Integration of Explainable Deep Neural Network with Blockchain Technology: Medical Indemnity Insurance

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Abstract

Extracting evidence for processing of medical claims can be time-consuming and complex due to the sharing of sensitive information among multiple organisations. This paper presents a blockchain-based framework for reliable access to sensitive data by utilizing a hybrid smart contract running on the Hyperledger blockchain platform. The framework incorporates evidential reasoning for pre-processing ambiguous legal evidence and an explainable deep neural network (DNN) model for transparent decision-making in insurance claims, which continuously learns from lawyers' input. It addresses the laws on the "Right to be Forgotten" by considering the immutability of the blockchain and the "Right to Explanation" by providing transparency despite the non-linear nature DNN. The study evaluates the proposed framework's effectiveness in pre-litigation decisions for the medical negligence of doctors, demonstrating the importance of periodic retraining using low-confidence samples annotated by lawyers to enhance the model's decision-making capability.

Keywords

Explainable AI, Blockchain, Legal, Insurance, GDPR

1. Introduction

Medical indemnity claims safeguard healthcare professionals against costs and compensation due to medical negligence [1]. The processing of claims by insurance lawyers is time-consuming and complex. Artificial Intelligence (AI) could automate parts of this process, but the ambiguous nature of sensitive medical insurance data may result in less than ideal AI decisions [2]. Explainable Artificial Intelligence (XAI) shows promise in insurance decision-making, rendering AI algorithmic decisions understandable for non-technical end-users and stakeholders [3, 4, 5, 6, 7]. Current research must focus on enabling secure access to sensitive medical records across diverse organisations, including insurance companies, legal firms, hospitals, and clinical labs [8, 9, 10, 11, 12].

The proposed framework utilises blockchain technology for secure, tamper-proof data transactions among various organisations to guarantee privacy and security for sensitive medical records. It employs a hybrid smart contract to execute both on-chain and off-chain computations, which automates data access policies and records access by authorised parties. The data accessed by blockchain is integrated with Explainable Deep Neural Network (x-DNN) models to increase trust and transparency in medical indemnity claim decisions. Moreover, it meets essential General Data Protection Regulation (GDPR) requirements on the "Right to be Forgotten" [13, 14, 15, 16] and "Right to Explanation" [17], despite the immutable nature of blockchain and the black-box aspect of AI models, respectively.

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2. Blockchain Architecture for Accessibility of Insurance Data

The blockchain architecture is evaluated and selected using a multi-criteria decision-making approach [18, 19]. This research explores alternative solutions for blockchain platforms, cloud data storage services, and cryptographic key storage for each design criterion. Figure 1 demonstrates the crucial aspects of selected architectural design for off-chain and on-chain data storage and computation. The web API server supports the interoperability between a web application for data collection, a blockchain plat-form, secured third-party cloud storage, and cryptographic key-management service providers. The consent to access the medical data is stored in the Blockchain plat-form for automated auditing of data access by hybrid on-chain and off-chain computation of conditional logic in smart contracts.

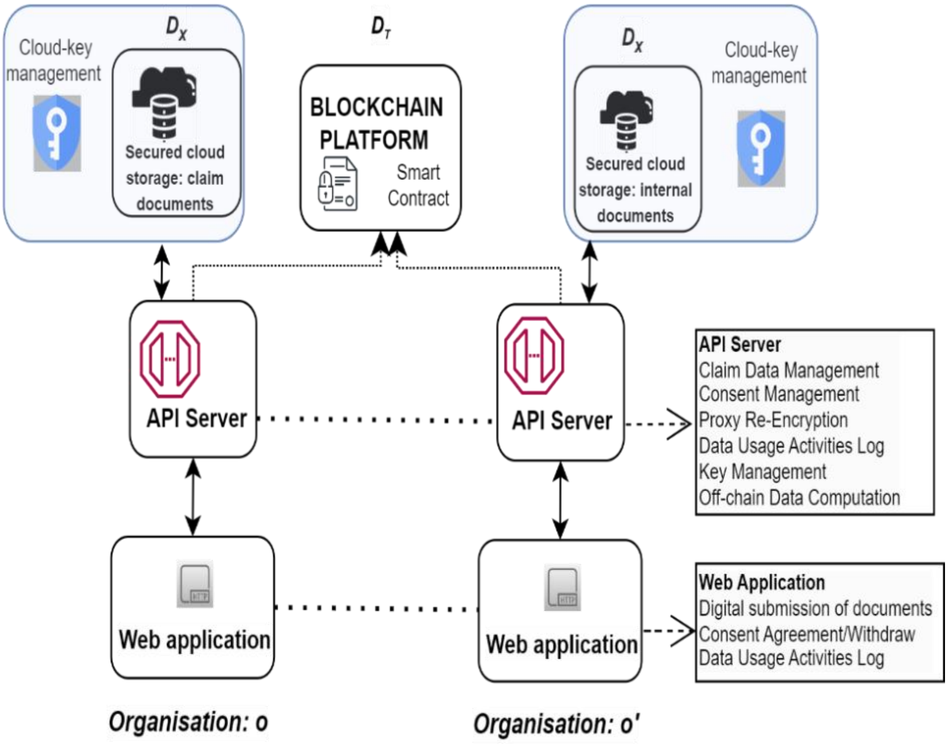

Figure 1: Framework to Manage Medical Insurance Claims by Blockchain

3. Introduction Continuous learning of x-DNN and ER Encoder

Medical data is often ambiguous and incomplete, requiring specialised processing techniques. ER algorithm is utilised to preprocess ambiguous data into explainable numerical features [2]. The features are used as an input sequence in a 1-dimensional deep Convolutional Neural Network (CNN) model. Human expert feedback, such as that from insurance lawyers, allows continuous learning of the CNN, fine-tuning the model for uncertain decisions [20]. The uncertainty in decisions is measured by Entropy [21].

The reasoning behind each decision by CNN can be understood by Layer Wise Relevance Propagation (LRP) [22], Shapley Additive Explanations (SHAP) [23] and Local Interpretable Model-agnostic Explanations (LIME) [24]. Figure 2 demonstrates the methodology.

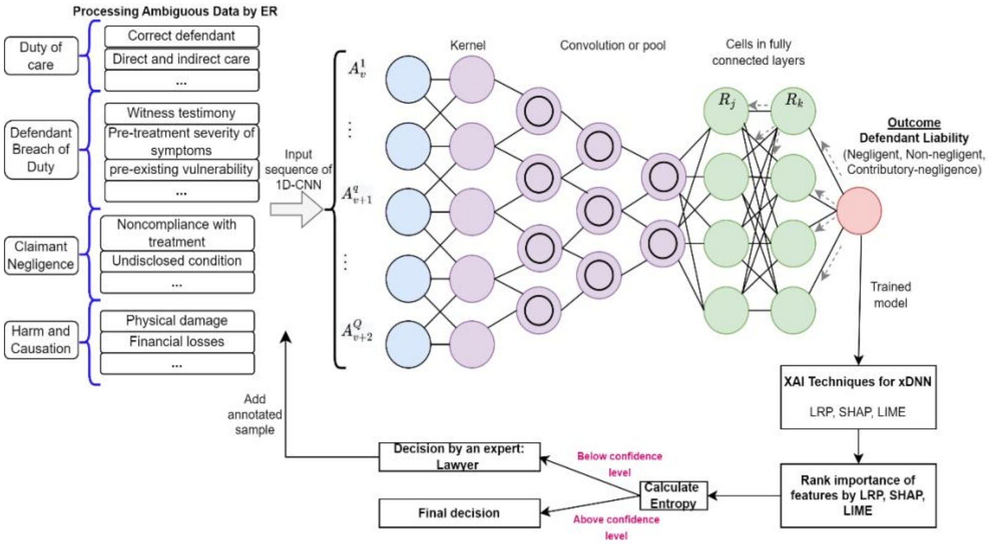

Figure 2: ER and x-DNN architecture to provide medical indemnity insurance decisions

4. Study on Medical Indemnity Claims

This study demonstrates the results of the proposed framework focusing on medical indemnity insurance for misdiagnosis and delayed cancer diagnosis. It evaluates the medical negligence of clinical oncologists before litigation, as most claims are re-solved outside of court through law firms. The dataset had 1888 instances and 23 attributes of medical indemnity claims; 8.52% were negligent, 19.40% were contributory-negligent, and the remaining 72.08% were non-negligent. Bayesian Optimisation trained the hyperparameters of CNN. The input sequence size (height × width) for the 1D-CNN is 84×1, followed by three convolution and pooling layers with kernel sizes of 50, 100, and 150, and two fully connected layers with 0.20 dropout rate.

Figure 3 shows the performance of Hyperledger Fabric Version 1.4 blockchain by the latency of creating a block and the number of valid transactions in a given time by throughput. A decision by CNN for a defendant (local explainability of an insurance case) can be understood by analysing the importance of features by heatmap of LRP values for four different techniques and the importance of the most relevant features by the SHAP and LIME, shown in Figure 4. Lawyers use these visual explanations as decision support. The ultimate verdict of a pre-litigation case depends on the lawyer's judgment, not the model's. The "negligence" decisions against the defendant were evaluated using the AUC metric through 3-fold cross-validation. The initial AUC score of a validation set by the original dataset is 0.86. The score improved to 0.91 after a second retraining iteration with newly annotated datasets by human lawyers. The accuracy can be improved after each iteration containing 100 new legal cases. The annotation activity is performed only for the least confident and unknown legal cases.

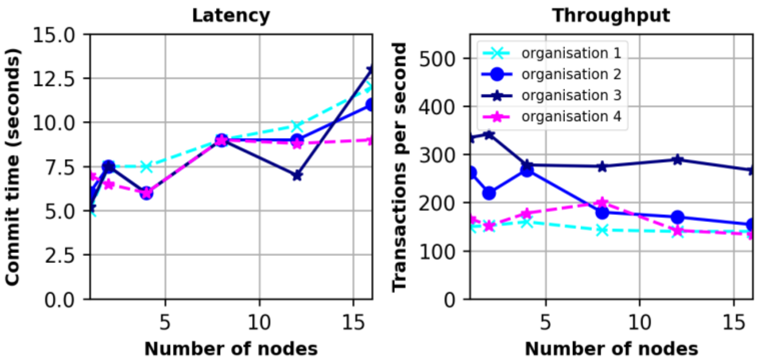

Figure 3: Latency and throughput of four organisations

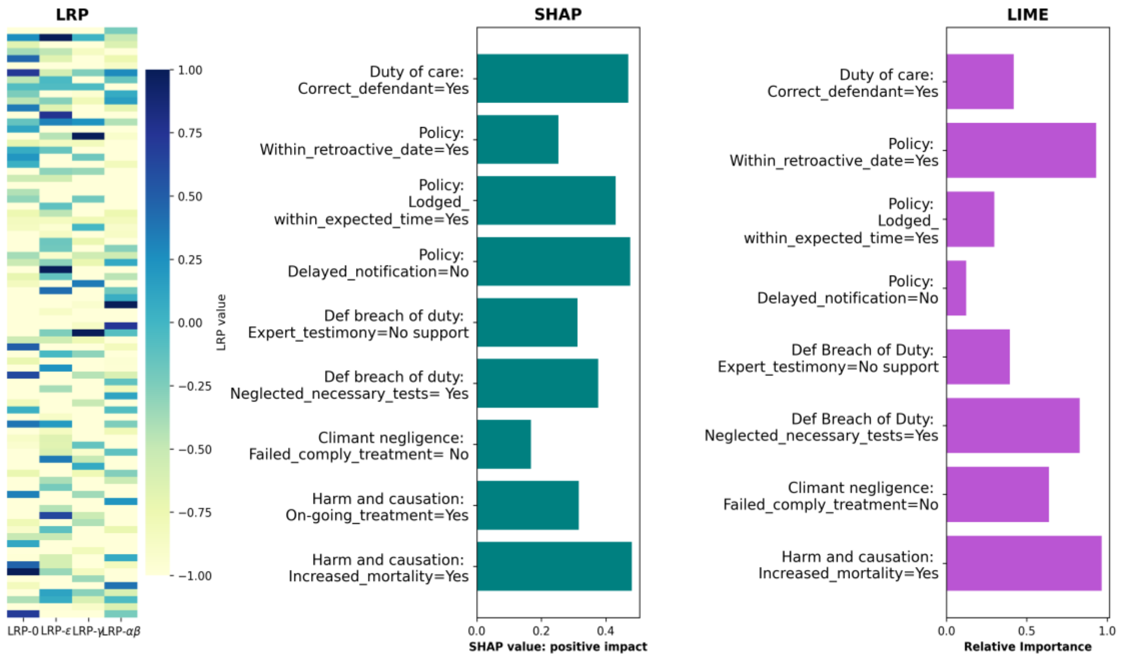

Figure 4: Local Explainability by LRP, SHAP, and LIME for a negligence medical claim

5. Conclusion

A blockchain-based framework is proposed in this study to ensure secure access to sensitive medical records across multiple organisations. It automates and enforces data access policies while incorporating an x-DNN model for transparent decision-making in medical indemnity claims, complying with GDPR requirements. The methodology is evaluated in pre-litigation decisions regarding clinical negligence by oncologists, emphasizing the significance of periodic retraining with low-confidence samples annotated by lawyers to enhance decision-making capabilities. The results show-case improved transparency, data privacy and security in medical indemnity claims.

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References

[1] Mathur, Manoj Chandra. "Professional Medical Indemnity Insurance-Protection for the experts, by the experts." Indian journal of ophthalmology 68, no. 1 (2020): 3.

[2] Sachan, Swati, Fatima Almaghrabi, Jian-Bo Yang, and Dong-Ling Xu. "Evidential reasoning for preprocessing uncertain categorical data for trustworthy decisions: An application on healthcare and finance." Expert Systems with Applications 185 (2021): 115597.

[3] Adadi, Amina, and Mohammed Berrada. "Peeking inside the black-box: a survey on explainable artificial intelligence (XAI)." IEEE access 6 (2018): 52138-52160.

[4] Sachan, Swati, Jian-Bo Yang, Dong-Ling Xu, David Eraso Benavides, and Yang Li. "An explainable AI decision-support-system to automate loan underwriting." Expert Systems with Applications 144 (2020): 113100.

[5] Rahimi, Nick, and Sai Sri Vineeth Gudapati. "Emergence of blockchain technology in the healthcare and insurance industries." In Blockchain Technology Solutions for the Security of Iot-Based Healthcare Systems, pp. 167-182. Academic Press, 2023.

[6] O'Sullivan, Shane, Nathalie Nevejans, Colin Allen, Andrew Blyth, Simon Leonard, Ugo Pagallo, Katharina Holzinger, Andreas Holzinger, Mohammed Imran Sajid, and Hutan Ashrafian. "Legal, regulatory, and ethical frameworks for development of standards in artificial intelligence (AI) and autonomous robotic surgery." The international journal of medical robotics and computer assisted surgery 15, no. 1 (2019): e1968.

[7] Smith, Helen, and Kit Fotheringham. "Artificial intelligence in clinical decision-making: rethinking liability." Medical Law International 20, no. 2 (2020): 131-154.

[8] Chen, Chin-Ling, Yong-Yuan Deng, Woei-Jiunn Tsaur, Chun-Ta Li, Cheng-Chi Lee, and Chih-Ming Wu. "A traceable online insurance claims system based on blockchain and smart contract technology." Sustainability 13, no. 16 (2021): 9386.

[9] Zhou, Lijing, Licheng Wang, and Yiru Sun. "MIStore: a blockchain-based medical insurance storage system." Journal of medical systems 42, no. 8 (2018): 149.

[10] Merlec, Mpyana Mwamba, Youn Kyu Lee, Seng-Phil Hong, and Hoh Peter In. "A smart contract-based dynamic consent management system for personal data usage under GDPR." Sensors 21, no. 23 (2021): 7994.

[11] Kumi, Sandra, Richard K. Lomotey, and Ralph Deters. "A Blockchain-based platform for data management and sharing." Procedia Computer Science 203 (2022): 95-102.

[12] Sutton, Andrew, and Reza Samavi. "Blockchain enabled privacy audit logs." In The Semantic Web–ISWC 2017: 16th International Semantic Web Conference, Vienna, Austria, October 21–25, 2017, Proceedings, Part I 16, pp. 645-660. Springer International Publishing, 2017.

[13] Finck, Michèle. "Blockchains and data protection in the European Union." Eur. Data Prot. L. Rev. 4 (2018): 17.

[14] Giordano, Marco Tullio. "Blockchain and the GDPR: new challenges for privacy and security." In Blockchain, Law and Governance, pp. 275-286. Springer International Publishing, 2021.

[15] Molina, Fernanda, Gustavo Betarte, and Carlos Luna. "Design principles for constructing GDPR-compliant blockchain solutions." In 2021 IEEE/ACM 4th International Workshop on Emerging Trends in Software Engineering for Blockchain (WETSEB), pp. 1-8. IEEE, 2021.

[16] Al-Abdullah, Muhammad, Izzat Alsmadi, Ruwaida AlAbdullah, and Bernie Farkas. "Designing privacy-friendly data repositories: a framework for a blockchain that follows the GDPR." Digital Policy, Regulation and Governance 22, no. 5/6 (2020): 389-411.

[17] Kaminski, Margot E. "The right to explanation, explained." Berkeley Technology Law Journal 34, no. 1 (2019): 189-218.

[18] Yang, Wenli, Saurabh Garg, Zhiqiang Huang, and Byeong Kang. "A decision model for blockchain applicability into knowledge-based conversation system." Knowledge-Based Systems 220 (2021): 106791.

[19] Sachan, Swati, Dale S. Fickett, Nan Ei Ei Kyaw, Rituparna Shome Purkayastha, and S. Renimol. "A Blockchain Framework in Compliance with Data Protection Law to Manage and Integrate

Human Knowledge by Fuzzy Cognitive Maps: Small Business Loans." In 2023 IEEE International Conference on Blockchain and Cryptocurrency (ICBC), pp. 1-4. IEEE, 2023.
[20] Turchi, Marco, Matteo Negri, M. Farajian, and Marcello Federico. "Continuous learning from human post-edits for neural machine translation." The Prague Bulletin of Mathematical Linguistics 108, no. 1 (2017): 233-244.
[21] Tornetta, Gabriele N. "Entropy methods for the confidence assessment of probabilistic classification models." arXiv preprint arXiv:2103.15157 (2021).
[22] Bach, Sebastian, Alexander Binder, Grégoire Montavon, Frederick Klauschen, Klaus-Robert Müller, and Wojciech Samek. "On pixel-wise explanations for non-linear classifier decisions by layer-wise relevance propagation." PloS one 10, no. 7 (2015): e0130140.
[23] Lundberg, Scott M., and Su-In Lee. "A unified approach to interpreting model predictions." Advances in neural information processing systems 30 (2017).
[24] Ribeiro, Marco Tulio, Sameer Singh, and Carlos Guestrin. "Why should I trust you?" Explaining the predictions of any classifier." In Proceedings of the 22nd ACM SIGKDD international conference on knowledge discovery and data mining, pp. 1135-1144. 2016.