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Synthetic Data-Driven Responsible AI: A Framework for Addressing Bias, Data Imbalance, and Privacy Challenges in Tabular Machine Learning Models

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ABSTRACT

Artificial Intelligence (AI) has become an integral component of modern decision-making systems across critical sectors such as healthcare, finance, education, cybersecurity, public administration, and smart governance, enabling organizations to derive valuable insights from large volumes of structured data. However, the increasing reliance on AI has also intensified concerns regarding algorithmic bias, data privacy, fairness, transparency, and the overall trustworthiness of machine learning models. Tabular datasets, which represent one of the most widely used forms of structured data in real-world applications, frequently suffer from challenges including class imbalance, demographic bias, missing values, limited minority class representation, and strict privacy regulations that restrict data sharing and collaborative model development. These issues often result in biased predictions, reduced model generalizability, privacy leakage, and unfair decision-making, particularly for underrepresented populations. To overcome these limitations, this study proposes a Synthetic Data-Driven Responsible AI Framework that leverages advanced synthetic data generation techniques to simultaneously address bias, data imbalance, and privacy challenges in tabular machine learning. The framework integrates state-of-the-art generative approaches, including Generative Adversarial Networks (GANs), Conditional Tabular GAN (CTGAN), Variational Autoencoders (VAEs), diffusion-based generative models, and differential privacy mechanisms to generate statistically representative yet privacy-preserving synthetic datasets. These datasets are evaluated using statistical similarity analysis, predictive utility, fairness metrics, privacy risk assessment, and explainability measures to ensure that they maintain the characteristics of the original data while protecting sensitive information. Furthermore, fairness-aware preprocessing techniques and synthetic oversampling strategies are incorporated to improve minority class representation and reduce algorithmic discrimination. The findings demonstrate that synthetic data generation significantly enhances fairness, privacy preservation, robustness, and predictive performance while enabling secure data sharing and regulatory compliance. Overall, the proposed framework provides a scalable and practical solution for developing trustworthy, transparent, and ethically responsible AI systems capable of supporting reliable decision-making across diverse real-world applications.

Keywords: *Responsible Artificial Intelligence, Synthetic Data Generation, Tabular Machine Learning, Fairness, Bias Mitigation, Data Imbalance.*