INTERNATIONAL JOURNAL OF RESEARCH AND INNOVATION IN SOCIAL SCIENCE (IJRISS)
ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue X October 2025

AISTY: An Explainable AI-Driven Vision-Based Adaptive Learning System for Children with Autism Spectrum Disorder

Muhammad Rifqi Zakirin Rofidi, Siti Azirah Asmai*, Muhammad Hafidz Fazli Md Fauadi, Nur Diana Izzani Masdzarif, Abdul Syukor Mohamad Jaya

Fakulti Kecerdasan Buatan dan Keselamatan Siber, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia

DOI: https://dx.doi.org/10.47772/IJRISS.2025.910000394

Received: 12 October 2025; Accepted: 20 October 2025; Published: 13 November 2025

ABSTRACT

The educational needs of children with autism spectrum disorder (ASD) require individualized approaches because they face major difficulties with communication and social skills and learning processes. The diverse requirements of children with ASD remain unmet by conventional educational approaches because these methods fail to provide suitable flexibility and expandability. The research develops Adaptive Interface System for Tracking Engagement (AISTY) as an explainable AI-based learning module which solves the current educational needs of children with ASD. The system AISTY uses computer vision to track behavioural data through real-time analysis while delivering interactive learning content that adjusts to student needs. The system uses a custom Convolutional Neural Network (CNN) model to analyse facial expressions for engagement and emotional state classification (Happy, Sad, Neutral, Surprise, Fear, Angry, Disgust) with 78% accuracy while operating at 14-16 frames per second on typical computer equipment. The system contains three learning modules (Mathematics, Sing-Along, and Mini-Games) which modify their content according to the child's current state. The system includes an explainable AI (XAI) dashboard that uses SHAP-inspired visualizations to show caregivers exactly what elements influence the system's adaptation decisions. The usability assessment with parents and a special education teacher validated the system's operational capabilities and user-friendly interface and confirmed its worth. The research shows AISTY offers a flexible autism education system which proves that explainable adaptive AI can be effectively used in special needs education to boost student participation and academic success.

Keywords- autism spectrum disorder (ASD), Artificial Intelligence, Computer Vision, Adaptive Learning, Emotion Recognition, Educational Technology**.**

INTRODUCTION

The neurodevelopmental disorder autism spectrum disorder (ASD) presents as a complex condition which affects social communication and interaction and causes restricted behavioral patterns and interests [1]. The World Health Organization reports that ASD affects 1 in 100 children worldwide based on recent global prevalence data [2]. The growing number of children with ASD requires immediate development of effective accessible intervention methods which can scale to meet the rising demand. The official ASD prevalence in Malaysia remains low because of under-diagnosis and restricted access to specialized care which demonstrates an urgent requirement for new intervention methods [3].

Children with ASD face exceptional difficulties in their educational environment. The learning abilities of ASD children differ widely because some excel at visual processing, but others face challenges with verbal skills and sensory sensitivity [4]. Standard educational methods that use uniform approaches create student disengagement which results in negative emotional responses and poor academic achievement. The most effective intervention method requires individualized programming which uses structured methods to adjust its content based on the child's changing attention span and emotional state [5]. The delivery of customized support to children requires extensive resources because it needs ongoing professional monitoring from trained therapists and caregivers, yet these resources are scarce due to financial and practical limitations.

Artificial Intelligence through its computer vision and machine learning subfields brings a revolutionary change to current practices[6]. AI systems track children's behavior through webcam video analysis to detect facial expressions and body movements which helps identify their level of engagement and emotional state [6]. The system uses real-time data to modify digital learning content which results in an individualized educational experience. The system detects rising frustration through its monitoring system which then provides easier tasks and relaxation activities for the child.

AI systems face challenges in healthcare and educational settings because their decision-making processes remain unclear to users. The lack of transparency in AI decision-making systems makes therapists and caregivers uncertain about following system recommendations [7]. Explainable AI (XAI) provides solutions to this problem through its ability to reveal AI decision-making processes in an understandable manner. The system uses XAI to display its reasoning about child disengagement through specific metrics which show 75% gaze aversion and 25% slumped posture.

The research presents the comprehensive development of AISTY, an innovative system that integrates AI technology with vision-based student tracking, adaptive learning content, and a transparent analytics dashboard. This study moves beyond conventional predictive approaches by developing an educational tool capable of providing clear and explainable outputs that enhance trust and support effective learning for children with autism spectrum disorder (ASD).

The objectives of the research are threefold: (1) to investigate and implement neural network models for real-time emotion and engagement recognition; (2) to design a user-friendly, sensory-aware system tailored for children with ASD and their caregivers; and (3) to develop and integrate an interactive learning platform featuring adaptive learning modules and continuous progress monitoring.

LITERATURE REVIEW

Autism Education and Technology

The educational approach for ASD students has traditionally relied on structured evidence-based methods. The learning principles of Applied Behavior Analysis (ABA) help professionals develop specific behaviors through Discrete Trial Training (DTT) [8]. The TEACCH (Treatment and Education of Autistic and related Communication handicapped Children) method provides structure through physical organization and visual schedules and work systems [9]. The SCERTS model among developmental approaches focuses on three main areas which include Social Communication and Emotional Regulation and Transactional Support [10].

The methods show effectiveness, yet they need human professionals for implementation and face difficulties when trying to expand their reach. The methods depend on periodic human observation for assessment, yet they fail to detect the small changes that occur in a child's state during the moment. The current situation requires technology to fill the void by offering continuous objective measurement and intervention capabilities.

AI and Computer Vision in Behavioral Analysis

The development of assistive technologies for ASD has received a transformative boost from artificial intelligence technology. Machine learning algorithms detect intricate patterns in data which human observers cannot detect.

Multiple research studies have employed AI systems to evaluate behavioral information for identifying children at risk of developing ASD. Bone et al. [11] created predictive models which achieved 81% accuracy through their analysis of initial behavioral indicators.

The use of computer vision technology allows for unobtrusive ongoing observation of behavior. The research by Yujian Cai et al. [12] achieved 87.31% accuracy in emotion detection through facial expression analysis. Goodwin et al. [13] implemented movement analysis algorithms to measure motor stereotypies (hand-flapping) through quantitative methods which replaced traditional clinical assessment methods.

The research by Seyderhelm et al. [14] presented systems which use real-time performance metrics to adjust task difficulty levels dynamically. The system maintains an optimal learning zone through performance-based adjustments which prevent child frustration.

The current systems face a common problem because they concentrate on individual features such as emotion detection or fixed games. The AISTY platform functions as a complete system which combines ongoing behavioral assessment with various adaptive educational content.

Adaptive Learning Systems

The combination of artificial intelligence with pedagogical design principles leads to the development of adaptive learning systems. The system modifies its content level and presentation format and learning speed through ongoing evaluations of student performance and emotional state. The ability of adaptive systems to adjust their operations helps ASD children control their anxiety while keeping them actively involved in learning. The current frameworks use rule-based systems and reinforcement learning to activate interventions through agitation detection which results in task simplification and break provision [8]. The adaptive logic of AISTY operates through real-time vision-based child state assessment to determine its actions.

METHODOLOGY

Research Design

This research project implemented Design Science Research (DSR) as its methodology to develop and assess new artifacts which solve specific problems. The development process followed an iterative agile structure which divided into two-week sprints. The system integration process received continuous testing and refinement of its AI model and modules and user interface components throughout each development cycle. The system design followed User-Centered Design principles which used ASD-friendly interface research to create initial design principles that later received validation through user testing.

System Architecture Overview

The system operates with a client-server structure but performs essential processing tasks on the client-side for both privacy protection and immediate system response. The system uses Python's CustomTkinter (CTkinter) library to create its frontend which provides a sensory-friendly graphical user interface through muted color schemes and high-contrast text and organized uncluttered layouts. The Python-based Backend (Client) section runs the core AI logic which performs video processing and model inference and module adaptation tasks in real-time. The cloud-based NoSQL database Google's Firebase Firebase operates as the database system to store anonymized session information and progress metrics and analytics data for both longitudinal tracking and cross-device access. The architecture of AISTY operates at a high level as shown in Figure 1. The system architecture diagram shows Webcam data entering OpenCV/MediaPipe Preprocessing which then feeds into the Custom CNN Model and Engagement Logic Engine and Adaptive Modules and Firebase and XAI Dashboard.

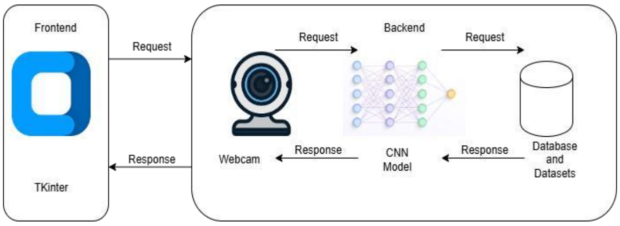

Fig. 1 System architecture

Data Acquisition

The emotion recognition CNN received its initial training from the FER2013 dataset which contains more than 35,000 grayscale face images with seven emotional labels. The model received additional training through a

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue X October 2025

smaller dataset of child facial expressions which researchers obtained from open-source repositories. The model received data augmentation through rotation and zoom and shear and horizontal flip operations to boost its performance and reduce overfitting.

AI Model Development

The AI model was developed using a sequential Convolutional Neural Network (CNN) architecture implemented through TensorFlow and Keras. The system was designed to balance accuracy and processing speed, enabling efficient real-time performance. To interpret user behaviour, an engagement logic engine was integrated, employing a rule-based state machine to process raw emotion classifications and determine the overall engagement state. Focused engagement is detected when users display happy or neutral emotions while maintaining their head position within a yaw range of –15° to +15° and a pitch range of –20° to +20°. Distraction is identified when neutral emotions coincide with head movements away from the screen or when users' hands obstruct the camera view. Meanwhile, agitation is recognised when users exhibit angry, sad, or fearful emotions with high confidence levels, or when neutral emotions are accompanied by gestures such as covering the face with their hands.

Development of Learning Modules

The system contains three interactive modules which share a common base class to maintain uniform integration with the monitoring and adaptation system. The system produces adaptive math problems through addition and subtraction operations. The system adjusts difficulty levels through number range modifications based on user performance results. The system provides visual feedback and maintains a scoring system. The system shows a "conceptual help" prompt after detecting extended periods of agitation from the user. The system recommends the Sing-Along Module to users when their engagement state reaches 'Agitated' according to the logic engine. Mini-Game Module contains three educational games which help users develop their cognitive abilities. Tetris serves as a visual-spatial reasoning and planning tool. The game features an "Infinite Mode" which eliminates game-ending situations to help players relax. The game Tic-Tac-Toe helps users develop basic strategic thinking abilities and theory of mind skills. The game includes an AI opponent which operates based on predefined rules. The Memory Game helps users improve their short-term memory and concentration abilities.

Explainable Analytics Dashboard

The dashboard system enables caregivers to access two levels of explanation through its interface. The session analytics section of the dashboard displays emotion and engagement patterns through line and bar charts generated by matplotlib for a single session. The system displays decision rationales through a simplified interface which shows SHAP-inspired factors that led to system actions such as "Suggested a break." The system displays two factors which explain the decision: 'Frustration' score at 70% and gaze aversion at 30%.

Evaluation Strategy

The trained CNN model achieved evaluation through standard metrics on 890 test images which included Accuracy and Precision and Recall and F1-Score.

The system underwent usability testing with five participants who included four parents of neurodiverse children and one special education teacher with experience. The system received feedback about its interface and responsiveness and analytics usefulness through participant interviews and System Usability Scale (SUS) assessments.

RESULTS

AI Model Performance

The custom CNN model reached a total test set accuracy of 78%. The model achieved its best results when detecting 'Happy' and 'Neutral' emotions but showed poor performance in identifying 'Disgust' and 'Fear'

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue X October 2025

emotions according to Table I. The model performed well in detecting 'Happy' and 'Neutral' emotions but failed to recognize 'Disgust' and 'Fear' expressions which matches previous research findings about expression recognition difficulties caused by unbalanced data and overlapping expression meanings.

Table I Emotion Recognition Model Performance Metrics

Emotion Class	Precision (%)	Recall (%)	F1-Score (%)	No. of samples
Happy	84.5	82.5	83.5	150
Sad	79.5	82.1	80.8	300
Neutral	81.0	79.2	80.1	145
Surprise	73.2	70.8	72.0	80
Fear	71.5	72.3	71.9	65
Angry	75.1	73.0	74.0	100
Disgust	64.8	65.6	65.2	50

In terms of real-time performance, the integrated system consistently processed video feeds at 14-16 frames per second (FPS) on the target hardware (Intel i5 CPU, 8GB RAM, integrated graphics), ensuring a fluid and responsive user experience.

System Usability and Functional Testing

The usability study yielded highly positive feedback. The System Usability Scale (SUS) score averaged **82.5**, which falls in the "excellent" range. Key qualitative findings are summarized in Table II.

Table Ii Summary of Usability Testing Feedback

System component	User Feedback Summary	Implication
Overall GUI & Interface	"Clean," "intuitive," "not overwhelming," "the colors are calming."	The sensory-friendly UCD approach was successful
Mathematics Module	“The structure is good for my child” “Immediate feedback helps” “Simple math for appropriate age”	The module's design aligns with the need for predictable, structured activities for children with ASD
Sing-Along Module	“This is perfect for calming down” “Great for transitions between activities.”	Validates the module's use as a tool for emotional regulation
Mini-Games Module	“My child was engaged for a long time”	The games are effective at maintaining interest and providing engaging cognitive training
Analytics Dashboard	“My child was engaged for a long time” “I can see exactly when he started to get	The explainable analytics empower caregivers with actionable insights, building trust

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue X October 2025

	frustrated” “Helps me understand what to work on”	in the system.
Adaptation System	“The break suggestion popped up at the right time” “Auto-adjusting math difficulty”	The rule-based logic is functionally correct, but there is a clear demand for more sophisticated, AI-driven adaptation

The system's core adaptive functionality was confirmed during testing. The rule-based engine successfully triggered on-screen suggestions (e.g., "Let's take a break and sing a song!") when the 'Agitated' state was detected, and these interventions were perceived as timely and appropriate by the users.

DISCUSSION

The AISTY development process together with evaluation results demonstrate that it is possible to build an integrated AI system which provides explainable solutions for autism education. The 78% model accuracy demonstrates strong performance for real-time applications although it presents opportunities for enhancement which establishes a solid base. The system demonstrates exceptional performance in detecting 'Happy' and 'Neutral' states because identifying positive engagement versus negative or distressed states represents the essential function for triggering adaptive responses.

The project design philosophy received strong positive feedback from users which confirms the project's success. The success of the sensory-friendly interface demonstrates how User-Centered Design (UCD) methods create essential tools for neurodiverse users. The analytics dashboard received praise from users because it provides transparent information which represents a vital success element that most AI interventions lack. AISTY becomes an active educational partner for caregivers through its explainable insights which build trust and supports data-driven decisions beyond application.

The research study demonstrates multiple areas for future development through its identified limitations. The model demonstrates poor performance when detecting 'Disgust' emotions and other rare feelings because it requires access to bigger ASD-specific datasets with diverse content. The current rule-based adaptation system operates effectively but it maintains basic functionality. The research direction toward developing a reinforcement learning (RL) agent for personalized intervention strategy learning matches user requests for advanced adaptation features.

The design of AISTY stands out because it uses Firebase for tracking children's development over time. The system allows future interventions to use long-term child development patterns for creating customized learning paths.

CONCLUSIONS

This research has developed AISTY, an AI-driven, vision-based adaptive learning system designed to support children with Autism Spectrum Disorder (ASD). By employing a real-time vision-based AI pipeline powered by a Convolutional Neural Network (CNN) model, AISTY is able to provide responsive and personalized learning experiences. The system integrates facial expression and emotion state classification to offer an analytics dashboard that provides transparent insights to caregivers and teachers, thereby fostering trust and facilitating informed, personalized interventions.

While the proposed AI-assisted emotion recognition system achieved promising preliminary results with 78% accuracy, several limitations should be acknowledged. The reliance on webcam-based facial analysis may not adequately capture the nuanced emotional cues of children with ASD, particularly those with atypical gaze or reduced facial expression. Furthermore, the absence of a longitudinal design restricts the understanding of sustained learning outcomes and behavioral adaptation. Future research will address these limitations by incorporating multimodal data sources, benchmarking against established assistive technologies, and conducting longitudinal studies to evaluate long-term educational impact.

Overall, the development and evaluation of AISTY highlights the use of AI-driven educational technologies for special needs learners can be both scalable and dependable. This study contributes not only a functional proof-of-concept but also a flexible framework that unites technical rigour with user-centred design and explainable AI principles, advancing the vision of inclusive and transparent intelligent learning environments.

ACKNOWLEDGMENT

The authors would like to thank the Faculty of Artificial Intelligence and Cyber Security(FAIX), Universiti Teknikal Malaysia Melaka (UTeM) for their assistance in this research.

REFERENCES

1. Martínez-González, A.E., Cervin, M. and Piqueras, J.A., (2022). Relationships between emotion regulation, social communication and repetitive behaviors in autism spectrum disorder. Journal of autism and developmental disorders, 52(10), pp.4519-4527.
2. World Health Organization: WHO. (2023), November 15). Autism. https://www.who.int/news-room/fact-sheets/detail/autism-spectrum-disorders
3. Jiar, Y.K., (2014). Factors Associated with Diagnosis of Autism Spectrum Disorder (ASD) under the Age of 24 Months in Malaysia. Sains Humanika, 2(1).
4. Lei, J., & Ventola, P. (2017). Pivotal response treatment for autism spectrum disorder: current perspectives. Neuropsychiatric Disease and Treatment, Volume 13, 1613–1626.
5. Lindroth, H., Nalaie, K., Raghu, R., Ayala, I.N., Busch, C., Bhattacharyya, A., Moreno Franco, P., Diedrich, D.A., Pickering, B.W. and Herasevich, V., (2024). Applied artificial intelligence in healthcare: a review of computer vision technology application in hospital settings. Journal of Imaging, 10(4), p.81.
6. Ahmmad, J., Al-Dayel, O.A., Khan, M.A. and Mahmood, T., (2025). AI-assisted technology optimization in disability support systems using fuzzy rough MABAC decision-making. Scientific Reports, 15(1), p.18335.
7. Hulsen, T., (2023). Explainable artificial intelligence (XAI): concepts and challenges in healthcare. Ai, 4(3), pp.652-666.
8. Gitimoghaddam, M., Chichkine, N., McArthur, L., Sangha, S.S. and Symington, V., (2022). Applied behavior analysis in children and youth with autism spectrum disorders: a scoping review. Perspectives on behavior science, 45(3), pp.521-557
Schopler, E. and Van Bourgondien, M.E., (2020). Treatment and Education of Autistic and Related Communication Children. In Autistic adults at Bittersweet Farms (pp. 85-94). Routledge.
9. Yu, L. and Zhu, X., (2018). Effectiveness of a SCERTS model-based intervention for children with autism spectrum disorder (ASD) in Hong Kong: A pilot study. Journal of Autism and Developmental Disorders, 48(11), pp.3794-3807.
10. Bone, C., Simmonds-Buckley, M., Thwaites, R., Sandford, D., Merzhvynska, M., Rubel, J., Deisenhofer, A., Lutz, W., & Delgadillo, J. (2021). Dynamic prediction of psychological treatment outcomes: development and validation of a prediction model using routinely collected symptom data. The Lancet Digital Health, 3(4), e231–e240. https://doi.org/10.1016/s2589-7500(21)00018-2
11. Cai, Y., Li, X., & Li, J. (2023). Emotion recognition using different sensors, emotion models, methods and datasets: A Comprehensive review. Sensors, 23(5), 2455. https://doi.org/10.3390/s23052455
12. Goodwin, M.S., Intille, S.S., Albinali, F. and Velicer, W.F., (2011). Automated detection of stereotypical motor movements. Journal of autism and developmental disorders, 41(6), pp.770-782. 1-12. Seyderhelm, A.J. and Blackmore, K., 2021. Quantifying in-game task difficulty using real-time cognitive load.