistive wearable technology projects like the current one.

### 3.2.1.2.2 Display

The display function of the interactive screen is among the main parts tasked with displaying comforting images to the child as animation, pictures, or simple games. In addition, when emotionally upset, the child is encouraged to work on the screen directly by means of drawings or scribbles, which may be used as an expressiveness tool to alleviate stress. Hence, display responsiveness and touch are inherent elements. There are two available options for display to choose from shown in Table 3.7.

Table 3.7: Comparison Of High-Definition Multimedia Interface (HDMI) Touch Screen and Thin-Film Transistor Liquid Crystal Display (TFT) LCD.



Characteristic	7 Inch HDMI Touch Screen [23]	TFT LCD [24]
Image		
Display Type	TFT LCD with HDMI interface	TFT LCD
Screen Size	7 inches	Small to medium (2.4"–4.3" typical)
Resolution	1024 × 600	Low to moderate (480×320)
Touchscreen Support	USB touch (capacitive or resistive)	Available (mostly resistive)
Image Quality	High resolution and sharpness	Acceptable
Cost	≈ \$39	≈ \$7
Interface Options	HDMI (display) + USB (touch)	SPI, I2C, and parallel

The HDMI 7-inch touch display was chosen for the ability to display colorful, reactive images and respond to touch, which is necessary for soothing and captivating the child. It can be used for scribbling or drawing when the child is upset, offering a healthy outlet. Unlike TFT LCDs that require complex wiring, The HDMI display operates as a plug-and-play monitor.

### 3.2.1.2.3 Speaker

The speaker component is essential in offering auditory feedback to the child during emotional distress. The feedback may be soothing music, calm nature, or simple audio messages. Choosing a speaker that will offer clear, pleasant, and non-intrusive sounds is critical, especially for children with autism, who are sound-sensitive. There are two available options for speakers to choose from shown in Table 3.8.

Table 3.8: Comparison of USB Speaker and Bluetooth Speaker

Characteristic	USB Speaker	Bluetooth Speaker
Image		
Audio Type	Digital audio via USB	Wireless audio via Bluetooth
Playback Quality	High quality, stable	High quality, stable sound
Integration	Requires USB host support	Easy pairing with phones or microcontrollers
Control Method	Controlled by USB host (e.g., Raspberry Pi)	Controlled by paired Bluetooth device
Power Consumption	Moderate to high	Moderate
Connectivity	Wired (USB)	Wireless (Bluetooth)
Price	≈ \$14 [25]	≈ \$15 [26]

The Bluetooth Speaker was chosen due to its wireless connection, portability, sound output of good quality, and suitability for devices like Raspberry Pi . It can be ideal in offering independently from the main system power supply increasing flexibility in placement and use.

### 3.3 Software Components and Design Alternatives

This section outlines the software components critical to the Smart Assistant System for Children with Autism.

#### 3.3.1 Stress Detection

The stress detection is the system's core, determining if the child is under stress. This detection is essential for alerting specialists and for triggering the feedback mechanisms, be it visual or auditory. The system continuously collects data and analyzes it from the Galvanic Skin Response sensor (GSR), Heart Rate sensor (HR), and Motion sensor sensor, HR sensor, and Motion sensor to

classify an emotional state of the child. This detection has to be efficient and reliable in decision making.

### **3.3.1.1 Threshold-Based Stress Detection**

Threshold-based stress detection is a rule-based technique that sorts out stress by measuring the physiological signals in real-time against the pre-established threshold values. The approach typically starts with a baseline calibration phase, during which normal Heart Rate (HR) and Galvanic Skin Response (GSR) levels are defined based on baseline values reported in existing scientific studies [27] [28].

During the process, stress is assumed when HR and GSR values exceed their baseline by a certain percentage. To improve reliability, signal smoothing may be applied, especially for GSR readings. Moreover, the integration of motion data could help determine which changes in physiology due to stress were not brought about by physical activity or other movements, for example, stimming. This approach enables simple and real-time stress classification suitable for embedded systems.

### **3.3.2 Communication Protocols**

In our project, we define protocols between different system components for communication and data interchange. The protocols allow system integration and operability. The protocols include Wi-Fi and BLE as described in Table 3.9 to help selection based on project needs and limitations. Their particular characteristics are provided to support decisions.

Table 3.9: Differences Between Communication Protocols

<b>Feature</b>	<b>BLE [29]</b>	<b>Wi-Fi [30]</b>
<b>Type</b>	Short-range Wireless Communication	High speed Wireless Networking
<b>Use Case</b>	Communication between wearable device, mobile application, and interactive display	Audio device pairing (speaker connection)
<b>Connection Type</b>	Intermittent (low duty cycle)	Persistent (infrastructure or P2P)
<b>Reliability</b>	Medium (depends on interference and environment)	High (reliable via TCP/IP)
<b>Overhead</b>	Low	High (due to TCP/IP stack)
<b>Power Usage</b>	Very low	High
<b>Range</b>	10–100 meters	Up to 100 meters
<b>Latency</b>	Low	Moderate

In our project, Wi-Fi acts as the main communication protocol for the transfer of data among the wearable device, mobile app, and interactive display, also giving stable and reliable connection. Bluetooth is used only for linking the speaker to the interactive display, which gives a simple and wireless audio solution.

### 3.4 Conceptual System Description

The conceptual system design here and the system block diagram in the next figure integrate multiple physiological sensors (Grove galvanic skin response, Heart Rate, Motion) for data collection, a ESP32 C3 ZERO processing unit to detect stress. a LED ring is used as a timer for activities and the specialist can set the time for activity. It will send notifications to a specialist’s mobile app when it detects stress. The specialist then uses an interactive screen with audio-visual feedback to provide calming interventions for the child’s sensory sensitivities.

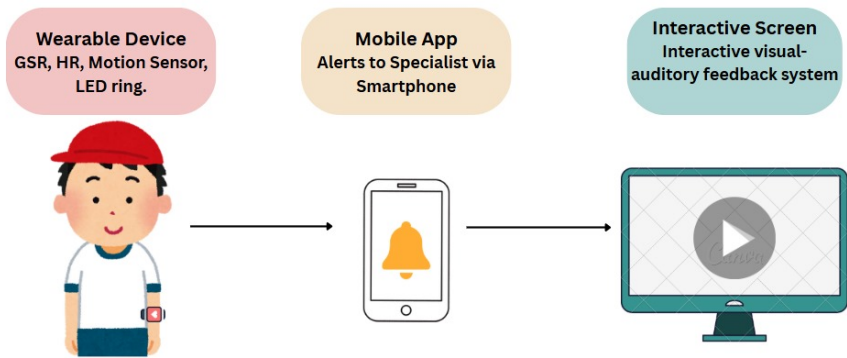


Figure 3.1: System Conceptual Diagram

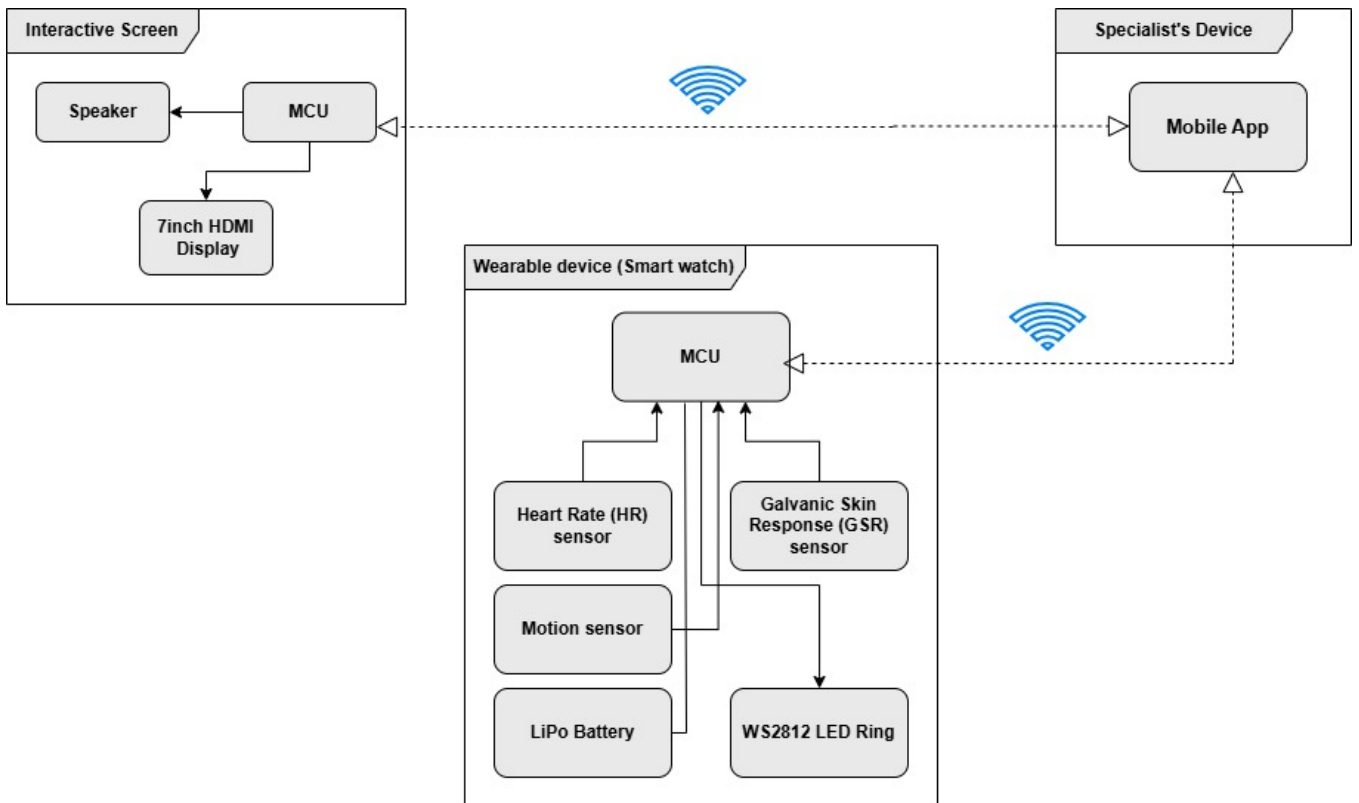


Figure 3.2: System Block Diagram

## 3.5 Algorithms and Methodologies

### 3.5.1 Stress Detection Pseudo Code

This pseudocode describes the threshold-based stress detection logic implemented on the wearable device. HR and GSR signals are analyzed relative to baseline values, while motion features extracted from the MPU6050 are used to differentiate between physical activity and repetitive motion (stimming) from emotional stress. To reduce noise, GSR is smoothed before applying thresholds.

#### Pseudo Code Part 1: Sensor Initialization and Data Acquisition

START

Initialize sensors (HR, GSR, Motion)

Load baseline HR and baseline GSR values

LOOP

    Read Heart Rate

    Compute average BPM

    Read GSR value

    Apply smoothing filter

    Read motion sensor data

    Classify motion as:

        LOW

        ACTIVITY

        STIMMING

    Compare HR and GSR with baseline thresholds

## Pseudo Code Part 2: Stress Classification

```
IF motion == LOW THEN
  IF HR is high AND GSR is high THEN
    State = HIGH STRESS
  ELSE IF HR is moderate OR GSR is moderate THEN
    State = MODERATE STRESS
  ELSE
    State = NORMAL
  END IF

ELSE IF motion == ACTIVITY THEN
  IF HR and GSR are strongly high THEN
    State = HIGH STRESS DURING ACTIVITY
  ELSE IF HR or GSR are moderate THEN
    State = MODERATE STRESS DURING ACTIVITY
  ELSE
    State = PHYSICAL ACTIVITY
  END IF

ELSE IF motion == STIMMING THEN
  IF HR and GSR are high THEN
    State = HIGH STRESS WITH STIMMING
  ELSE IF HR or GSR are moderate THEN
    State = MODERATE STRESS WITH STIMMING
  ELSE
    State = STIMMING WITHOUT STRESS
  END IF
END IF

END LOOP
```

### 3.5.2 Interactive Screen Control Pseudo Code

The following pseudo code outlines the core workflow of the Interactive Screen subsystem. The operations of the screen can be done from the mobile application exclusively utilized by the specialist. The specialist can control the type of relaxing response shown on the screen without having to work with the screen directly using the mobile application.

## Pseudo Code for Interactive Screen Control

START

Launch interactive screen interface

Wait for control command from supervisor mobile app

IF command == "COLOR":

    Display calming colors

ELSE IF command == "VIDEO":

    Play relaxing video

ELSE IF command == "BREATHING":

    Show breathing exercise animation

ELSE IF command == "STOP":

    Stop all content and reset screen

END

### 3.5.3 Sequence Diagram

The sequence diagram shows the stress detection system and support task transitions, it shows the flow from detecting the stress signs from the sensors in the wearable device to alerting the specialist to take the suitable decision.

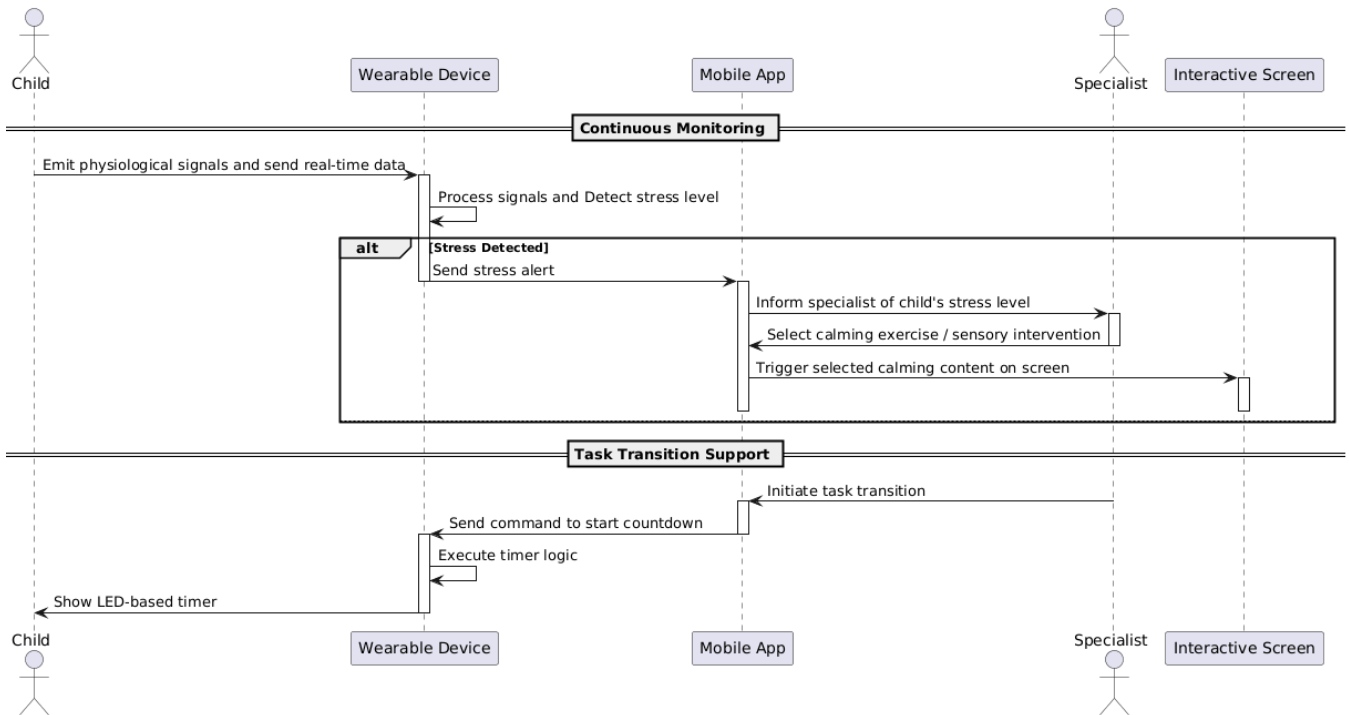


Figure 3.3: Sequence Diagram

### 3.6 Schematic Diagram

The schematic diagram shows the hardware layout of the wearable device. The ESP32 C3 ZERO microcontroller serves as the central unit, connected to the GSR sensor, MPU6050 motion sensor and the MAX30102 heart rate sensor for collecting physiological data. It also shows the WS2812 LED ring that provides the visual feedback and a rechargeable lithium battery with a TP4056 protection and charging module, as well as a voltage boost circuit to ensure stable power delivery and safe operation of the wearable device.

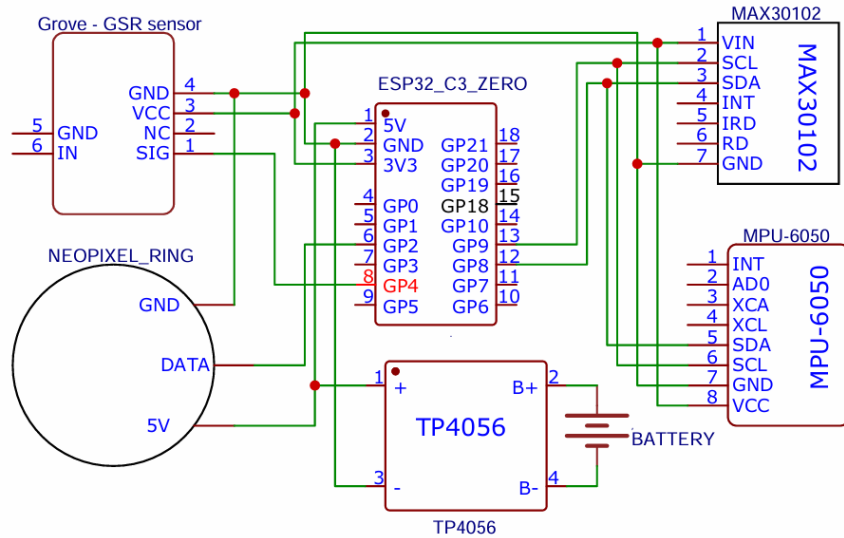


Figure 3.4: Schematic Diagram of Wearable Device

The schematic diagram here shows the hardware layout of the interactive screen module. A Raspberry Pi 3 Model B serves as the main processing unit, interfacing with a HDMI display for visual output. A Bluetooth speaker is connected to provide audio feedback.

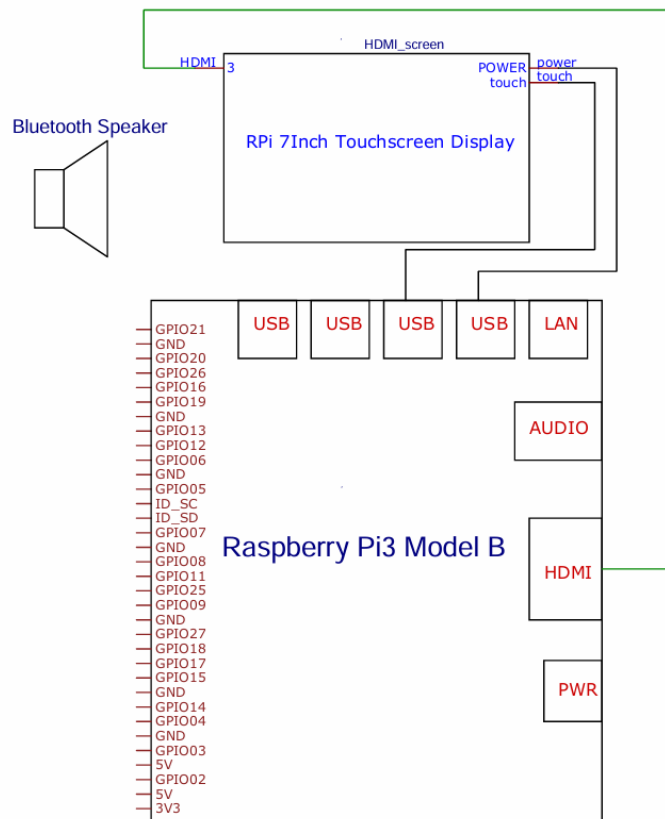


Figure 3.5: Schematic Diagram of Interactive Screen

## 3.7 Summary

In this chapter, we have discussed the system hardware and software components with their alternatives. The conceptual description of the system and the general flow of the system with all necessary diagrams are presented, too.

# Chapter 4

## Implementation

### 4.1 Overview

This chapter describes the implementation part of the project in more detail. It dives deep into the different hardware components of the system and its software with all of its modules.

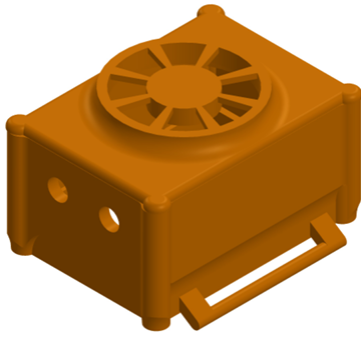
### 4.2 Hardware Implementation

In the previous chapter, we showed how the components are interrelated to each other. This section describes how the hardware components were physically assembled and connected. The whole hardware implementation consists of two main subsystems, which are a wearable stress detection device and an interactive screen module.

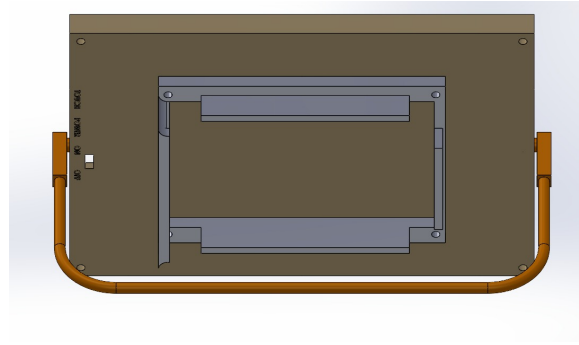
#### 4.2.1 Prototype Setup

Our prototype consists of two main components: a wearable device for use on the child's wrist and an interactive screen located in the environment, as shown in Figure 4.1(a) and (b).

The wearable device integrates physiological sensors (heart rate and galvanic skin response), a motion sensor, and an ESP32 microcontroller for local processing, all enclosed in a compact housing and powered by a LiPo battery, while the interactive screen component is a combination of a Raspberry Pi, a display screen, and a speaker. The enclosures of both the wearable and the interactive screen were designed to be fabricated using a 3D printer.



(a) Wearable Device Design



(b) Interactive Screen Design

Figure 4.1: Prototype Design Showing The Wearable Device and The Interactive Screen Module

## 4.2.2 Wearable Stress Detection Device

The wearable stress detection device is responsible for monitoring the child’s physiological signals and providing visual feedback. It is built around an ESP32 microcontroller, which is the main processing device.

### 4.2.2.1 Sensing Unit

The sensing unit integrates multiple physiological sensors connected to the ESP32 microcontroller to detect stress-indicative aspects.

- **(MAX30102) Heart Rate Sensor**

We connected MAX30102 sensor to the ESP32, with its VIN pin to 3.3V, SDA to GPIO 8, and SCL to GPIO 9 with a unique I2C address. It is used to measure the child’s heart rate. It is placed on the index finger to ensure stronger and more stable signal acquisition due to higher blood perfusion compared to wrist-based measurements.

- **Galvanic Skin Response (GSR) Sensor**

We connected the GSR sensor to the ESP32, with its VCC pin to 3.3V, SIG to GPIO 4. It measures variations in skin conductance associated with emotional arousal and stress.

- **(MPU6050) Motion Sensor**

We connected the MPU6050 sensor to the ESP32, with its VIN pin to 3.3V, SDA to GPIO 8, and SCL to GPIO 9 with a unique I2C address. It provides motion and acceleration data, which is used to differentiate emotional stress from physical activity.

### 4.2.2.2 Visual Feedback Module

The wearable device includes a WS2812 NeoPixel LED ring used as a visual countdown timer; we connected this to GPIO 2. The LED ring acts as non-verbal visual cues to support task transitions and scheduled activities, helping reduce anxiety caused by sudden changes.

### 4.2.2.3 Power Supply

The wearable device is powered by a rechargeable battery, allowing it to be used conveniently and portably when worn by a child.

### 4.2.3 Interactive Screen Module

The interactive screen module provides calming visual and auditory feedback to the child when stress is detected. It is designed to operate as an external support unit within the child's environment and is controlled through a Raspberry Pi.

- **Raspberry Pi**

The Raspberry Pi acts as main controller for the interactive screen. It runs the necessary software to manage visual content and receive control commands from mobile application.

- **Display Screen**

The display screen is connected to a Raspberry Pi via HDMI and it is utilized to display calming videos, animations, and guided breathing exercises.

- **Speaker**

A speaker is connected to the Raspberry Pi with Bluetooth to deliver soothing sounds or voice instructions.

## 4.3 Software Implementation

This section describes the software implementation of AutoSense. The system enables real-time physiological sensing, threshold-based stress detection, and calming responses through an interactive screen. In addition, the system includes a mobile application for real-time monitoring and calming mode selection, and a Telegram Bot for stress alert notifications.

### 4.3.1 Wearable Device Software

The firmware code of the wearable device was developed using the ESP32 with the Arduino development environment. Based on the ESP32 readings from the physiological sensors and motion sensors, the calibration procedure for the baselines, the smoothing technique for noise removal, and the decision-making method based on thresholds were implemented with the objective of identifying the status of the child (normal, stressed, or physically active).

#### 4.3.1.1 Libraries and Sensor Communication

The firmware integrates several libraries to support sensor communication, signal processing, networking, and user feedback.

Sensor and hardware-related libraries include:

- **I2C Communication (Wire library)**

It is used to connect MAX30102 and MPU-6050 on the I2C bus. The MAX30102 has a default I2C address of 0x57 and the MPU-6050 has a default address of 0x68, and therefore they can share the I2C bus without conflict.

- **MAX3010x libraries**

used to extract heart rate readings from the PPG signal.

- **Adafruit MPU6050 library**

used to compute motion level based on acceleration readings.

- **Adafruit NeoPixel library** used to control the WS2812 NeoPixel ring as a visual timer for sessions and activities.

Network and communication libraries include:

- **WiFi library** Enables the wearable device to connect to the local Wi-Fi network.

- **WebServer library** Used to host lightweight HTTP endpoints for real-time data access and system monitoring.

- **HTTPClient and WiFiClientSecure libraries** Used to send HTTP and HTTPS requests to external services, including secure communication with the Telegram Bot API for stress alert delivery.

#### 4.3.1.2 Baseline Calibration and Smoothing

The calibration technique introduced to enhance stability and to account for individual variations allows the wearable device to first perform an initial calibration procedure to determine the values for the heart and GSR sensors.

To improve the robustness of the GSR signal prior to threshold evaluation, we apply an exponential moving average (EMA) low-pass filter. The EMA is computed recursively as

$$\text{EMA}_t = \alpha x_t + (1 - \alpha)\text{EMA}_{t-1}, \quad (4.1)$$

where  $x_t$  is the current GSR sample and  $\alpha$  controls the trade-off between responsiveness and noise suppression [31].

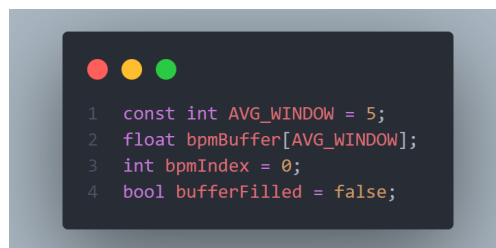
Exponential smoothing is widely used in practice to reduce measurement noise and mitigate motion/contact artifacts in electrodermal activity (EDA/GSR) preprocessing pipelines [32].

GSR readings are smoothed using an Exponential Moving Average(EMA) to reduce sudden spikes and measurement noise before applying the stress logic.

### 4.3.1.3 Threshold-Based Stress Detection

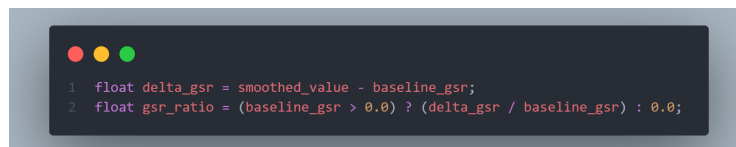
This threshold-based approach is supported by prior studies, which show that baseline-corrected increases in heart rate can precede stress-related behaviors in children with autism [27]. Additionally, adaptive, baseline-relative thresholding of electrodermal activity improves sensitivity to meaningful arousal changes across individuals [28].

As shown in Figure 4.2a, Heart rate values are not evaluated based on a single instantaneous beat. Instead, the system computes the average heart rate over a sliding window of five consecutive beats, which reduces short-term fluctuations and sensor noise before applying the threshold-based stress decision. The mathematical formulations used to compute the heart rate and GSR ratios are shown in Figure 4.2b and Figure 4.2c.



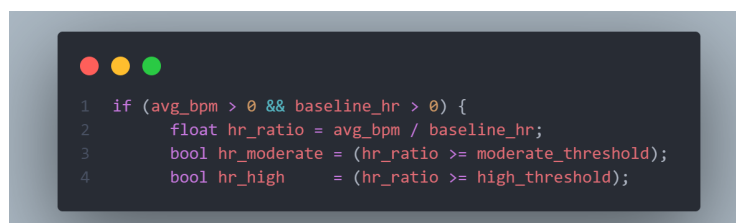
```
1  const int AVG_WINDOW = 5;
2  float bpmBuffer[AVG_WINDOW];
3  int bpmIndex = 0;
4  bool bufferFilled = false;
```

(a) Five-beat averaged heart rate used for threshold evaluation.



```
1  float delta_gsr = smoothed_value - baseline_gsr;
2  float gsr_ratio = (baseline_gsr > 0.0) ? (delta_gsr / baseline_gsr) : 0.0;
```

(b) Baseline-relative GSR ratio



```
1  if (avg_bpm > 0 && baseline_hr > 0) {
2      float hr_ratio = avg_bpm / baseline_hr;
3      bool hr_moderate = (hr_ratio >= moderate_threshold);
4      bool hr_high     = (hr_ratio >= high_threshold);
}
```

(c) Baseline-heart rate ratio

Figure 4.2: Threshold-based stress computation equations and logic

### 4.3.1.4 Distinguishing Stress from Physical Activity

Motion analysis in the AutoSense system helps differentiate stress-induced physiological responses from those stemming from physical movement in children with autism. Elevated heart rate or electrodermal activity during play, stimming, or emotional distress could lead to false-positive stress detection if motion is not considered. The motion module’s goal is to identify and distinguish between general physical activity and repetitive stimming behaviors associated with stress or self-regulation.

The MPU6050 (accelerometer + gyroscope) computes three interpretable motion features over a 1-second window at approximately 50 Hz :

- (1)  $\mathbf{A}_{\text{rms}}$ : the root mean square (RMS) of dynamic acceleration after removing gravity, representing movement intensity.
- (2)  $\mathbf{B}_{\text{vib}}$ : the mean absolute difference between consecutive acceleration samples, capturing rapid repetitive vibration typical of hand-flapping (stimming).
- (3)  $\mathbf{C}_{\text{gyro,rms}}$ : the RMS magnitude of the gyroscope readings, reflecting rotational activity.

To obtain device-specific thresholds, motion data was collected in REST, ACTIVITY, and STIMMING sessions. Thresholds were computed using a midpoint-based formulation between rest and target motion states, as shown in the following equation (4.2) [33]:

$$TH = \frac{\max(\text{REST}) + \text{median}(\text{TARGET})}{2} \quad (4.2)$$

Motion is classified every second into one of three states based on motion features and predefined thresholds.

- **ACTIVITY**: motion is classified as ACTIVITY if [34]

$$A_{\text{rms}} > TH_A \quad \text{or} \quad C_{\text{gyro,rms}} > TH_C$$

- **STIMMING**: motion is classified as STIMMING if [33]

$$B_{\text{vib}} > TH_B$$

and the ACTIVITY condition is not satisfied.

- **LOW**: motion is classified as LOW when neither ACTIVITY nor STIMMING conditions are met.

To reduce classification jitter, decisions are temporally stabilized. The ACTIVITY state is confirmed after 2 seconds of persistence, while both STIMMING and LOW states require 4 seconds of persistence [33].

The resulting motion state is then used to contextualize (HR) and (GSR): during ACTIVITY, moderate rises are treated as exertion unless both signals indicate strong stress; during STIMMING, concurrent (HR) and (GSR) elevation indicates stress while isolated stimming is treated as non-stress; during LOW motion, significant HR and GSR increases are directly interpreted as stress [35].

### 4.3.2 Interactive Screen Software

The interactive screen module was implemented using Python 3 on Raspberry Pi. a local full-screen GUI application that displays calming visual content using Tkinter.

```
sudo apt install -y python3-tk
```

To enable remote control, a lightweight Flask web server runs locally on the Raspberry Pi and listens for HTTP commands sent from the mobile application over the local network. Additional dependencies included Pillow for image rendering in Tkinter, pygame for audio playback, and VLC for full-screen video playback.

```
pip3 install flask pygame pillow
sudo apt install -y vlc
```

#### 4.3.2.1 GUI Modes and Content

The screen provides multiple calming modes designed for stress reduction:

- **Breathing Mode**  
guided breathing sequence using images (flower/candle) synchronized with short voice prompts.
- **Calming Video Mode**  
plays selected calming videos in full screen.
- **Coloring Mode**  
interactive coloring activity with simple tools (blue/green brush, eraser, clear, next page).
- **Stop / Home Mode** returns to the main screen

#### 4.3.2.2 Flask API for Remote Control

To enable mobile control, the Raspberry Pi runs a Flask server exposing RESTful endpoints such as:

**/health** to verify system availability

**/set\_mode** to switch between modes (breathing/video/coloring/stop) and select specific video content.

### 4.3.3 Mobile Application Software

The mobile application was developed using Flutter to provide specialists with a simple interface for session monitoring and interactive screen control, as shown in Figure 4.3.

The application communicates with the Raspberry Pi interactive screen via HTTP requests over the local Wi-Fi network to control calming modes such as breathing exercises, videos, and coloring activities.

The mobile application also presents real-time stress levels and sensor data collected from the wearable device, allowing specialists to monitor the child’s state throughout the session.

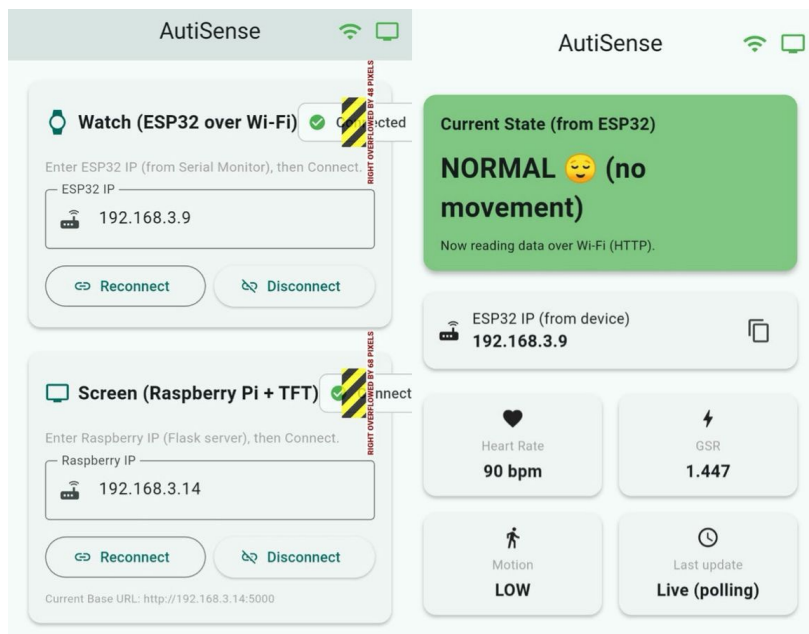


Figure 4.3: Mobile application interface for real-time monitoring and screen control

#### 4.3.4 Telegram Bot Notification Workflow

To deliver stress alerts when the mobile application is inactive, a Telegram Bot–based notification system was established. A bot was created using BotFather, generating a unique authentication token. Specialists provide their Telegram chat IDs to enable direct message delivery, as shown in Figure 4.4,

Stress detection is performed at the wearable device level; upon detecting moderate or high stress, an HTTP request is sent to the Telegram Bot API, triggering an alert notification. A 30-second cooldown interval is enforced between consecutive alerts to prevent notification flooding while ensuring timely intervention.

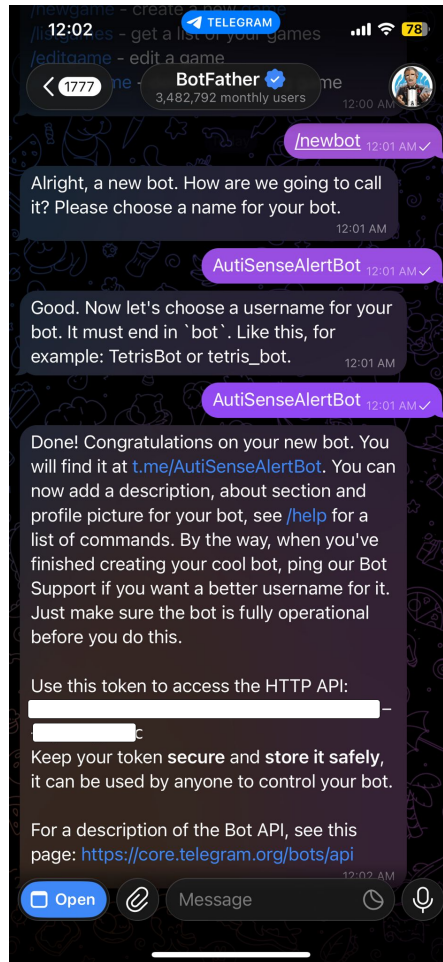


Figure 4.4: Telegram bot setup

### 4.3.5 Implementation Issues

1. One challenge was differentiating stress-related physiological responses from strong physical activity and repetitive movements in children with autism. Both can elevate heart rate and GSR, but their motion patterns are distinct. This was resolved by incorporating motion intensity data from the MPU6050 sensor into the stress detection logic, improving the classification of stress, strong activity, or stimming movements.
2. GSR readings were initially prone to false stress detections due to noise from hand movement and sensor contact variations, so an (Exponential Moving Average) EMA smoothing technique was employed.
3. To ensure that stress alerts are delivered regardless of the mobile application's state, a Telegram Bot-based notification mechanism was implemented, enabling push-style notifications instead of in-app alerts.

## 4.4 Summary

In this chapter we reviewed the hardware and software implementation each component was fully explained, then we discussed the issues and challenges we faced during the implementation phase.

# Chapter 5

## Testing and Results

### 5.1 Preface

The testing of all system components and the results will be covered in this chapter.

### 5.2 Validation and Testing

The validation process focused on unit testing and integration testing of the system components. Each module was tested independently to ensure correct functionality before validating the complete system workflow.

#### 5.2.1 Hardware Unit Testing

This section discusses the testing process of each of our hardware components.

##### 5.2.1.1 ESP32 Wearable Module

The ESP32-C3 microcontroller was tested as the processing unit of the wearable stress monitoring device. The ESP32 is responsible for acquiring physiological sensor data, processing stress levels locally, and communicating directly with the mobile application over a local Wi-Fi network.

##### 5.2.1.2 Heart Rate Sensor (MAX30102)

The heart rate sensor was tested for accuracy in heart rate acquisition, including I2C communication verification with the ESP32, real-time measurements at rest, and monitoring of signal stability during minor hand movements. The sensor delivered consistent and reliable readings, deemed suitable for stress detection.

##### 5.2.1.3 Galvanic Skin Response (GSR) Sensor

To verify that the GSR sensor readings were correct and meaningful, we performed a set of validation checks focusing on signal plausibility and artifact behavior. First, the sensor output was logged while

the subject was seated and relaxed to confirm a stable baseline (no drifting or saturation). The raw ADC values were inspected to ensure they remained within the valid range and did not clip at 0 or at the ADC maximum during normal contact.

Next, we verified that the signal responded in the expected direction: when contact pressure increased or the skin became slightly more moist, the measured conductance increased smoothly, while removing the finger (loss of contact) produced a clear abrupt change and unstable/noisy values. These scenarios were intentionally introduced to confirm that the system can detect contact-related artifacts and that the measured variations were not random noise.

Finally, baseline-relative normalization was verified by repeating the calibration procedure multiple times and confirming that the computed GSR ratio remained close to 1.0

#### 5.2.1.4 Motion Sensor (MPU6050)

The MPU6050 motion sensor was tested and verified by recording motion data at 50 Hz under controlled REST (R), ACTIVITY (A), and STIMMING (S) conditions, as shown in Figure 5.1. During REST, motion features remained low and stable ( $A_{\text{rms}} \approx 0.33$ ,  $B_{\text{vib}} < 0.08$ ,  $C_{\text{gyro,rms}} \approx 0.04$ ), confirming correct baseline behavior. During ACTIVITY, feature values increased significantly ( $A_{\text{rms}} > 4.0$ ,  $C_{\text{gyro,rms}} > 3.0$ ), while STIMMING produced intermediate acceleration with elevated vibration ( $B_{\text{vib}} > 0.9$ ). The clear separation between these ranges verified correct sensor readings and validated the motion-aware threshold logic, which successfully reduced false stress detection caused by physical activity.

motion_log_	5.003 A	15.571204	4.575058	5.300412	50.00
motion_log_	6.003 A	14.172274	4.634296	4.606083	50.00
motion_log_	4.003 R	0.332890	0.034812	0.045201	50.00
motion_log_	5.003 R	0.345663	0.074469	0.053813	50.00
motion_log_	11.003 S	4.561702	1.633692	2.006850	50.00
motion_log_	12.003 S	3.918751	1.353177	2.131152	50.00

Figure 5.1: Sample Motion Feature Values Extracted From MPU6050 Measurements.

#### 5.2.1.5 NeoPixel LED Indicator

The NeoPixel LED ring was tested as a visual timer and feedback mechanism for activity sessions. As shown in Figure 5.2 (a), the LEDs were used to represent the remaining time of activities. As shown in Figure 5.2(b) and (c), the LEDs progressively turned off to indicate the elapsed session time. Color changes to orange and blinking patterns indicated the final minute of the session. The NeoPixel timer responded accurately to timer updates sent from the mobile application.



(a) Full timer display



(b) Final-Minute Warning  
Orange



(c) Final-minute warning blinking

Figure 5.2: NeoPixel LED Timer Behavior During Activity Sessions

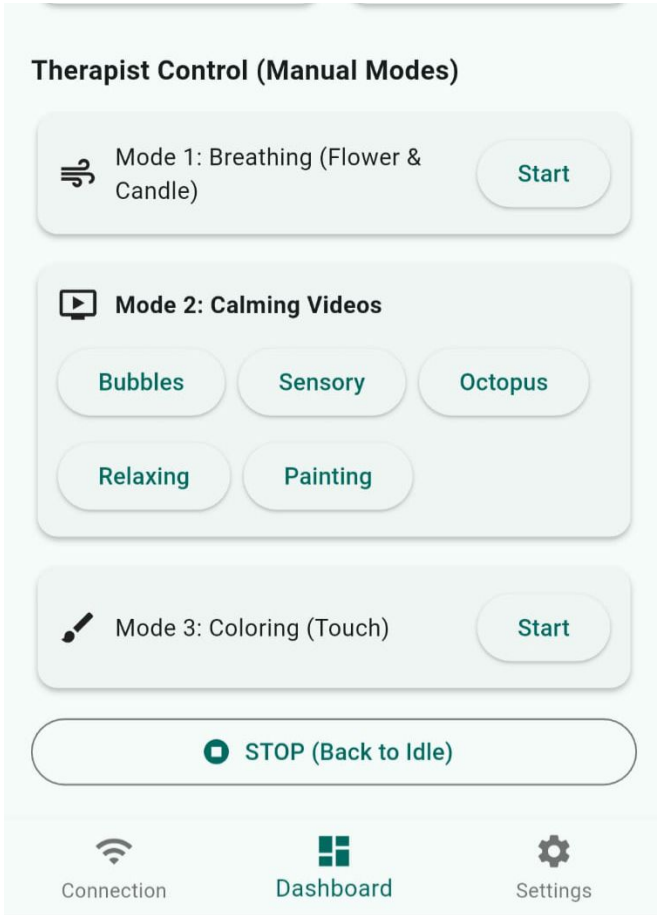
### 5.2.1.6 Lithium Battery and Power Consumption

The wearable device is powered by a rechargeable lithium battery, which was tested under normal operating conditions. After a full charge, the system operated continuously for approximately 4–5 hours while running all sensors, Wi-Fi communication, and LED indicators. No significant performance degradation was observed during the discharge period. This battery life is sufficient for short monitoring and therapy sessions.

### 5.2.1.7 Raspberry Pi

The Raspberry Pi was tested as the central unit responsible for displaying calming visual and auditory content, including network connectivity over the local Wi-Fi network, communication with the Flutter mobile application via HTTP requests.

As shown in Figure 5.3, Therapist Control in flutter app, when click the start button on mode 1, show breathing in screen (is show flower image with voice prompt smell the flower and candle image with voice prompt Blow out the candle), but the voice in arabic, when click any button on mode 2 displays calming videos in screen that support sensory regulation and relaxation for children with autism, and when click the start button on mode 3 displays coloring. The Raspberry Pi passed all tests successfully and operated.



(a) Therapist Control Interface in the Flutter Mobile Application



(b) Example of Interactive Screen Displaying the Coloring Mode

Figure 5.3: Mobile Application Control and Interactive Screen Operation

## 5.2.2 Software Unit Testing

This section summarizes the testing procedures for the software components of the AutiSense system.

### 5.2.2.1 Mobile Application Testing

The mobile application was developed to support system interaction through multiple functional views. These include device connection setup using IP addresses, real-time monitoring of physiological sensor data received from the ESP32, manual control of the NeoPixel activity timer for session management, and selection of calming modes displayed on the Raspberry Pi screen. Detailed screenshots of the mobile application interfaces used during the testing phase are presented in Appendix A.

### 5.2.2.2 Notification System Testing

As shown in Figure 5.4, the Telegram Bot notification system was tested to ensure specialists receive alerts during elevated stress levels detected by the ESP32 wearable device. Testing included

verifying alert delivery during high-stress events. All notifications were delivered successfully with minimal latency, confirming reliable real-time alerting through the Telegram platform.

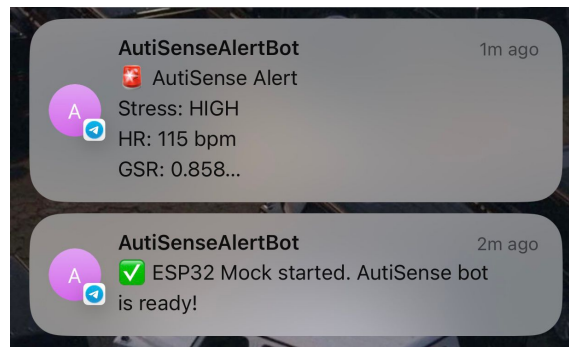


Figure 5.4: Stress Notification Received on The Tabletelegram Bot

### 5.2.3 Stress and Motion Classification Performance Evaluation

To evaluate the real-time stress and motion classification performance of the system, controlled scenario-based experiments were conducted. Serial monitor logs were recorded under five predefined conditions: Normal (no movement), Stimming (no stress), Activity(physical movement), Moderate Stress, and High Stress.

Each condition was tested multiple times to ensure consistency and reliability. Representative samples from the recorded data are presented in the following subsections to demonstrate the classification accuracy of the system.

#### 5.2.3.1 Normal State (No Movement)

**Baseline HR:** 60.1 BPM

**Baseline GSR:** 2.363 V

Table 5.1: Normal State (No Movement) Samples

Sample	HR (BPM)	GSR (V)	GSR %	Motion	State
1	68.0	2.367	0.16%	LOW	NORMAL
2	72.8	2.367	0.16%	LOW	NORMAL
3	80.0	2.367	0.15%	LOW	NORMAL
4	68.0	2.368	0.18%	LOW	NORMAL
5	72.8	2.367	0.17%	LOW	NORMAL

**Analysis:** GSR variation remained below 0.2%, and HR increase did not exceed the stress thresholds. The system correctly classified all samples as **NORMAL**.

### 5.2.3.2 Stimming (No Stress)

Table 5.2: Stimming Samples

Sample	HR (BPM)	GSR (V)	GSR %	Motion	State
1	117.1	2.367	0.16%	STIMMING	STIMMING
2	117.1	2.368	0.18%	STIMMING	STIMMING
3	125.0	2.367	0.16%	STIMMING	STIMMING
4	117.1	2.365	0.07%	STIMMING	STIMMING
5	123.9	2.367	0.15%	STIMMING	STIMMING

**Analysis:** Despite elevated heart rate due to movement, the GSR ratio remained close to baseline. The motion-aware filter successfully prevented false stress detection, and the system correctly classified the condition as **STIMMING**.

### 5.2.3.3 Activity (Physical Movement)

Table 5.3: Physical Activity Samples

Sample	HR (BPM)	GSR (V)	GSR %	Motion	State
1	123.9	2.364	0.03%	ACTIVITY	ACTIVITY
2	123.9	2.366	0.10%	ACTIVITY	ACTIVITY
3	123.9	2.368	0.20%	ACTIVITY	ACTIVITY
4	140.0	2.368	0.18%	ACTIVITY	ACTIVITY
5	125.0	2.367	0.16%	ACTIVITY	ACTIVITY

**Analysis:** Although heart rate increased significantly during movement, GSR variation remained below the stress thresholds. The system correctly classified the condition as **ACTIVITY** rather than stress.

### 5.2.3.4 Moderate Stress

Table 5.4: Moderate Stress Samples

Sample	HR (BPM)	GSR %	Motion	State
1	82.0	2.3%	LOW	MODERATE
2	85.5	3.1%	LOW	MODERATE
3	90.0	3.8%	LOW	MODERATE
4	88.0	2.5%	LOW	MODERATE
5	92.0	4.2%	LOW	MODERATE

**Analysis:** Both HR ratio (> 20% above baseline) and GSR ratio (> 2%) exceeded the moderate thresholds, resulting in correct **MODERATE STRESS** classification.

### 5.2.3.5 High Stress

Table 5.5: High Stress Samples

Sample	HR (BPM)	GSR %	Motion	State
1	100.0	5.1%	LOW	HIGH
2	110.0	6.4%	LOW	HIGH
3	120.0	7.2%	LOW	HIGH
4	105.0	5.8%	LOW	HIGH
5	115.0	6.9%	LOW	HIGH

**Analysis:** HR exceeded 40% above baseline and the GSR ratio exceeded 5%, triggering **HIGH STRESS** detection and a Telegram notification (with cooldown enforcement).

### 5.2.4 Integrated System Workflow Testing

Each functionality of the AutoSense system was tested independently to ensure correct performance and reliable integration between system components. The testing workflow focused on the interaction between the ESP32 wearable device, the mobile application, the Raspberry Pi calming screen, and the notification system. The sequence of operations, including physiological data acquisition, stress level classification, mobile application interaction, activity timer control, calming mode selection, and alert notification delivery, was executed step-by-step. The outcomes of these tests are summarized in Table 5.1.

Table 5.6: Testing Table

Case	Result
Load mobile application interface	The application loads correctly and displays all expected interface elements.
Connect to ESP32 wearable device	Successful connection established using the ESP32 IP address, enabling real-time data retrieval.
Display real-time sensor data	Heart rate, GSR, motion state, and stress level are displayed correctly in real time.
Stress level classification	The system accurately classifies stress levels into calm, moderate stress, and high stress states.
Motion-aware filtering	Physical activity and stimming movements are correctly distinguished from stress-related physiological changes.
NeoPixel activity timer control	Activity session duration is successfully updated from the mobile application and reflected on the NeoPixel LED timer.
Connect to Raspberry Pi screen	Successful connection established using the Raspberry Pi IP address for screen control.
Calming mode selection	Selected calming modes are correctly displayed on the Raspberry Pi screen.
Telegram alert notification	High stress alerts are delivered successfully via the Telegram bot with an enforced cooldown interval.
System stability	The system operates continuously without crashes or data loss during testing sessions.

### 5.3 Summary

In this chapter, the Hardware and Software unit testing and validation processes of the AutoSense system were presented. Overall, the testing results demonstrate that AutoSense operates effectively as a stress monitoring and support system for children with Autism Spectrum Disorder.

# Chapter 6

## Conclusion and Future Work

### 6.1 Conclusion

In this work, we presented AutoSense, a smart assistive system aiming at supporting ASD children by real-time stress monitoring and adaptive calming interventions. The proposed system is composed of one wearable device, one interactive screen, and one mobile application to make the support solution complete and responsive.

Applying pattern analysis to Heart Rate (HR), Galvanic Skin Response (GSR), and motion data, this system can detect states of stress while differentiating emotional stress from physical activity or repetitive movements. Upon identification of stress, at appropriate times, AutoSense will provide various formats of visual and auditory feedback and alert the caregivers accordingly when necessary.

### 6.2 Future Work

- Include a front-facing camera positioned in front of the child; by capturing the face, it will be able to pick up facial expressions and behavioral cues. The system could analyze visual features such as facial emotions, gaze direction, or head movements to enhance the accuracy of stress detection and give a better understanding of the child's emotional state.
- Optimizing the wearable design so that it becomes smaller in size and more comfortable.

# Appendices

## Appendix A

### Mobile Application Interface

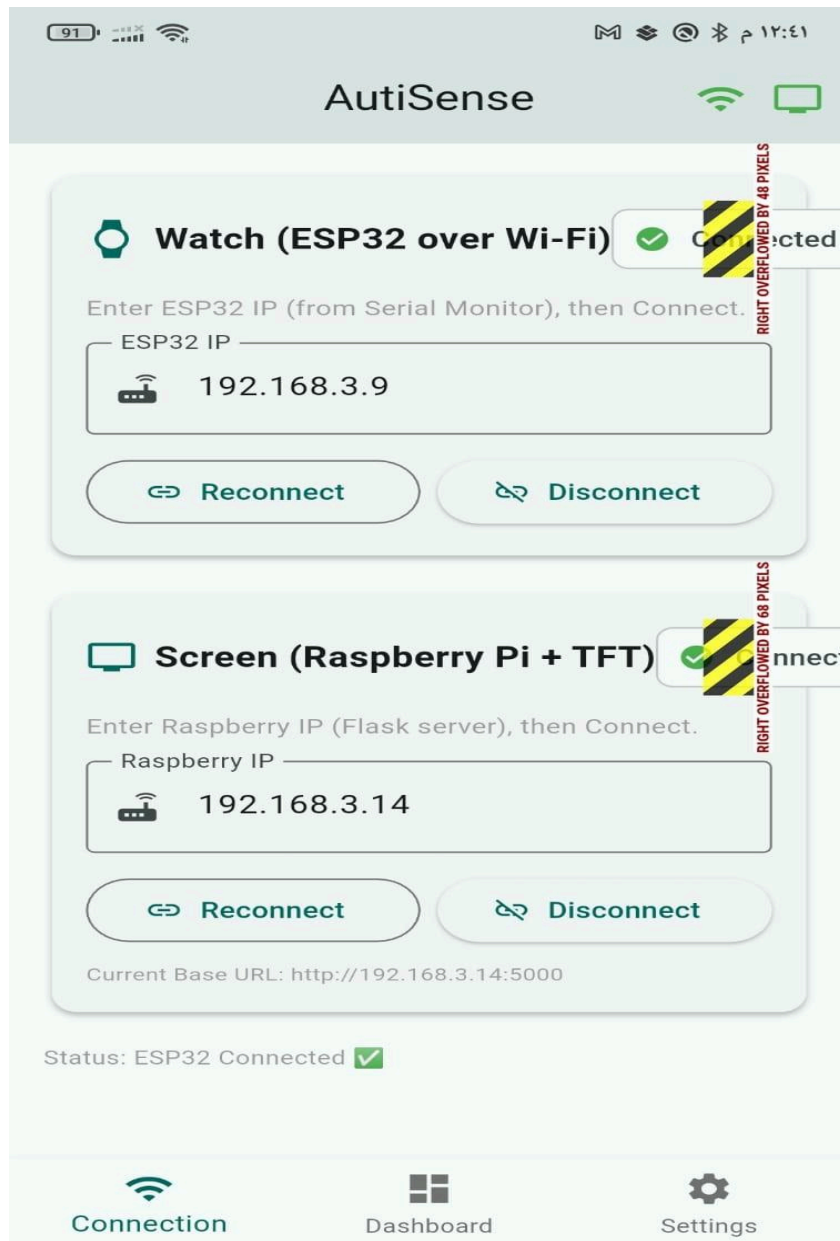
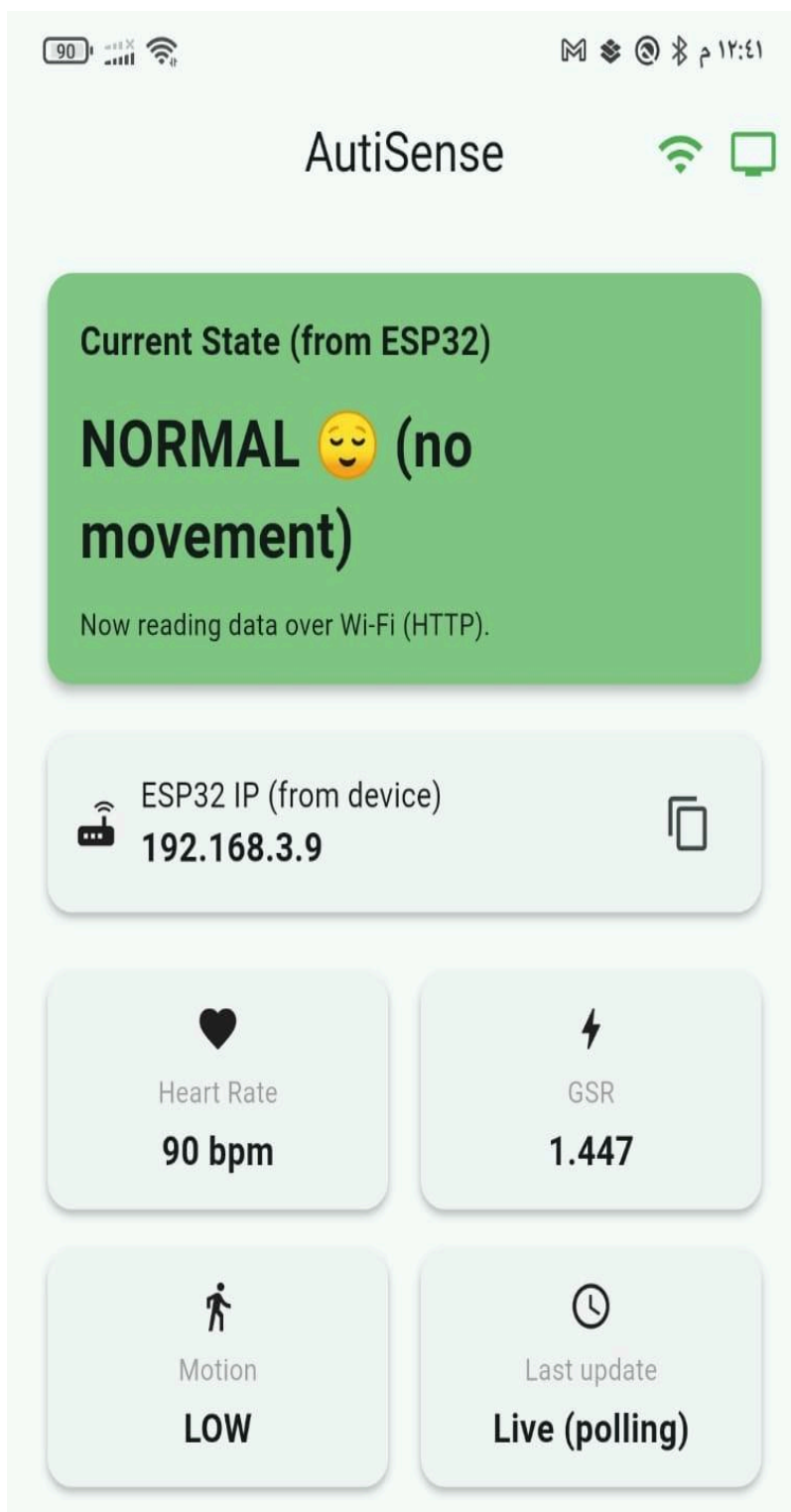
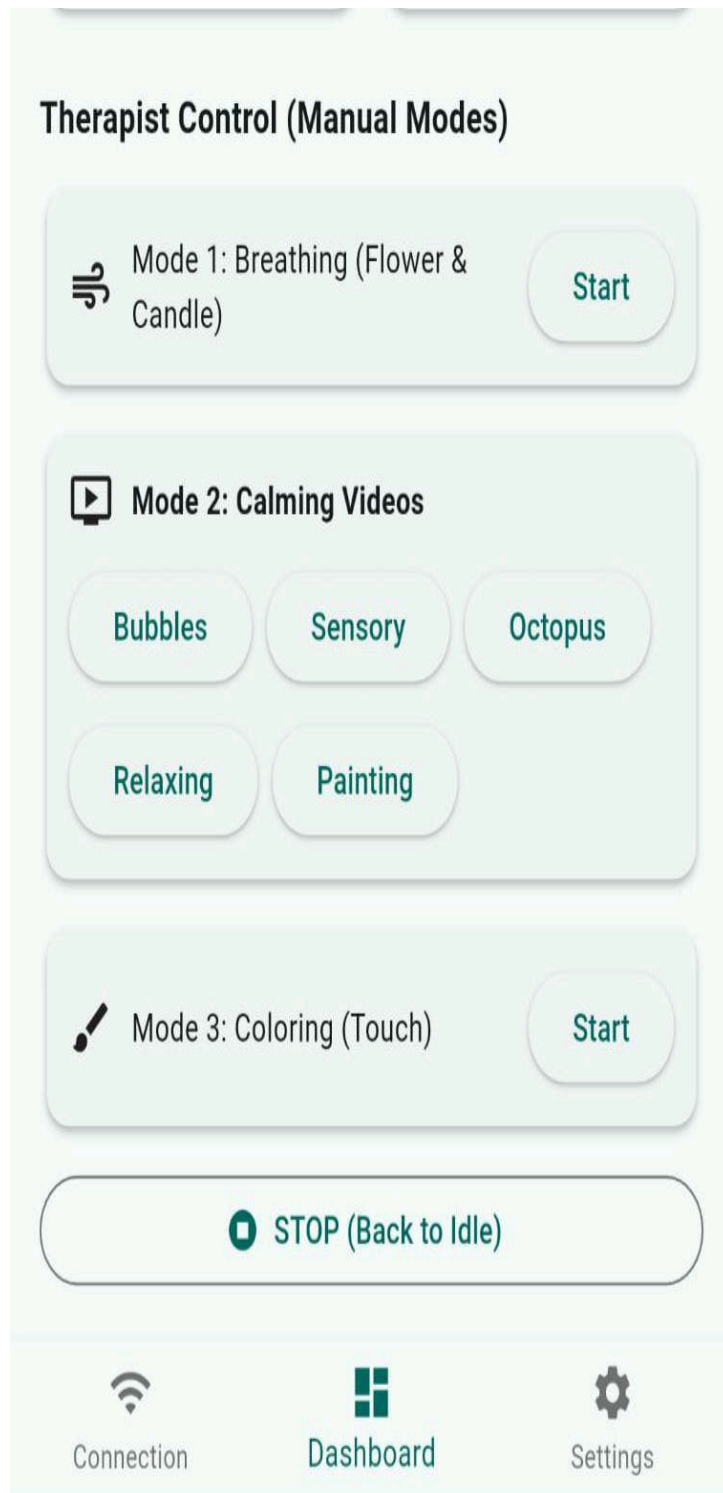


Figure A.1: Device Connection Setup Using IP Addresses



**Figure A.2: Real-Time Physiological Data Monitoring**



**Figure A.3: Calming Mode Selection Interface**

## Watch Timer (ESP32 over Wi-Fi)

Session duration (minutes)



➤ Send to ESP32 (/timer)

This sends POST /timer {"minutes": X} to ESP32.  
Make sure ESP32 is connected and IP is correct.

**Figure A.4: Manual Control of the NeoPixel Activity Timer**

# Appendix

## نموذج إقرار وتوثيق استخدام أدوات الذكاء الاصطناعي في مشروع التخرج

أسماء الطلبة : رغد درابيع , بتول شاهين	عنوان المشروع : AutiSense : Smart Assistant system for children with autism
الأرقام الجامعية : 237010 , 237008	اسم المشرف الأكاديمي : م. وائل التكروري
الكلية / الدائرة : كلية تكنولوجيا المعلومات و هندسة الحاسوب / دائرة هندسة الحاسوب	السنة/الفصل الدراسي : 2026/2025 / الفصل الاول

ملاحظات	نسبة الاستخدام التقديرية	هل تم تعديل الناتج؟	الأمر الأساسي المستخدم (Prompt)	أماكن الاستخدام في التقرير (فصول / صفحات)	اسم الأداة	الغرض من الاستخدام
تمت مراجعة النص وصياغته دون تغيير المحتوى.	3%	نعم	Review and improve writing of these project aims and objectives.	الفصل 1 ، صفحة 2	ChatGPT	توليد نصوص
	2%	نعم	Enhance clarity and readability of the following requirements while keeping all original ideas intact	الفصل 1 ، صفحة 2-3		
	2%	نعم	Review and enhance readability of these project constraints, keeping all content unchanged	الفصل 1 ، صفحة 4		
	4%	نعم	· Improve the wording of the testing preface and validation section to sound more academic, without changing the testing steps.	الفصل 5		

تدقيق لغوي كامل مع تعديلات طفيفة.	10%	نعم	—	كامل التقرير	Grammarly	تدقيق لغوي
تمت المراجعة للتأكد من بقاء الأفكار الأصلية	2%	نعم	Improve writing and wording the following problem statement	الفصل 1 , صفحة 1	ChatGPT	
	4%	نعم	Summarize the definition and classifications of Autism Spectrum Disorder (ASD) based on IDEA and DSM-5	الفصل 2 , 2.2. : 1 Definition and Classifications, صفحة 6-9 .	ChatGPT	تلخيص محتوى
تم تبسيط وشرح المفاهيم التقنية لتسهيل الفهم والقراءة مع الحفاظ على التفاصيل الأصلية.	2%	نعم	Enhance clarity and readability of technical explanations for stress detection logic without changing content	الفصل 3.3.1 , Stress Detection صفحة 22 , 23-.		
تم تلخيص وتوضيح البروتوكولات مع تبسيط الشرح لتسهيل الفهم والقراءة.	3%	نعم	Summarize and clarify communication protocols used (Wi-Fi, BLE ) for system integration without changing content	الفصل 3.3.2 , Communication Protocols. صفحة 23-24.		

تلخيص وتنظيم الفقرة.	%4	نعم	Summarize the hardware implementation section into 4–5 concise sentences while preserving all components and connections	الفصل 4		
—	—	—	—	—	—	تحليل بيانات
الاستخدام اقتصر على توليد الـ Sequence Diagram	%7	نعم	Code for Sequence Diagram	الفصل الثالث, صفحة 28	Plantuml	رسم مخططات / أشكال
	%3	نعم	Write ESP32 Arduino Telegram HTTPS notification code with URL encoding and cooldown.	In the code	ChatGPT	كتابة أكواد برمجية
	%3	نعم	“Create the AutoSense communication APIs: ESP32 endpoints (/health, /sensor JSON, /timer POST minutes) and Raspberry Pi Flask endpoints (/health, /set_mode). Keep stress-detection logic unchanged.	In the code	ChatGPT	
—	—	—	—	—	—	توثيق مراجع

## إقرار فريق مشروع التخرج:

نقر بأن استخدام أدوات الذكاء الاصطناعي تم بشكل مسؤول وبما يتوافق مع السياسات الجامعية، وقد راجعنا وحررنا كافة المخرجات بما يعكس فهمنا الشخصي.

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توقيع الطالب / الطلبة: رغد درابيع , بتول شاهين

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