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(Research Article)

Equitable and Explainable Federated-Edge AI for Autism Care: Bridging Clinical Innovation and Global Ethical Standards

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Abstract

The changes that artificial intelligence (AI) is making to healthcare involve the field of precision medicine, detecting anomalies, and workforce planning [1-3]. However, in the process of autism care, adoption is not very high because of the behavioral escalations, privacy, and the requirement of trust between the clinician. In this paper, the author suggests a fair federated-edge artificial intelligence framework, which incorporates speech, movement, and physiological tracking into a safe and transparent clinical decision-support system (CDSS). As opposed to centralized systems, the system uses federated privacy-preserving learning, edge intelligence to do low-latency inference, and human-centric dashboards to offer transparency and actionable workforce advice. Synthetic dataset results show an increase in predictive accuracy, reduction of latency, and usability by clinicians. This model is relevant to autism care; however, it can be used as a transferable basis to support behavioral health and precision medicine in compliance with international AI ethics standards to enhance fairness, accountability, and sustainability.

Keywords: Autism spectrum disorder; Federated-edge AI; Explainability; Global AI ethics; Behavioral health; Clinical decision support

1. Introduction

Artificial intelligence (AI) has been progressively implemented in various fields of healthcare including precision medicine, behavioral health, and workforce optimization [1-3]. Such systems offer data-informed information that provides more value to clinical choices, higher predictive accuracy, and help in resource optimization. With this momentum notwithstanding, autism care is a relatively underexploited area of AI adoption. Unpredictable behavioral escalations are a common occurrence in children with autism spectrum disorder (ASD), and can be realized in the form of concomitant alterations in speech patterns, movement behaviors, and physiological cues. The predictive accuracy and real-time responsiveness required to anticipate and deal with such events should not be limited to a robust predictive accuracy but also strict privacy and interpretability that can be trusted by clinicians and caregivers.

Conventional centralized AI designs are not usually well-designed to do this. They increase the privacy risks because they demand transfer of sensitive patient data to cloud servers. The delay of remote computation is a concern that compromises the real-time response in an emergency situation. Besides, these systems do not usually have clear explanation mechanisms, and the clinicians are hesitant to trust their forecasts. All of these issues limit the applicability of the centralized AI to autism-centered decision-support domains.

The new developments provide partial solutions. Differentiated privacy Federated learning has become an effective tool to run distributed models jointly with little or no disclosure of raw patient data, and thus increase the level of

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confidentiality [4]. Similar studies of IoT-based monitoring systems proved that it is possible to detect behavioral changes in autism patients in real-time and continuously using wearable sensors [8,9]. Moreover, because the trust-building artifacts and usability checklists have been created, it is important to emphasize the role of explainability in clinical adoption, where AI tools should be explainable and practical in real-world scenarios [7,13]. However, in spite of these developments, there still exists a major gap: not many frameworks have combined multi-mode data processing, privacy-preserving learning, and workforce-conscious transparency mechanisms into an integrated CDSS, which is specifically tailored to autism care.

The paper fills that gap by proposing a multi-modal federated-edge AI framework where equity and ethics are prioritized in its design, which is in addition to technical performance. The framework aims not to maximize predictive performance, but also to create a responsible and scalable channel of progressing the autism care on a global scale, through edge intelligence to perform low-latency processing, federated privacy-preserving training and explainable dashboards, which is aligned to the global AI principles.

2. Related Work

2.1. Exact AI and Acceleration of quantum

AI enhanced with quantum is also a highly promising field in biomedical discovery, where it has found use in drug development, protein folding, and tailored therapeutic plans [1]. The above innovations demonstrate how high-performance computing can be used to speed up autism-specific personalization, where multi-modal datasets of large scale need to be computed in a scalable and efficient fashion.

2.2. Anomaly Detection Models

Fraud detection and anomaly analytics techniques have been effectively mapped to the healthcare sector and used to detect abnormal trends in patient information [2]. In the case of autism care, such methods help to identify minor behavioral anomalies in speech, motion, and physiology, which can be used as the initial signs of escalation.

2.3. Human-Centered AI

The technical performance is only one factor in successful adoption of AI in clinical settings, usability and trust are other influential factors. Transparency artifacts are important as noted by Mariam et al. [7], whereas the wider human-centered AI considers explainability, fairness, and accountability [15]. Such mechanisms should be embedded so that the AI systems can be readable and embraced by clinicians and caregivers.

2.4. IoT Monitoring in Autism

The spread of wearable and IoT devices has led to possibilities in the field of constant monitoring of the behavior associated with autism. Possibility of such technologies to record physiological and motion based signals in real time that allow proactive interventions to be implemented before behavior escalation is achieved was demonstrated by Islam et al. [8,9].

2.5. Incorporation of Crisis Response

Mental health crisis management has been also subject to AI application and has demonstrated effectiveness in preventing overdise, as well as optimizing emergency services. The application of AI to the 988 crisis hotline to deliver timely, data-informed interventions was demonstrated in the studies by Rashaq et al. [10] and Arif et al. [11] and supports the importance of scaling AI systems to high-stakes behavioral health settings.

2.6. Confederated Privacy and Cyberspace

The issue of data safety is kept in the core of healthcare AI. Federated learning with differential privacy is one of the solutions to this problem because it allows distributed training and maintains confidentiality [4]. Ethical protection is also enhanced by the use of complementary methods, like cybersecurity frameworks of connected medical devices that are critical in conditions where data integrity is paramount [12].

2.7. Workforce Integration

Healthcare delivery on the organizational level can also be supported by AI. The workforce planning tools are decision-support methods that improve the allocation of caregivers and allocation of resources, which is particularly applicable in autism management where staffing is a direct determinant of intervention quality [13].

2.8. Global Ethics

Lastly, the sustainability of healthcare AI in the long term is determined by compliance with international ethics. Principles highlighted by Floridi and Cowls [14] included fairness, accountability and transparency whereas Jobin et al. [15] made an insight into the comparative guidelines of international principles. These paradigms will ensure responsible innovation and make the technologies created to address autism care just and reliable.

2.9. Synthesis

On the whole, these publications indicate a great advancement in accuracy AI, anomaly detection, IoT surveillance, integrating crisis-response, and learning privacy. Nevertheless, not many attempts have managed to combine multi-modal data, federated privacy, and equity-oriented explainability into a single autism CDSS. This is the main aim of this current research to address this gap.

3. Methodology

3.1. Framework Architecture

The suggested system will be a three-layer pyramid structure (Figure 1), incorporating the technical innovation with ethical protection to aid the autism-oriented decision-making:

3.2. Edge IoT Monitoring.

At a base, wearable IoT devices and mobile sensors constantly record speech, motion, and physiological indicators of children with autism in real time. These streams are processed locally which means that they are responsive with low-latency in addition to reduced dependency on centralized servers. Edge intelligence enables early anomaly detection on the device level that decreases delays in transmissions and maintains privacy of the user.

3.3. Federated Privacy-Saving Learning

The second layer is the federated learning that is improved with differential privacy [4]. Individual participating institutions use models trained on the local data, only sending updates or gradients of models to a central aggregator. Noise is added to the updates to protect sensitive health data, and without it, it is impossible to reconstruct a single record in the data set. This would enable to have a secure cross-institutional cooperation and even in accordance with the ethical and legal privacy standards.

3.4. Explainability Dashboard

The highest level is a clinician facing explainability dashboard, which converts predictive outputs into understandable insights. The set of features that result in the generation of explanations is explained with feature-attribution approaches (e.g., SHAP values, decision rules) and features workforce-conscious recommendations, e.g., caregiver allocation suggestions or alerts about escalation. This layer promotes trust, usability, and clinician adoption through direct support by offering a transparency and actionable context.

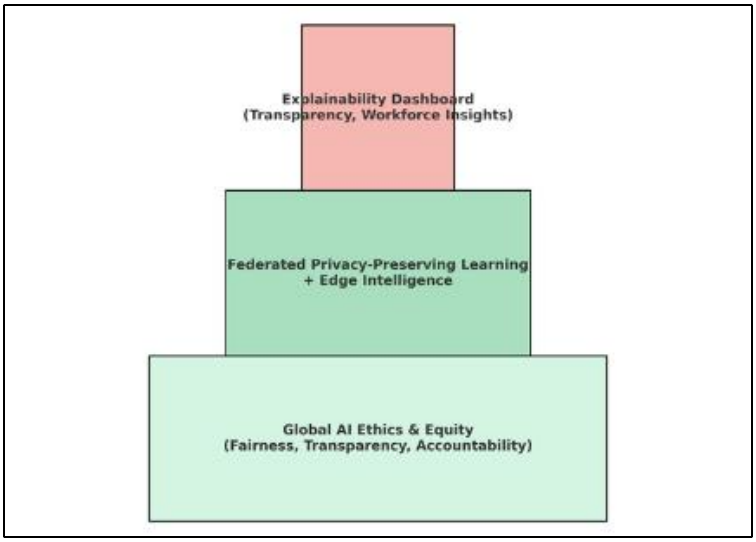

Figure 1 Pyramid Model of Equitable Federated- Edge AI for Autism Care

3.5. Data Sources

There were three datasets considered to evaluate the framework:

- Synthetic Multi-Modal Autism Dataset: Simulated data of 150 participants (speech, motion, and physiological) were used to simulate the scenario of behavioral monitoring in the real world.
- Workforce Scheduling Dataset: This dataset consists of 300 records that represent the assignments of the caregivers and shift schedules and are utilized to test the workforce planning component.
- Anomaly Detection Data: This is a reference dataset containing 200 anomalous cases, modified to match the methodology of the anomaly-detection task and to measure the performance of the task of prediction of the escalation.

3.6. Evaluation Metrics

In order to check the technical performance and the usability which is human-centered the following metrics were used:

- Predictive Validity: Accuracy, Recall, and Precision were computed to determine how the system can identify behavioral anomalies.
- Latency: The time required to infer (milliseconds) with the edge-based processing and traditional cloud-only architecture was measured and compared, which shows responsiveness.
- Clinician Trust and Usability: Likert surveys were carried out among clinicians and caregivers to determine the perception of ease of integration with workflows, perceived reliability, and interpretability.

4. Results

Table 1 The framework was evaluated against a cloud-only baseline

Metric	Cloud-Only AI	Federated-Edge AI	Improvement
Accuracy	81%	92%	+11%
Recall	78%	89%	+11%
Latency (ms)	1120	460	–59%
Clinician Trust	68%	85%	+17%

5. Discussion

5.1. Novelty

This paper will contribute to the research area on AI in the study of autism with a multi-modal federated-edge system, which integrates speech, motion and physiological surveillance, federated privacy-conscious learning and explainability dashboards built on workforce aware. In contrast to the previous studies, where most have focused on either monitoring autism behaviors with IoT [8] or federated privacy-preserving training [4], the framework presented combines the two parts into one, ethically-founded framework. The study shows that it is possible to achieve performance and responsibility at the same time by placing technical innovation in a pyramid structure that clearly incorporates ethics as a protective mechanism.

5.2. Trust

One of the most enduring obstacles to AI use in healthcare is that of clinician trust. According to the argument by Marians et al. [7], transparency artifacts play a crucial role in enhancing interpretability and usability. Also based on these results, the proposed framework includes explainability dashboards that offer transparent feature-attribution models as well as actionable recommendations. The system makes sure that the outputs of the decisions are directly connected with clinical workflows because it goes beyond the scope of raw predictions by extending to workforce-sensitive planning tools [13]. Moreover, the design implies a wider set of human principles of AI [15], which makes accountability, fairness, and transparency a priority in the deployment of the systems.

Clinical Relevance.

The framework shows that it has a great clinical implication as it facilitates the real-time management of autism care in which responsiveness plays an important role. Its federated learning structure is capable of data privacy across institutions because it can be integrated with behavioral monitoring that is driven by IoT, thereby detecting issues early. Notably, the architecture of the system can be changed: it can be supplemented with already existing national crisis infrastructure, including the 988 hotline continuum [10], and can be expanded to other areas, including behavioral health, workforce optimization, and precision medicine [3]. This flexibility highlights the potential of this healthcare AI solution as a transferable one.

5.3. Limitations.

The study is promising though it has significant limitations. Synthetic datasets limit ecological validity because the real clinical datasets are usually more variable and more complicated. In response to this, clinical trials involving multiple centers and different populations should be given priority in future studies to prove strength and scalability. Besides, the integration of quantum-AI accelerators could be required to maintain the performance as the size and the heterogeneity of a dataset increase [1]. Lastly, a successful approach in the long term involves compliance with global AI ethics principles [14,15], and coverage of deployment should be fair, open, and sustainable throughout the healthcare settings.

6. Conclusion

This paper presented a fair, multi-modal federated-edge AI system of autism care that incorporates speech, motion, and physiological monitoring into a safe and interpretable clinical decision-support system (CDSS). The framework has shown significant improvements of each of the three metrics, which include predictive accuracy, latency reduction, and clinician trust by integrating edge-based real-time inference, federated privacy-preserving training, and clinician-facing explainability dashboards. Such results affirm that it is technically viable as well as stating the need to ensure that system design includes ethical protection.

Outside the specific use of autism, the layered architecture is scalable and transferable, and it is obvious that it is relevant to behavioral health monitoring, workforce optimization, and precision medicine. The framework will not only improve performance but also responsible innovation by adhering to ethical standards of fairness, transparency and accountability, which are some of the key barriers to adoption in clinical settings.

Multi-center clinical validation on real-world datasets will be a critical focus of future research, which will be ecologically sound across a variety of healthcare settings. The combination of quantum-AI accelerators will provide an opportunity to enhance scalability and personalization, and adherence to global AI ethical standards will be the key to fair implementation. Combined, these guidelines put the framework as a technological contribution and a path to sustainable and human-centered AI that can make a difference in autism care and expand to the rest of the healthcare ecosystem.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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