Ellie's Adventures: A gamified application to enhance Communication, Emotional, Cognitive, and Motor skills in children with autism.

RP 24-25J-114

Project Proposal Report

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Declaration

I declare that this is my own work, and this proposal does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other university or Institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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Abstract

This research proposal outlines the development and implementation of an innovative, gamified approach to enhance motor skills in children with Autism Spectrum Disorder (ASD). The study leverages advanced digital technologies to create an interactive mobile application that integrates real-time feedback mechanisms within personalized learning environments. The application is designed to assess and improve both fine and gross motor skills through engaging, child-centric activities. The proposed system features two primary components: the first is a game aimed at enhancing gross motor skills, where children are assessed on their ability to mimic actions performed by an avatar. This component utilizes MediaPipe for real-time body landmark detection and Long Short-Term Memory (LSTM) networks to analyze and provide feedback based on the angles of the child's body joints. The second component focuses on fine motor skills through a LEGO block color pattern construction game, designed to improve pattern recognition and dexterity. This game employs OpenCV for image processing, and a Convolutional Neural Network (CNN) architecture developed with TensorFlow to accurately assess the child's performance in constructing the LEGO patterns. Additionally, the application incorporates a sensory-friendly design and employs cutting-edge software solutions to ensure a user-friendly and inclusive experience. This research proposes an innovative approach by providing real-time, adaptive feedback tailored to the child's motor skill development, thereby offering a significant contribution to the educational tools available for children with ASD.

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List of Abbreviations

Abbreviation	Description
ABA	Applied Behavior Analysis
AR	Augmented Reality
ASD	Autism Spectrum Disorder
CNN	Convolutional Neural Network
DS	Down Syndrome
LSTM	Long Short-Term Memory
ML	Machine Learning
UI	User Interface
UX	User Experience
VS	Visual Studio
WBS	Work Breakdown Structure

1. Introduction

1.1. Background and Literature Survey

The improvement of technological advancement and innovative educational practices has created remarkable opportunities concerning the fulfillment of the unique needs of children with various developmental disorders. The subject of the current research is centered on children with Autism Spectrum Disorder (ASD), a significantly impacted group by developmental challenges [1]. ASD is a neurological and developmental disorder that affects how people interact with others, communicate, learn, and behave [2].

Children with ASD often experience difficulty in their motor skills development. Past research has highlighted that many autistic children have difficulties with posture, coordination, and motor planning when considering both gross and fine motor skills [3]. Motor skill development depends on forming complex connections between various parts of the brain that link sensory information from the body with information from the environment. Early identification of these difficulties is crucial to address them through targeted approaches.

The use of technology in supporting the educational and developmental needs of children with ASD has gained significant attention in recent years. Various studies have explored the effectiveness of digital tools in enhancing cognitive and motor skills, providing personalized learning experiences, and fostering social interaction.

There is numerous research done on improving the motor skills of children with ASD. The development of a personalized and interactive learning platform is discussed in the research [1], focusing on enhancing both cognitive and motor skills. The platform focuses on improving speech-language abilities, cognitive behavior, social interaction skills, and physical conduct. In the area of improving physical behaviors, the research utilizes Augmented Reality (AR) technology to develop specialized mobile games that target improvements in manual-visual dexterity, hand-eye coordination, and motor planning. These games aim to enhance both fine and gross motor coordination.

The research [4], explores the integration of deep learning technologies in developing an educational mobile application aimed at fostering cognitive, speech, and motor skill development in children with disabilities. The research focuses on the disabilities of children with Down Syndrome (DS). Unlike previous studies that primarily addressed isolated areas, this solution incorporates engaging activities and personalized plans, generating reports for parents and therapists. Utilizing deep learning models within a sophisticated system architecture, the application aims to bridge the educational gap between children with DS and their typically developing peers, fostering inclusivity, and improving overall learning experiences.

The research discussed in [5] emphasizes the development of a tablet-based game software design specifically aimed at assessing motor skills in children with ASD, leveraging advancements in digital technology for early diagnosis. The software design is part of broader research and features a game where children drag moving images to target locations. By utilizing Unity 2D and C#, the software aims to quantitatively measure motor trajectories through engaging tasks that require hand-eye coordination and attentional skills, while also fostering pattern recognition skills through fine motor activity. The study emphasizes the significance of early detection of motor impairments as potential indicators of ASD, and advocates for integration of innovative assessment tools that detailed behavioral metrics, thereby facilitating timely interventions, and improving diagnostic accuracy in clinical settings.

1.2. Research Gap

There are plenty of research studies conducted to address the various challenges faced by children with ASD, aiming to enhance their overall development. When considering the motor skills, many applications have been developed to improve motor skills. Most applications were considering the improvement of fine motor skills. Research [1] and research [5] are such research that have been studied the development of applications to improve fine motor skills of children with ASD.

The integration of deep learning technologies in educational tools has been widely explored, particularly for enhancing motor skill development and promoting educational inclusion for children with various motor skill difficulties. For instance, the research 'A' [4] highlights the potential of a personalized learning environment driven by deep learning to support children with Down syndrome. This research emphasizes the adaptability of educational content to meet individual needs, highlighting the broader advantages of technology in special education. While the research provides valuable insights into motor skill development, it offers a limited exploration into the availability of diverse motor skill exercises specifically designed for children with motor skill difficulties, revealing a gap in research dedicated to physical skill enhancement. The research primarily addresses the enhancement of fine motor skills through a hand gesture recognition game and indirectly through a mathematical game aimed at improving cognitive skills, where the child demonstrates answers using their fingers [4].

Moreover, the role of real-time feedback in educational tools is recognized as essential for creating an adaptive learning experience. The research 'A' [4] primarily discusses post-activity analysis and adaptive learning based on cumulative data, with limited attention given to real-time feedback mechanisms that respond instantaneously to a child's actions during motor skill exercises. This gap indicates the need for further research into continuous feedback systems, especially those tailored for children with ASD. Incorporating principles from Applied Behavioral Analysis (ABA), including both positive and negative reinforcement, could significantly enhance the effectiveness of supporting the learning and motor skills development of children with ASD.

Additionally, the enhancement of pattern recognition skills, especially through gamified approaches, is underexplored in research 'A' [4]. While the cognitive benefits of using deep learning models for motor skill development are well-documented, the research provides minimal discussion on improving pattern recognition skills. Enhancing pattern recognition, a cognitive task, can significantly contribute to the development of problem-solving, planning, organizational skills, and spatial awareness. Interactive games, such as LEGO block pattern identification, offer a unique opportunity to develop these skills. This task requires the child to understand the spatial relationships between blocks, which not only strengthens cognitive abilities but also enhances fine motor skills through precise hand movements and coordination. Despite its potential, this area remains unexplored in the current research landscape.

The research 'B' [1], focuses on developing a comprehensive mobile application specifically designed for children with ASD, aiming to enhance their speech-language abilities, cognitive skills, social interactions, and physical conduct [1]. The application leverages interactive mobile games and AR technology to create a personalized and engaging learning environment that caters to the unique educational needs of autistic children. The application addresses both gross motor and fine motor skills including hand-eye coordination, dexterity, and general motor planning. Cognitive development is also targeted through puzzles, pattern recognition, and memory-based challenges. However, despite its focus on motor skills enhancement of autistic children, the research notably lacks the implementation of a real-time feedback system. Also, it emphasizes that it offers a limited variety of exercises. The pattern recognition aspect in the research is primarily addressed through a puzzle game, leaving a gap in exploring more dynamic activities. Therefore, introducing a LEGO color pattern identification game that integrates cognitive and motor skill development could provide a valuable and innovative contribution to this research area.

The research 'C' [5] focuses on the architecture and design of another game-based software. Aimed at collecting quantitative and automatic metrics to measure movement difficulties in children with ASD. Utilizing advanced technology, the software engages children in interactive activities while assessing their motor skills. The game involves dragging moving images onto target ones, using digital technologies to facilitate cognitive tasks, and capturing motor patterns through touch-screen interactions [5]. The study emphasizes the importance of visual learning

strategies for children with ASD and aims to enhance early diagnosis and intervention through quantitative assessments of motor and cognitive skills. Although the software effectively enhances pattern recognition and fine motor skills, it does not specifically address the improvement of gross motor skills, which may require different physical activities beyond the scope of the current game design. Additionally, the design does not explicitly mention real-time feedback mechanisms.

Fig. 1 depicts a comprehensive summary for the research gap analysis presented above.

SYSTEM	Various exercises available	Real-time feedback available	Enhancement of pattern recognition skills	Gamified approach
RESEARCH A	✗	✗	✗	✓
RESEARCH B	✗	✗	✓	✓
RESEARCH C	✗	✗	✓	✓
PROPOSED SYSTEM	✓	✓	✓	✓

Figure 1 Research Gap Analysis

1.3. Research Problem

According to the American Academy of Neurology and Child Neurology Society's definition of autism, 7.4% of children in a significant study carried out in Sri Lanka showed red flag symptoms. Furthermore, according to this study, one in ninety-three children in Sri Lanka is diagnosed with autism [6].

Autistic children often experience a delay in their motor skills development compared to normal children. So, the enhancement of motor skills in children with ASD remains a critical area of focus in educational and therapeutic interventions. It has been discovered that ASD is frequently characterized by a delay in the development of fine motor abilities, which is usually a stronger diagnostic indicator than gross motor skills [7]. So, it is essential to consider the improvement of both gross and fine motor skills of autistic children.

Although various digital platforms and mobile applications have been developed to support motor skills, these often lack the necessary personalization, real-time feedback, integration of both gross and fine motor skill tasks that are essential for children with ASD. Specifically, the challenge lies in creating an engaging and adaptive platform that not only helps children improve their gross motor skills but also integrates cognitive tasks which are associated with fine motor skills such as pattern recognition, which are vital for their overall development. Additionally, physical therapists are increasingly becoming integral members of the treatment team for children with ASD, particularly in addressing motor impairments [8]. The reliance on therapy centers for structured activities will lead to limited opportunities for autistic children to practice and enhance these skills at home.

So, the main problem that is being addressed by this research component is as below:

"The absence of a comprehensive, personalized, and adaptive digital solution that bridges the gap between therapy center and the home environment may limit the frequency and consistency of motor skill development in children with ASD, potentially hindering their overall development."

The following sub-problems have been identified based on the main problem to guide the development of a comprehensive solution:

1. How can we understand and measure a child's current motor skill abilities at home?
2. What criteria or milestones should we use to assess a child’s progress in motor skills?
3. What type of activities or games can be used at home to effectively improve the child's motor skills when considering both gross and fine motor skills?
4. What steps can be taken to help the child overcome these specific motor skill challenges at home?
5. How to provide the necessary guidance for the child to improve their motor skills?

Considering this challenge, the research intends to develop a comprehensive solution that bridges the gap between home and therapy centers for children with autism, with a particular focus on enhancing their motor skills.

By addressing the outlined sub-problems, this study seeks to develop an efficient and practical approach to evaluate and improve motor skills development in children with autism within the home environment. This will reduce the burden on parents while providing a consistent, personalized, and interactive platform that supports the developmental needs of autistic children, contributing to their overall development and quality of life.

2. Objectives

2.1. Main Objectives

The **main objective of the research** is to bridge the gap between home and therapy centers to make it easier for children with ASD to continue their therapy exercises and activities in a convenient environment under parental supervision.

The **main objective of the component** described in this report is to enhance the motor skills of children with ASD by engaging them in a series of games and activities that can be done comfortably at home, eliminating the need to wait for the next visit to the therapy center.

The mentioned objective will be realized through a **gamified mobile application** that features a 3D avatar as the primary communication agent between the child and the application. The focused area of this research component, which is the enhancement of motor skills of children with ASD is aimed to be achieved by two games.

The **first game** targets the enhancement of gross motor skills by having the child mimic various exercises performed by the avatar. The device camera will track the child's movements and the accuracy of them performing the particular exercise will be analyzed by comparing the angles of the posture. Based on the analysis, the child will be given real-time feedback on their performance, helping the child to make necessary adjustments. This interactive approach encourages physical activity while providing personalized guidance to support gross motor skill development.

The **second game** focuses on enhancing fine motor skills by having the child construct a simple color pattern given by the application using a set of LEGO blocks. The assembled blocks will be analyzed through the device camera to assess how accurately they match the given pattern. Feedback will be provided afterward, offering insights into the child's performance. This game promotes fine motor skill development through precise hand movements and coordination, while also improving pattern recognition and spatial awareness.

2.2. Specific Objectives

The above main objective will be achieved through the five sub-objectives below.

Train the model to identify the various actions performed by the child.

To accurately recognize and classify the various exercises or actions performed by the child, a Long Short-Term Memory (LSTM) model will be trained. The actions to be recognized by the model could include basic movements like raising one hand, raising both hands, extending the arms, standing on one leg, and so forth.

Evaluate the child's ability to mimic the given exercises correctly.

The accuracy of the action performed by the child will be assessed based on the prediction provided by the LSTM model. Then the angles between key body joints will be calculated to determine whether the child's posture aligns with the correct execution of the action. This ensures that both the overall action and the specific joint angles are evaluated to verify proper performance.

Provide real-time feedback and encouragement based on the performance.

Real-time feedback will be provided to the child during the exercise based on the evaluated data. This feedback will be generated by considering both the accuracy of the actions as predicted by the LSTM model and the analysis of joint angles to ensure correct posture. The feedback will include corrective suggestions and positive reinforcement, as well as constructive criticism, to support the child's progress and engagement.

Train the model to identify color segmentations and patterns.

A Convolutional Neural Network (CNN) will be trained to recognize and analyze color segmentations and patterns within the constructed LEGO block structures. The model will ensure accurate detection and evaluation of color patterns, thereby providing a foundation for assessing the pattern recognition skills of the child.

Evaluate the child's ability to create a given color pattern with a set of objects (LEGO blocks)

The accuracy of replicating the specified color pattern using LEGO blocks will be assessed by analyzing the constructed pattern through the device camera. The trained CNN model will be utilized to evaluate how well the given pattern is constructed. This approach ensures that the child's pattern recognition skills are precisely evaluated and that their fine motor skills are enhanced.

3. Methodology

3.1. System Architecture

Gamified Approach to Enhance Gross Motor Skills

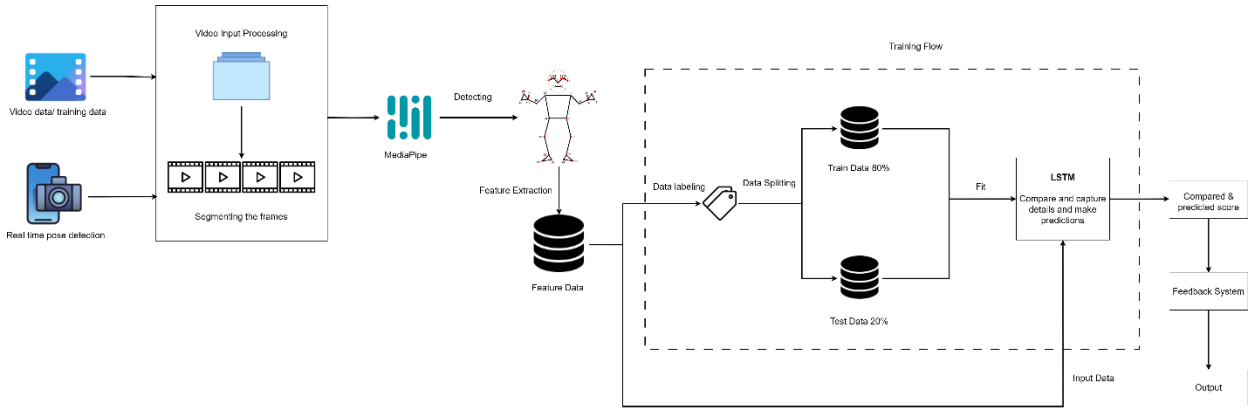

Figure 2 High-Level Architecture Diagram of Gross Motor Skills Game

Fig. 2 depicts the high-level architecture of the proposed solution for gross motor skills enhancement. Initially, the training data set will be taken from a set of videos where the children perform different actions. Then the video input will be segmented into frames and the pose body landmarks will be extracted through MediaPipe's Pose Landmarker library [9] and will be stored as feature data. Then the data will be labeled according to various activities and the LSTM model will be trained to give the correct predictions according to a sequence of movements.

To play the game the gross motor skill development game should be selected through the mobile application. It is advised to use the application under parental supervision. Then an avatar will be appeared in the screen and will perform certain exercises by encouraging the child to mimic the avatar. The video segments will be captured through the device's camera and the feature data will be extracted through MediaPipe. These data will be sent into the LSTM model as sequential data to analyze and predict if the action is performed correctly [4]. Then the prediction score received by the LSTM model will be inserted into the feedback system to generate real-time feedback considering the positive and negative reinforcement aspects of ABA [10] [11]. Furthermore, the angles between the key body joints will be compared to analyze whether the child performs the action correctly and feedback will be given if the angles are not as expected [4]. (E.g. If the child

is instructed to raise hands, but the child is not raising the hands enough, then the angles between the arm and the body will be calculated and analyzed to give feedback)

Gamified Approach to Enhance Fine Motor Skills

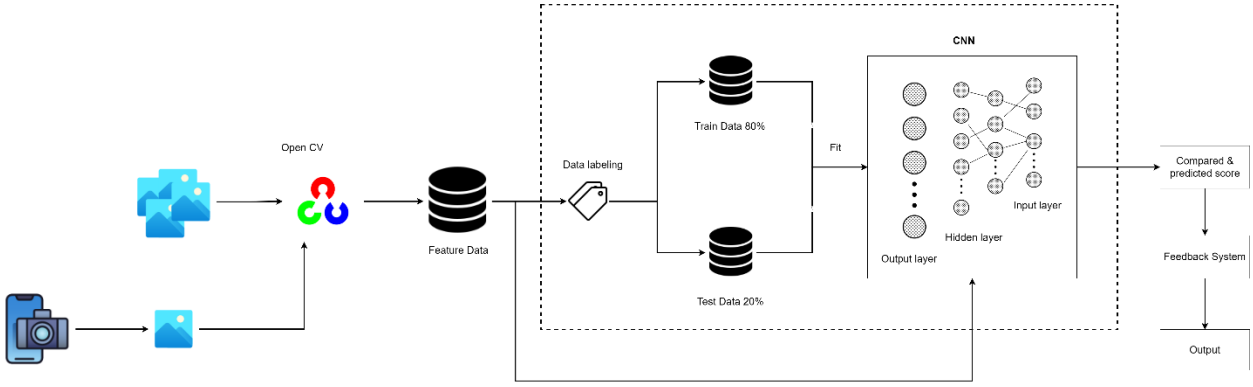

Figure 3 High-Level Architecture Diagram of Fine Motor Skills Game

Fig. 3 depicts the high-level architecture diagram of the fine motor skill enhancement game, designed to improve both pattern recognition and dexterity in autistic children. The process begins with training a Convolutional Neural Network (CNN) using a dataset of LEGO blocks featuring various color patterns. Once trained, CNN is used to recognize and classify these patterns considering spatial relationships [12].

During gameplay, the device camera continuously captures images of the LEGO structures built by the child in real time. These images are processed frame-by-frame using OpenCV [13]. For each frame, the preprocessing steps include color segmentation to distinguish between different colors, edge detection to outline the block shapes, and perspective correction to adjust for any distortions from the camera angle. This preprocessing ensures that each frame is optimized for accurate analysis. Once preprocessed, the images are fed into a TensorFlow model, which utilizes the trained CNN to classify the LEGO patterns. Based on the classification results, the system provides immediate feedback to the child, helping them improve their pattern recognition and fine motor skills.

Table 1Technologies, Techniques, and Algorithms to be used

Technologies	Flutter, Python, MediaPipe, OpenCV, TensorFlow, Firebase Database, VS code
Techniques	Feature extraction and segmentation, Image pre-processing, Data labeling
Algorithms	LSTM, CNN

3.1.1. Software Solution

Customized and Personalized UI/UX

Customization and personalization of user interface (UI) and user experience (UX) are essential addressing the unique needs of children with autism. Tailoring the interface to align with their specific preferences enables children to interact with the software more effectively and enjoyably. Personalized UX creates a more engaging and user-friendly environment, which helps maintain the child's attention and ensures that the learning experience is both enjoyable and beneficial. Furthermore, this approach allows parents and therapists to adjust the platform to fit the individual needs and preferences of each child.

Sensory-Friendly Design

A sensory-friendly design prioritizes creating an environment that reduces sensory overload, which is especially beneficial for children with autism. It involves a thoughtful selection of color palettes, sound levels, and visual elements to ensure they are calming rather than overwhelming. The goal is to minimize distractions and foster a soothing atmosphere, thereby helping children concentrate on their tasks more effectively. By incorporating sensory-friendly features, the application becomes more inclusive and user-friendly, enabling children to engage with the content comfortably without becoming overwhelmed.

Google Confidential Computing [14]

Google Confidential Computing is a security technology designed to keep data encrypted even while it is being processed in the cloud. This technology is particularly important for applications that handle sensitive information, such as data related to children, where privacy and security are critical. By employing this technology, the application can ensure that personal information, including speech and language data, remains protected from unauthorized access. This capability not only fosters user trust but also ensures compliance with strict data protection regulations.

Multi-Tenant Encrypted Storage

Multi-tenant encrypted storage is a secure storage solution that enables multiple users or tenants to store their data within the same system while ensuring that each tenant's data remains isolated and encrypted. This is especially crucial in systems designed for children with autism, as it facilitates the secure management of personalized information for various users, such as different families or therapy centers. By employing encrypted storage, the system protects sensitive data, maintaining both data integrity and confidentiality across all user accounts.

Layered Client-Server Architecture

A layered client-server architecture organizes an application's functionality into distinct layers, such as the presentation layer, application layer, and data layer. This architectural approach promotes enhanced scalability, maintainability, and flexibility. For applications designed for children with autism, this architecture ensures efficient communication between the client (UI) and the server (where the data is processed). It supports the handling of numerous users and substantial data volumes, providing a responsive and dependable user experience.

Deploy as a Distributed System

Deploying the application as a distributed system involves running it across multiple servers or machines instead of relying on a single server. This method enhances the system's reliability, scalability, and performance. For a platform focused on supporting the motor skills development of children with autism, distributed deployment ensures the application can efficiently manage high volumes of data input and processing. It provides a smooth experience even as the user base expands and offers improved fault tolerance, minimizing downtime and ensuring continuous availability.

Unit Testing in Flutter with Flutter Test

Unit testing plays a vital role in the development process by validating that individual components of an application operate as intended. With flutter_test, developers can automate tests for Flutter applications to ensure each segment of the code performs correctly. This is especially important for educational apps, where reliable and precise functionality is critical for effective learning. Implementing unit testing allows developers to detect and resolve issues early, resulting in a more stable application.

Linting Code Using Tools Such as Dart Linting for Flutter and PyLint for Python

Linting involves examining code to detect potential errors, bugs, or deviations from coding standards. Tools such as Dart Lint for Flutter and PyLint for Python assist developers in upholding high code quality by enforcing best practices and catching issues early. For projects focused on improving motor skills in children with autism, employing these linting tools ensures that the codebase remains clean, efficient, and less susceptible to errors. This practice enhances the software's robustness and maintainability, ensuring its continued functionality and adaptability over time.

3.1.2. Commercialization

Two subscription plans are offered as FREE and PREMIUM to cater the different user needs, considering the application’s commercialization. The application's fundamental functions, including limited real-time feedback, are offered to families without any financial commitment through the FREE plan, which lets them test out the main features. The plan is ideal for customers who are just beginning to use the platform and would like to learn about its advantages before committing any money. The PREMIUM plan, with a cost of LKR 4000, grants unlimited access to all the functions of the application. This includes more personalized feedback, which can foster the learning experience of the child. The premium plan is ideal for families and therapy centers looking for a more comprehensive tool to support the overall development of children with autism. Additionally, the subscription of PREMIUM plan contributes to the advanced maintenance of the application to remain an outstanding tool used in ASD therapy.

4. Project Requirements and Design

4.1. Functional Requirements

I. The system should accurately detect whether the child has performed the given exercises correctly

II. The system should provide real-time feedback based on the child's performance.

III. The system should employ a trained model to assess whether the child has successfully created the specified color pattern.

IV. The games should be designed with minimal distractions, creating a focused and engaging environment that sustains the child's attention and maximizes the effectiveness of the exercises.

4.2. Non-Functional Requirements

I. The interfaces should be user-friendly, with adaptability to meet the specific needs of each child, ensuring ease of use and enhancing engagement

II. The action recognition system should operate with high efficiency, processing the child's movements quickly to provide timely and accurate feedbacks.

III. The system should be reliable, ensuring consistent accuracy in recognizing exercises and correctly identifying color patterns.

IV. The design of the interfaces should prioritize simplicity and adaptability, tailored to the child's requirements to foster a comfortable and engaging user experience.

4.3. System Requirements

I. A device with a camera

II. Adequate storage and memory to support the application.

III. The system should be compatible with major operating systems.

IV. Dependencies - relevant ML libraries and game development tools.

V. A strong network connection to set up and update.

4.4. Personnel Requirements

The mobile application will be designed specifically for children with Autism who experience challenges in motor skills development. The games within the app are intended to be played under the supervision of parents or caregivers, with their full consent. The research will be supported by data and resources supplied by the primary external supervisor, aligned with the specific research requirements.

4.5. Design (System and Software design documents)

4.5.1. Use Case Diagram

4.5.2. User Interface Designs

Figure 4 User Interface Designs of Ellie's Adventures

5. Gantt Chart

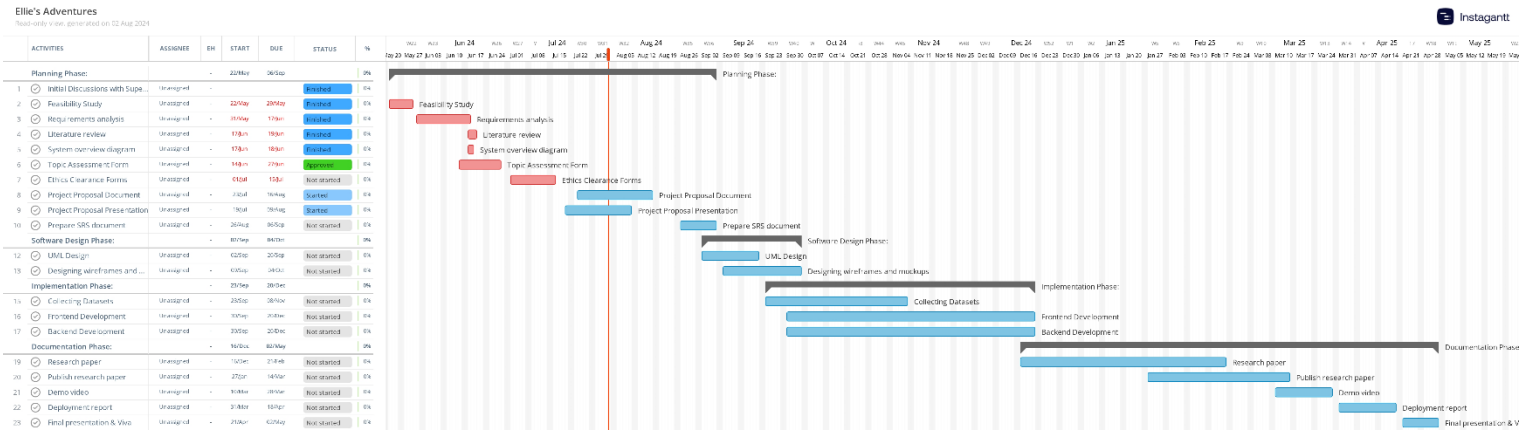

Figure 5 Gantt Chart

5.1. Work Breakdown Structure (WBS)

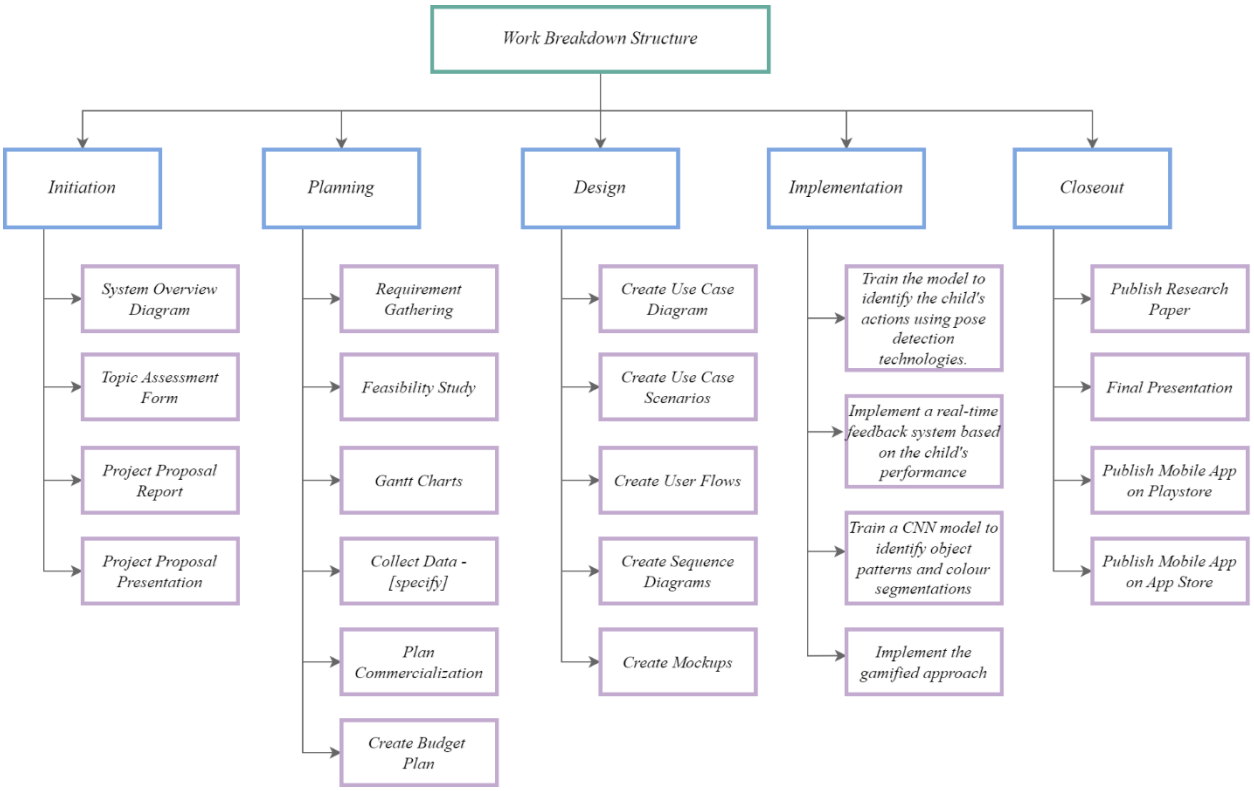

Figure 6 Work Breakdown Structure

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Appendices

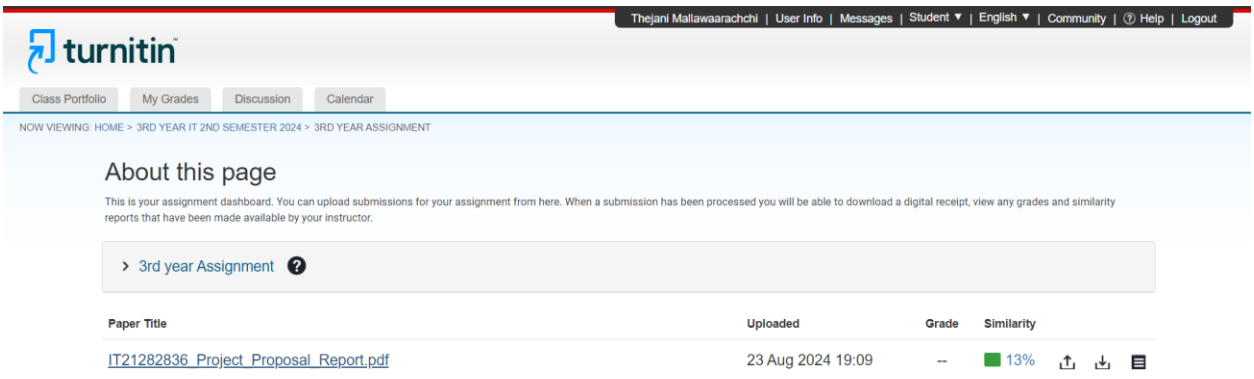

Figure 7 Plagiarism Report