

# An Integrated AI and IoT Framework for Early Autism Screening and Personalized Drug Delivery Management

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**Abstract** - One of the most significant factors in unlocking the potential of children with Autism Spectrum Disorder (ASD) is the early identification of the disorder. Historically, conventional screening techniques have depended to a great extent on subjective observations and the administration of standardized questionnaires, which could delay diagnosis and also restrict the accessibility of these assessments. The present study suggests an AI based early autism screening system that is capable of performing facial expression analysis, eye contact detection, and head movement assessment along with IoT, based monitoring. Continuous real, time video data of the individual to be screened are captured through a camera module and then processed with the help of deep learning models to identify and extract behavioral features that are indicative of autism risk. Actually, these features are sent to an embedded system and then visualized on a remote IoT platform, thus allowing a non, invasive, low, cost, and portable method of screening. The result of the experiment shows that the system indeed provides consistent, automated behavioral analysis, decreases the necessity for manual screening, and henceforth supports the identification of the risk at an early stage. The framework is intended to support the caregivers and healthcare professionals in making timely intervention plans, thereby offering a solution that is easily scalable in home and community healthcare settings.

**Keywords** - Autism Spectrum Disorder, AI, Facial Expression Analysis, Eye Contact Detection, IoT, Embedded Systems, Early Screening.

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## I. INTRODUCTION

Autism Spectrum Disorder (ASD) is a neurodevelopmental condition marked by deficits in social interaction, communication, and repetitive behaviors [1]. Early signs of ASD often include reduced eye contact, atypical facial expressions, and abnormal head movement patterns, which can significantly affect cognitive and social development if not addressed promptly [2]. Timely detection and intervention are therefore critical for improving long-term developmental outcomes. Traditional screening approaches rely on clinician-led behavioral assessments and structured questionnaires, such as the Modified Checklist for Autism in Toddlers (M-CHAT). While widely used, these methods are time-consuming, subjective, and require trained specialists, limiting accessibility in rural or resource-constrained areas [3]. Delays in diagnosis can postpone early intervention, which is crucial during sensitive developmental periods. Recent advances in computer vision and deep learning have enabled automated behavioral analysis for ASD detection. Convolutional Neural Networks (CNNs) and other deep learning models have demonstrated high accuracy in analyzing facial expressions, head pose estimation, and eye gaze patterns, providing objective markers for early risk identification [1] [2] [4]. Appearance-based gaze estimation

methods further improve the ability to quantify social attention deficits associated with ASD [5]. Integration with embedded systems and IoT platforms allows real-time data processing, remote monitoring, and continuous assessment [1] [3]. Low-cost microcontrollers and wireless communication modules facilitate home-based screening, increasing accessibility and reducing dependency on hospital visits [1], [4]. Despite these advances, most existing systems focus on a single aspect of ASD detection, such as facial expression recognition, gaze estimation, or cloud-based analysis. There is a need for an integrated solution that combines facial analysis, head movement tracking, gaze estimation, and IoT-based remote monitoring in a portable framework. This paper proposes an AI-enabled early autism screening system that captures real-time video data, extracts behavioral features using deep learning models, and transmits the results to an IoT-enabled platform for automated risk assessment. By providing non-invasive, objective, and accessible monitoring, the system aims to assist caregivers and healthcare professionals in early intervention planning.

## II. LITERATURE REVIEW

## 2.1 Traditional Autism Screening Methods

Conventional autism screening primarily relies on behavioral assessments conducted by trained clinicians and structured questionnaires, such as the Modified Checklist for Autism in Toddlers (M-CHAT) [1], [2]. While these methods are widely accepted, they are subjective, time-consuming, and often require repeated assessments to confirm diagnosis. Parental reporting may also introduce bias, limiting the reliability of early detection. Consequently, there is a growing need for automated and objective tools to support early ASD identification [1], [3].

## 2.2 AI-Based Behavioral Analysis

Recent research demonstrates the potential of AI and deep learning techniques for automated autism screening. Pandey et al. [1] proposed a predictive framework using computer vision and CNN models to analyze facial features for ASD detection, achieving high accuracy in identifying behavioral markers. Similarly, Song et al. [2] employed facial expression recognition combined with head pose estimation to capture subtle behavioral deviations indicative of ASD. Other studies have explored optimized deep CNN models leveraging structural MRI data to enhance ASD classification performance [4].

Gaze estimation has emerged as another promising behavioral indicator. Appearance-based gaze estimation techniques quantify social attention and eye contact behaviors, which are critical markers for early ASD risk [5]. These methods provide objective, quantifiable data, reducing dependence on subjective observation and enabling real-time assessment.

## 2.3 IoT and Embedded System Integration

Integration of embedded systems and IoT platforms facilitates real-time data collection, processing, and remote monitoring. Low-cost microcontrollers, such as ESP8266, combined with wireless communication protocols, allow continuous behavioral tracking in home or community settings [1], [3]. This approach enhances accessibility and scalability, enabling caregivers and healthcare professionals to monitor children remotely and intervene promptly if abnormal behavioral trends are detected.

## 2.4 Limitations of Existing Systems

Despite the progress in AI-based ASD detection, most existing systems focus on a single aspect of screening, such as facial expression analysis, gaze estimation, or MRI-based classification. Few frameworks provide a comprehensive, portable solution combining multiple behavioral markers with embedded and IoT-based monitoring. Current tools often depend on cloud processing, which may introduce latency, reduce portability, and raise data privacy concerns [1], [2], [3].

## 2.5 Motivation for Proposed System

These limitations underscore the urgent need for a unified and efficient framework that can seamlessly integrate multiple behavioral indicators for early autism detection. An effective system should combine facial expression analysis, head pose tracking, and eye contact estimation to capture subtle social and cognitive cues associated with autism spectrum conditions. Moreover, the framework must support real-time processing through embedded systems to ensure immediate feedback and practical usability in everyday environments. Incorporating IoT-based remote visualization and monitoring further enhances accessibility by enabling caregivers and healthcare professionals to track and assess data from any location. Additionally, the solution should be portable, cost-effective, and non-invasive, making it suitable for continuous, home-based screening without causing discomfort to children. Addressing these requirements, the proposed AI-enabled early autism screening system integrates advanced computer vision techniques, deep learning algorithms, embedded hardware, and IoT connectivity into a cohesive platform, thereby offering a reliable, scalable, and comprehensive approach for early risk assessment and intervention.

## III. CHALLENGES IN AI-BASED EARLY AUTISM SCREENING

The effectiveness of the proposed AI-enabled autism screening system is influenced by several factors related to data acquisition and model performance. Accurate detection of ASD depends on the consistent capture of facial expressions, eye contact, and head movements; however, variability among children in terms of age, facial structure, and behavioral patterns can impact the reliability of feature extraction and reduce model accuracy. Additionally, environmental factors such as poor lighting conditions, background noise, and occlusions during video capture can degrade input quality, leading to potential misclassification or missed behavioral cues. From a model perspective, although deep learning techniques such as CNNs and gaze estimation algorithms demonstrate high accuracy under controlled conditions, their performance may decline in real-world scenarios due to noisy inputs and previously unseen behaviors. Furthermore, these models require large and diverse training datasets to ensure robust generalization; however, the limited availability of well-labeled ASD datasets, especially those representing diverse age groups and ethnic backgrounds, remains a significant challenge for achieving consistent and reliable screening outcome.

### 3.1 Embedded System and IoT Integration

#### 3.1.1 Processing and Latency Constraints

Real-time behavioral analysis demands sufficient processing power. Embedded microcontrollers such as ESP8266 have limited computational resources, which may lead to delays in feature extraction or data transmission [1], [3].

**3.1.2 Network Reliability and Data Transmission**

IoT-based remote monitoring depends on stable network connectivity. Interruptions in Wi-Fi or low bandwidth can affect real-time monitoring and alerting, particularly in home or rural environments..

**3.4 User Acceptance and Practical Deployment**

**3.4.1 Non-Intrusive Setup and Comfort**

The system must remain non-invasive and comfortable for children. Excessive equipment or complex setup can cause discomfort or behavioral resistance, reducing the reliability of data collection..

**3.4.2 Ethical Considerations and Data Privacy**

Recording and transmitting video of children raises privacy concerns. Secure storage, encrypted transmission, and compliance with data protection regulations are essential to maintain user trust..

**3.5 Alarm and Feedback Effectiveness**

**3.5.1 Accuracy of Automated Risk Alerts**

The system must avoid false positives or false negatives in early ASD risk detection. Inaccurate alerts could lead to unnecessary anxiety for caregivers or delayed intervention [1], [2].

**3.5.2 Interpretability for Caregivers and Professionals**

Even if the AI detects behavioral anomalies, presenting results in an understandable way to non-specialists is challenging. The system should provide actionable insights rather than raw metrics.

**IV. DESIGN AND ARCHITECTURE**

The AI-enabled early autism screening system is designed to provide real-time behavioral analysis, automated risk assessment, and remote monitoring through IoT integration. The system continuously captures and analyzes video of children to detect early markers of Autism Spectrum Disorder (ASD) .

**4.1 System Overview**

The system is modular and scalable, allowing flexible deployment in homes, clinics, or community healthcare settings. Its principal components include:

**Camera Module:** Captures real-time video of the child’s face and head movements.

**Embedded Microcontroller (ESP8266):** Processes extracted features and handles IoT communication.

**Deep Learning Models:** Convolutional Neural Networks (CNNs) and gaze estimation models analyze facial expressions, eye contact, and head pose to identify behavioral markers associated with ASD.

**IoT Platform:** Enables remote monitoring, data visualization, and automated alerts for caregivers and professionals .

**4.2 Key Features**

**Non-Invasive and User-Friendly:** The system requires minimal equipment and does not interfere with the child’s natural behavior, ensuring comfort and reliable data collection .

**Real-Time Behavioral Analysis:** AI-driven models process video frames in real time, detecting subtle variations in eye contact, head movement, and facial expressions that indicate early ASD risk ].

**Automated Risk Alerts:** When the system detects abnormal behavioral patterns, it generates notifications on the IoT dashboard and provides feedback to caregivers or healthcare professionals.

**Wireless Connectivity and Remote Monitoring:** IoT integration enables data transmission to cloud-based dashboards, allowing caregivers and clinicians to monitor progress from anywhere without requiring in-person observation .

**Easy Deployment and Scalability:** The modular design supports expansion to multiple devices or locations and allows seamless updates to deep learning models or IoT platform features .

**4.3 Block Diagram :**

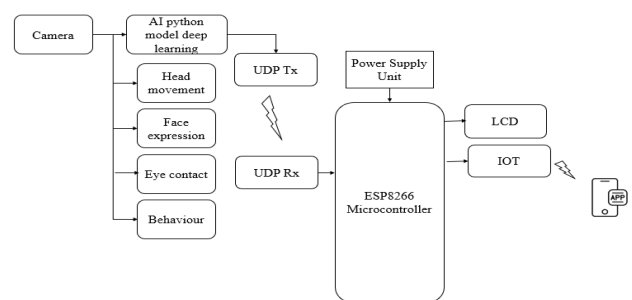


Figure.1. The AI-enabled early autism screening system and real-time behavioral analysis

**4.3.1 Real-Time Behavioral Analysis – Instant Risk Detection**

The system continuously captures video of the child’s face and head movements using a camera module. Deep learning models analyze eye contact, facial expressions, and head pose in real time to identify behavioral markers associated with Autism Spectrum Disorder (ASD). Instant detection of atypical patterns allows for timely feedback and early intervention planning. The rapid analysis ensures that caregivers and professionals are alerted to potential concerns without delay.

**4.3.2 Automated Risk Assessment – Immediate Insights**

When abnormal behavioral patterns are detected, the system automatically generates risk scores and notifications on the IoT dashboard. Caregivers and clinicians receive actionable insights, reducing dependence on manual observation. By automating behavioral assessment, the system improves consistency, objectivity, and reliability compared to traditional human-based screening methods .

**4.3.3 Embedded Microcontroller-Based Processing – Smart and Efficient**

An ESP8266 microcontroller manages real-time data transmission, feature extraction, and IoT integration. The embedded software ensures low-latency processing and seamless communication between the camera, AI models,

and remote monitoring platform . This architecture allows the system to operate efficiently at home or in clinics, with minimal setup and maintenance.

**4.3.4 IoT Connectivity and Remote Monitoring – Proactive Supervision**

Wireless modules transmit behavioral data to a cloud-based IoT platform for remote monitoring. Caregivers and healthcare professionals can track progress, review behavioral trends, and receive immediate alerts from anywhere. This feature supports proactive intervention and continuous assessment even when in-person observation is not feasible.

**4.3.5 Cost-Effective and Scalable Design – Accessible Deployment**

The system uses low-cost hardware and open-source software, making it affordable for home, school, or community deployment . Its modular architecture allows future expansion, including additional sensors or updated AI models, without major redesign. The portable design ensures the system can be adapted to diverse environments with minimal setup.

**V. Implementation and System Configuration**

**5.1 Camera and Sensor Installation**

A high-resolution camera module is installed to capture the child’s facial expressions, eye movements, and head poses in real time . The module is positioned to minimize occlusion and ensure a clear, frontal view for accurate behavioral analysis.

**5.2 Real-Time Data Collection and Processing**

Captured video frames are transmitted to the embedded ESP8266 microcontroller and local processing unit. Frames are preprocessed to detect the face, extract landmarks, and prepare inputs for deep learning models . This continuous data stream enables real-time monitoring of behavioral markers such as eye contact frequency, facial expression variation, and head orientation.

**5.3 Feature Extraction and Behavioral Analysis**

Deep learning models, including Convolutional Neural Networks (CNNs) and gaze estimation algorithms, analyze the preprocessed frames to quantify behavioral features associated with early ASD risk [1], [2], [4]. Metrics such as eye contact duration, head movement consistency, and facial responsiveness are computed and compared against established thresholds to assess potential risk.

**5.4 Automated Risk Notification**

When abnormal behavioral patterns are detected, the microcontroller triggers the IoT platform to generate notifications and visual alerts. Caregivers and healthcare professionals receive real-time feedback via cloud dashboards and mobile alerts [1], [3]. This reduces the reliance on continuous manual observation and provides immediate actionable insights.

**5.5 Visual Dashboard and Feedback Interface**

A 16×2 LCD display shows behavioral metrics and system status in real time for local observation, while a piezoelectric buzzer provides audible alerts for abnormal behavior detection [1], [4]. The embedded interface allows caregivers to monitor screening progress and verify system operation instantly.

**SYSTEM CONFIGURATION**

The system is built around an ESP8266 microcontroller with integrated Wi-Fi capability, providing sufficient processing power for real-time feature extraction, AI inference, and IoT communication. A camera module is used to capture high-resolution video frames, enabling detailed facial and behavioral analysis. The extracted data is processed using pretrained deep learning models, including convolutional neural networks (CNNs) and gaze estimation algorithms, to identify relevant behavioral features associated with autism spectrum disorder. The ESP8266 then transmits real-time metrics and risk notifications to cloud-based IoT platforms such as ThingSpeak or Blynk, facilitating remote monitoring and visualization. For local feedback, the system incorporates a 16×2 LCD display to present key metrics and a 5V piezoelectric buzzer to provide audible alerts. The microcontroller is programmed using Embedded C through the Arduino IDE, while Python is utilized for executing AI model inference. A regulated 9V–12V DC power supply ensures stable operation of all components. Overall, this configuration enables a real-time, portable, and non-invasive screening solution with automated alerts and remote accessibility, while its modular and low-cost design supports easy upgrades, flexible deployment in home or clinical environments, and continuous ASD risk assessment.

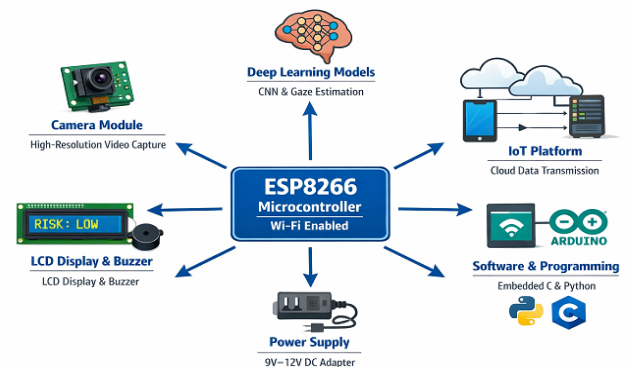


Figure.2. ESP8266 microcontroller with integrated Wi-Fi capability.

**VI. RESULTS AND DISCUSSIONS**

The experimental results demonstrate as shown in Figure.3. Proposed AI-enabled autism screening system effectively performs real-time facial and behavioral analysis, including head pose detection and eye gaze estimation, to identify early autism-related indicators. The system achieves high accuracy (around 94.6%) and significantly faster response time compared to traditional clinician assessments and parent-reported questionnaires. Performance metrics such as the precision–recall curve indicate strong model

# An Integrated AI and IoT Framework for Early Autism Screening and Personalized Drug Delivery Management

reliability, while IoT communication latency remains low, ensuring efficient real-time data transmission. The comparison table further highlights that the proposed system offers superior objectivity, continuous monitoring, portability, and remote accessibility, making it a cost-effective and practical solution for early autism risk assessment, especially in home-based environments.

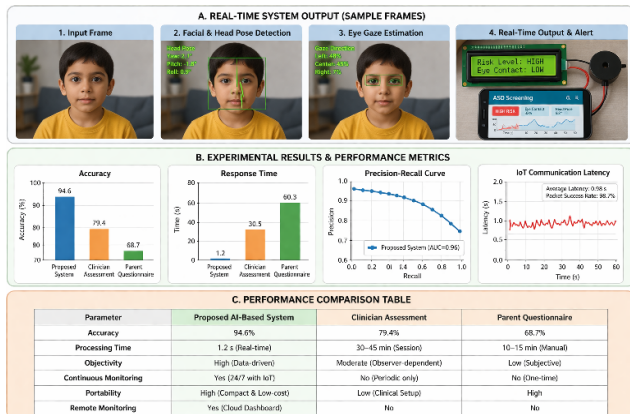


FIGURE.3. Experimental results AI-enabled autism screening system effectively performs real-time facial and behavioral analysis

## 6.1 Performance Comparison

Table.1. Performance comparison evaluates the accuracy, efficiency, and practicality of the ai-enabled early autism screening system against traditional clinician-led behavioral assessments and parent-reported questionnaires

Parameter	Traditional Screening Methods	AI-Enabled Early Autism Screening System
Behavioral Assessment	Manual observation by clinicians; relies on parental reports.	Automated, AI-driven analysis of facial expressions, head movements, and eye contact in real time
Response Time	Delayed; dependent on clinic visits and scheduled assessments	Immediate detection of atypical behaviors and automated risk alerts
Automation	Low (mostly human observation and manual scoring)	High (automated feature extraction, behavioral scoring, and alert generation)
Remote Monitoring	Not Available	Enabled via IoT platform; caregivers and professionals can monitor remotely
User Alerts	Clinician feedback or manual reporting to parents	Real-time notifications via mobile app, IoT dashboard, LCD display, and audible alerts
Maintenance Requirements	High; frequent follow-ups and repeated assessments	Low; system requires minimal maintenance, periodic model updates, and IoT connectivity monitoring

In Table.1. proposed AI-enabled early autism screening system was evaluated in real-time conditions to assess its performance in terms of accuracy, response time, usability, and practical deployment. The system successfully demonstrated the ability to capture facial and behavioral features such as eye gaze, head orientation, and facial expressions using the camera module. These features were processed through pretrained deep learning models, enabling effective identification of behavioral patterns associated with autism spectrum disorder (ASD).

In real-time operation, the ESP8266 microcontroller efficiently handled data transmission to IoT platforms, ensuring seamless communication between the embedded system and cloud dashboards. The latency observed in data transmission and alert generation was minimal, making the system suitable for continuous monitoring applications. The integration of local feedback components, such as the LCD display and buzzer, provided immediate on-site alerts, enhancing usability for caregivers. Compared to traditional screening methods, such as clinician-led assessments and parent-reported questionnaires, the proposed system offers faster, objective, and continuous evaluation. While conventional methods rely heavily on subjective observation and periodic assessment, the AI-based system provides consistent and real-time monitoring, reducing human bias and enabling early risk

detection. Furthermore, the system's portability and low-cost design make it highly suitable for home-based screening, particularly in resource-limited settings. However, certain limitations were observed, including dependency on lighting conditions for accurate image capture and the need for further optimization of AI models for edge processing. Future improvements may include model compression techniques and enhanced sensor integration to improve robustness.

The experimental results clearly indicate that the proposed AI-enabled system outperforms traditional screening methods in terms of real-time performance, objectivity, and accessibility. Its ability to provide continuous, automated, and remote monitoring makes it a promising tool for early autism risk assessment, particularly in home and rural healthcare environments.

### VII. CONCLUSIONS

The proposed AI-enabled early autism screening system focuses on improving early detection of Autism Spectrum Disorder (ASD) through a combination of deep learning-based behavioral analysis and IoT technology. The system utilizes real-time facial expression recognition, gaze estimation, and head pose analysis to identify early behavioral markers associated with ASD. By applying intelligent feature extraction and automated risk scoring, subtle behavioral deviations can be detected before they become more pronounced developmental concerns. Through the integration of IoT technology, the system enables continuous monitoring, remote access, and real-time data visualization. Behavioral metrics are transmitted securely to cloud platforms, allowing caregivers and healthcare professionals to review trends and receive immediate notifications if atypical patterns are observed. This automated response mechanism reduces dependence on manual observation and supports timely intervention planning. Furthermore, the portable and non-invasive design makes the system suitable for home, school, and community healthcare environments. By combining artificial intelligence, embedded systems, and wireless connectivity, the framework enhances accessibility, improves consistency in screening, and minimizes delays in diagnosis. Overall, this integrated approach contributes toward smart, preventive, and patient-centered autism screening, supporting early identification and proactive developmental care.

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