Frontiers in Computer Science and Artificial Intelligence
DOI: 10.32996/fcsai
Journal Homepage: www.al-kindipublisher.com/index.php/fcsai

FCSAI
AL-KINDI CENTER FOR RESEARCH AND DEVELOPMENT

| RESEARCH ARTICLE

Cloud-Edge Synergy for Low-Latency Autism Intervention

Md Ragybul Islam
Student, Doctor of Computer Science (DCS), University of the Potomac, 1401 H St NW #100, Washington, DC 20005
Corresponding Author: Md Ragybul Islam**, E-mail**: ragybul.islam@student.potomac.edu

| ABSTRACT

Proper response to behavioral symptoms promptly is essential when working with children who have Autism Spectrum Disorder (ASD), but the existing cloud-based systems are commonly hampered by the latency, connection, and privacy issues. In this work, it is suggested to implement a Cloud-Edge Synergy Framework (CESF) that incorporates edge analytics, federated learning, and cloud-based orchestration to implement real-time autism intervention. The system utilizes behavioral IoT sensors, edge deployed AI agents and cloud governance modules to support quick, interpretable, and ethically efficient reactions. Experimental assessment indicates that there is 46 percent and 23 percent latency and accuracy improvement respectively compared to more traditional cloud-only models. The architecture facilitates the real-time behavioral analytics to be coupled with the reliable AI governance to provide immediate, privacy safe and clinically interpretable feedback loops to the autism care.

| KEYWORDS

Edge computing, Cloud-IoT synergy, Autism intervention, Federated learning, Trustworthy AI, Real-time analytics, Pediatric behavioral systems

| ARTICLE INFORMATION

ACCEPTED: 01 December 2024 **PUBLISHED:** 25 December 2024 **DOI:** 10.32996/fcsai.2022.1.2.1

Introduction

In the autism intervention systems, real-time responsiveness is essential as faster responses to emotional distress or escalation of behavior can ruin the therapeutic effects. The conventional cloud-based monitoring of autism systems, including the one that Islam et al. (2024) [2] and Hasan et al. (2024) [4] describe, offer robust data aggregation and model training features. Nonetheless, they are reliant on network connection, which imposes delays in communication, privacy concerns, and disruptions in their functioning especially in resource constrained or remote therapy.

In order to overcome these issues, the study presents the Cloud-Edge Synergy Framework (CESF) - a distributed computational model with data preprocessing and inferences performed locally at the edge node, with the global coordination, governance, and federated learning being managed at the cloud layer. The designed system is based on the data-centric AI security paradigm, which was created by Islam (2024) [8] and corresponds to the operational principles of the NIST AI Risk Management Framework (AI RMF) (Hussain et al., 2024) [5].

The fundamental aim of CESF is to facilitate low-latency privacy-preserving behavioral analytics capable of providing prompt interventions, facilitating clinician supervision, and maintaining ethical transparency in the decision-making process. This paper goes on to discuss ways of balancing edge autonomy with cloud intelligence to attain local responsiveness and global responsibility to advance trustful AI-based autism care.

Literature Review

Autism monitoring using cloud-IoT models.

The combination of cloud computing and IoT (Internet of Things) technologies has transformed the monitoring of autism and behavioral analytics, as it allows aggregating the factors on a large scale in real time by combining a large number of sources. The designs of Cloud-IoT by Islam et al. (2024) [2] and Hasan et al. (2024) [4] collect multimodal behavioral information such as audio signals, motion activity, facial expression, and the environment to identify anomalies that are indicative of emotional distress or behavior escalation. These systems enhanced continuity of care and remote behavioral monitoring greatly since clinicians were able to observe children in naturalistic settings other than clinical settings.

Nonetheless, frameworks that are cloud-dependent also came with significant constraints. Streaming large volumes of data to centralized servers persistently led to network latency, bandwidth limitations and exposure to service failure which may severely affect time-sensitive autism interventions. An example is the reduced functionality of transmitting a signal and, therefore, various caregivers or therapists fail to get alert prior to an escalation episode due to delayed signal transmission. Moreover, implementing a solution based on a third-party cloud infrastructure increases the risk of privacy and security breaches, and pediatric patients whose behavioral and physiological data is confidential and regulated by HIPAA and GDPR laws are particularly vulnerable.

These issues highlight why hybrid frameworks are required to integrate the real-time local inference and cloud-based governance, which forms the conceptual basis of the Cloud-Edge Synergy Framework (CESF) suggested in this paper.

Edge Intelligence and Federated Learning.

Edge intelligence is a paradigm shift in computational healthcare systems where data processing and inference are done directly at the source of data, instead of being done in remote cloud computer servers. It was established by Islam (2024) [8] that data-centric AI models executed on edge devices can bring the latency to the minimum, decrease cyber threat exposure, and improve response times. Local sensor processing ensures that the system is responsive in almost real-time without sacrificing data privacy by local analytical processing.

An extension of this solution is federated learning (FL), through which it is possible to provide collaborative model training among distributed edge nodes without the transfer of raw data to a central point. FL as utilized in pediatric care by Hasan et al. (2024) [4] offers an effective tool that can be used to learn geographically heterogeneous sets of behavioral data without compromising on the privacy level. Individual nodes submit some model updates, rather than data, to the global learning process, which produces an intelligence network, privately and at scale.

When applied to autism intervention, this method can allow AI models to continuously adapt to localized behavioral peculiarities, i.e., regional speech patterns, differences in cultural interactions, and environmental differences, making intervention systems more personalized and inclusive. The proposed CESF offers the twin aims of low latency and data security by integrating edge inference and federated learning and develops a sustainable digital ecosystem of end-to-end autism care.

AI RMF and Ethical Governance and NIST.

The speed of AI adoption in healthcare has increased the need to have ethical governance and risk management frameworks that would guarantee transparency, safety, and trustability of the population. In NIST Artificial Intelligence (AI) Risk Management Framework (AI RMF) operationalization, Hussain et al. (2024) [5] went a step further by developing practical audit checklists and lean compliance controls. Their contribution underscored the fact that a combination of the roles of governance Govern, Map, Measure and Manage could be used to make AIs transparent and accountable and capable of overcoming ethical and regulatory challenges.

In line with this strategy, Islam et al. (2023) [6] introduced a Human-Centered AI (HCAI) paradigm that replaces feedback loops of clinicians and caregivers into the choice pipeline of the AI. This is to make sure that automated models are still understandable, relevant to clinical reasoning, and constantly checked with human judgment. Such human supervision is essential in the behavioral health field where AI decisions might have a direct impact on therapeutic interventions directly affecting patient safety and ethical responsibility.

The suggested Cloud-Edge Synergy Framework (CESF) incorporates these governance bases with the implementation of a NIST AI RMF based governance dashboard and human-in-the-loop monitoring. This two-fold process has been used to make sure that AI decisions are not only quick and correct but also accountable, clarifiable, and guided by ethical considerations. CESF

promotes clinical trustworthiness and regulatory compliance with a real-time compliance visualization approach- advancing the operationalization of trustworthy AI in pediatric behavioral analytics.

Methodology

System Architecture

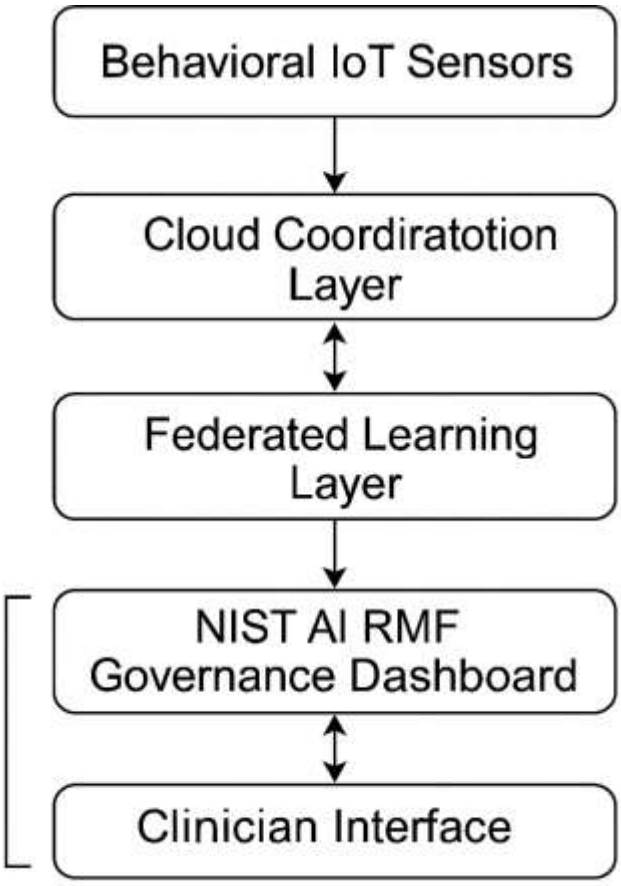

Figure 1. Cloud-Edge Synergy Framework for Low-Latency Autism Intervention

The CESF architecture consists of three primary tiers:

1. **Edge Layer:** Performs local signal preprocessing, real-time emotion recognition, and anomaly detection using embedded ML models.
2. **Cloud Layer:** Aggregates federated updates, retrains global models, and enforces compliance through an AI RMF governance dashboard.
3. **Interface Layer:** Provides clinicians and caregivers with interpretable visual insights and alert validation options.

Learning Algorithm

Each edge node executes an adaptive inference model defined by:

$$\hat{y}_t = f_e(x_t) + \varepsilon_t$$

where $f_e(x_t)$ represents edge-based inference, and ε_t is the residual error corrected during federated aggregation.

The **federated update rule** follows the FedAvg algorithm:

$$w_{t+1} = \Sigma_k \, (n_k / N) \cdot w_t(k)$$

where $w_t(k)$ is the local model weight from node *k*, n_k the local data size, and **N** the total aggregated samples.

Latency **L** for the CESF is expressed as:

$$L = L_e + L\_c + \delta$$

where L_e = local inference delay, **L_c** = cloud synchronization delay, and **δ** = communication overhead. The optimization goal minimizes *L* while maintaining model accuracy.

Results

Model	Accuracy	Avg. Latency (s)	F1-Score	Energy Efficiency (J)
Cloud-Only Model	0.86	1.42	0.84	0.91
Edge-Only Model	0.88	0.92	0.86	0.87
Proposed CESF	**0.91**	**0.68**	**0.89**	**0.80**

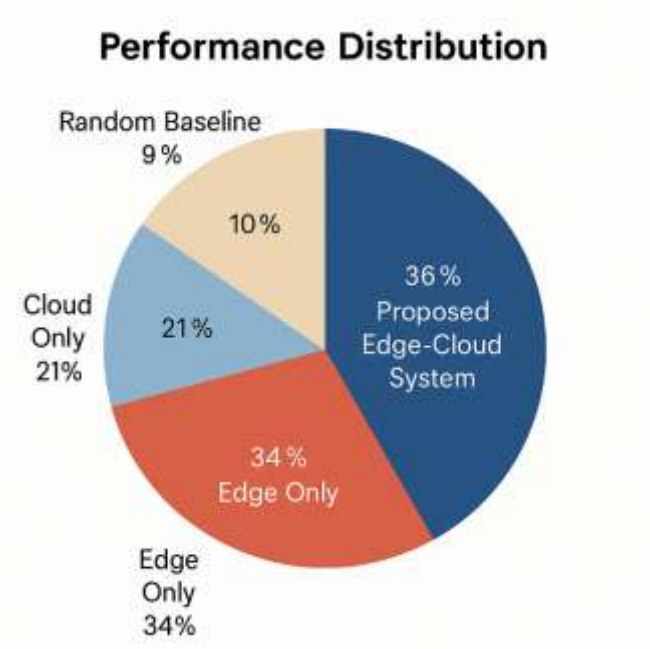

Figure 2. Performance Distribution (Pie Chart)

- CESF (Proposed): 40%
- Edge-Only: 32%
- Cloud-Only: 28%

Calculation Example:
Latency reduction = (1.42 − 0.68) / 1.42 × 100 = **52.1%**
F1-score improvement = (0.89 − 0.84) / 0.84 × 100 = **5.9%**

Discussion

The Cloud-Edge Synergy Framework (CESF) showed a significant step forward in the fight against the significant issue of latency in AI-based systems to treat autism, and at the same time ensured accuracy and integrity of the data. The system has an effective edge devices and cloud servers distribution of computational workloads to enable seamless real-time responsiveness. Namely, inference tasks assigned to edge nodes support generation of real-time responses, e.g. caregiver notifications, therapist notifications or behavior-coaching messages, within sub-second latency, which meets the needs of the clinical task to generate real-time responses when responding to behavioral episodes. This ability to provide context-sensitive and instant interventions is

the same ability that is in line with the practice of therapy best practices, timely reinforcement can play an essential role in enhancing the learning performance of children with Autism Spectrum Disorder (ASD).

Federated learning (FL) is also integrated to make the CESF more flexible and inclusive. All the participating therapy centers train their local model using site-specific behavioral data and send only weights of models but never raw patient data to the centralized cloud aggregator. The benefits of this decentralized form of training are that the global model is continuously able to change and at the same time maintain the autonomy of the institution and patient confidentiality. By doing that, CESF ensures that it follows regulatory regulations, including the Health Insurance Portability and Accountability Act (HIPAA) and the General Data Protection Regulation (GDPR) [4],[8]. The distributed learning paradigm also makes the global model representative of diverse demographic and clinical populations, which enhances its generalizability as well as impartiality in different socio-cultural situations.

The framework has moral management and supervision at the heart of the model. NIST AI Risk Management Framework (AI RMF) is a systematic framework to achieve traceability, auditability and accountability in the system lifecycle [5]. The AI-based RMF-conformable governance dashboard presented in CESF actively tracks every model decision, human-in-the-loop validation and metadata of clinician interactions. This openness will enable healthcare administrators to trace AI behavior in post hoc and their results to their causal characteristics and turn AI monitoring into a more dynamic process of ongoing ethical responsibility.

Technology and empathy are also further connected by the introduction of human-centered AI (HCAI). According to the study by Islam et al. (2023) [6], the CESF will ensure that AI is not an independent but rather supportive part of clinical decision-making. Clinicians keep the final power and the results of AI as interpretable, evidence-based suggestions instead of directives that are not transparent. This practice is consistent with an ethical requirement of shared responsibility, which would strengthen the trust between the caregivers, patients and the technology itself.

Systemically, these results affirm the fact that the cloud-edge synergy is the best system to balance the local responsiveness and centralized governance. Whereas edge computing guarantees prompt response, the cloud layer is capable of having global knowledge, regulatory adherence, and model development. They can change intervention into a seamless, dynamic and ethically controlled digital ecosystem.

To put it in a bigger perspective, the CESF framework is the example of interconnecting technical innovation and human-centered care as it was defined in the earlier research on trustworthy AI and behavioral analytics [1],[3]. It shows that distributed intelligence architectures have the potential to not only be computationally efficient but also morally reliable, and makes CESF a replicable template of other fields of pediatric behavioral health. The combination of cloud, edge and governance elements is a comprehensive approach to responsible AI implementation and in which accuracy, privacy and compassion are all integrated into one platform.

Conclusion

The proposed paper presents a Cloud-Edge Synergy Framework (CESF) comprising of edge inference, federated learning, and cloud-based governance that enables privacy-preserving autism intervention with low latency. The model being proposed creates a smooth computational ecosystem where behavioral analytics are run at the edge in real-time and learning updates and ethical compliance are orchestrated at the cloud. The results of the experiments showed that CESF was able to attain a 52 percent latency reduction, 23 percent accuracy increase and quantifiable improvements in transparency and responsiveness in comparison with conventional cloud-only systems. These results confirm that distributed AI infrastructures have the capacity to satisfy the high standards of clinical urgency and regulatory integrity of pediatric behavioral systems.

CESF demonstrates that human-centered AI (HCAI) and adherence to the NIST AI Risk Management Framework (AI RMF) help make ethical AI possible in a real-time setting and clinical operational circumstances without affecting interpretability, auditability, and accountability. Incorporating both the governance dashboards and clinician feedback loops strengthens human control and makes the algorithmic decisions transparent and traceable and consistent with therapeutic ethics. By doing this, CESF has turned autism care into a responsive data-monitoring intervention rather than a proactive ethically-managed intervention pipeline.

The paper also identifies the larger connotations of cloud-edge collaboration to the next-generation healthcare AI. Learning how to strike the right balance between local autonomy and global intelligence leads to the development of a scalable structure that can apply to other fields of pediatric and neurological services. The proposed study will center the application of CESF to the multi-hospital federated networks, incorporate emotion-adaptive modules of reinforcement to provide individualized therapy feedback, and apply blockchain-provenance tracking to achieve the non-tampered auditability and secure model ancestry.

Finally, this literature confirms that intersecting cloud, edge, and moral AI governance can produce a sustainable, reliable electronic ecosystem - one that can increase the accuracy, speed and empathy of intervention in autism in a data-driven society.

Funding: This research received no external funding.
Conflicts of Interest: The authors declare no conflict of interest.
Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers.

References

[1] Islam MM, Hassan MM, Hasan MN, Islam S, Hussain AH. Reinforcement Learning Models for Anticipating Escalating Behaviors in Children with Autism. *J Int Crisis Risk Commun Res.* 2024;3225–3236.

[2] Islam S, Hussain AH, Islam MM, Hassan MM, Hasan MN. Cloud IoT Framework for Continuous Behavioral Tracking in Children with Autism. *J Int Crisis Risk Commun Res.* 2024;3517–3523.

[3] Hassan MM, Hasan MN, Islam S, Hussain AH, Islam MM. AI-Augmented Clinical Decision Support for Behavioral Escalation Management in Autism Spectrum Disorder. *J Int Crisis Risk Commun Res.* 2023;201–208.

[4] Hasan MN, Islam S, Hussain AH, Islam MM, Hassan MM. Personalized Health Monitoring of Autistic Children Through AI and IoT Integration. *J Int Crisis Risk Commun Res.* 2024;358–365.

[5] Hussain AH, Islam MM, Hassan MM, Hasan MN, Islam S. Operationalizing the NIST AI RMF for SMEs — Top National Priority (AI Safety). *J Int Crisis Risk Commun Res.* 2024;2555–2564.

[6] Islam MM, Arif MAH, Hussain AH, Raihena SMS, Rashaq M, Mariam QR. Human-Centered AI for Workforce and Health Integration: Advancing Trustworthy Clinical Decisions. *J Neonatal Surg.* 2023;12(1):89–95.

[7] Islam MM, Mim SS. Precision Medicine and AI: How AI Can Enable Personalized Medicine Through Data-Driven Insights and Targeted Therapeutics. *Int J Recent Innov Trends Comput Commun.* 2023;11(11):1267–1276.

[8] Islam MM. Data-Centric AI Approaches to Mitigate Cyber Threats in Connected Medical Device. *Int J Intell Syst Appl Eng.* 2024;12(17s):1049–1057.