Innovative Approaches in Association Rule Mining for Heart Disease Forecasting in Distributed Healthcare Environments

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Abstract: Association rule mining (ARM) is one of the most vital data mining techniques that uses the Apriori algorithm to extract relations and patterns among items in large databases. Although classic ARM approaches are useful for applications such as inventory control and telecommunications, it produces an extraordinarily high number of rules, which become hard to handle and are barely comprehensible. The latent pattern discovery capability of ARM is used within the context of heart disease prediction in this paper to establish its potential use. Predictive models can now increasingly better improve disease diagnosis and treatment based on the enormous volumes of medical data with advancements in Machine Learning (ML) and the Internet of Medical Things (IoMT). However, heterogeneous data, computational complexity, and privacy issues continue to persist. This paper essentially gives insights into the efficacy of ARM techniques in healthcare analytics by foregrounding current advancements in ARM techniques and their integration with contemporary prediction models. Given emphasis on contributions towards the prediction of heart disease, it attempts to provide a comparative review of several research projects on data mining techniques such as Decision Trees, Naïve Bayes, and hybrid approaches. Results indicate how advanced algorithms and hybrid approaches may improve the predictability and speed up the identification of a disease at an early stage, which would eventually lead to achieving better clinical decision-making.

Keywords: Association Rule Mining, Apriori Algorithm, Heart Disease Prediction, Machine Learning, Data Mining Techniques

I. Introduction

One of the ways of identifying which procedures often happen together is through using the Association Rule. The a priori algorithm is used for the Association Rule. An a priori algorithm is a data retrieval system that uses associative principles to determine the associative link of item combinations in order to ascertain those. A system for determining support and confidence from the relationship of commodities is used to implement the association rules in question. A relational database is used to find relationships or association rules between collections of items. It has recently been found that association rule mining is one of the best algorithms in solving a number of problems. Association rules are found to extensively apply in numerous domains, including markets, human age risk, inventory control, and networks of telecommunications. Mining association rules can discover strong relationships between database objects; therefore, it is an important part of data mining and knowledge discovery. There is a severe flaw, however, with standard association rules. The mining approach could provide an enormous number of association rules that depend on how the parameters are set. [1].

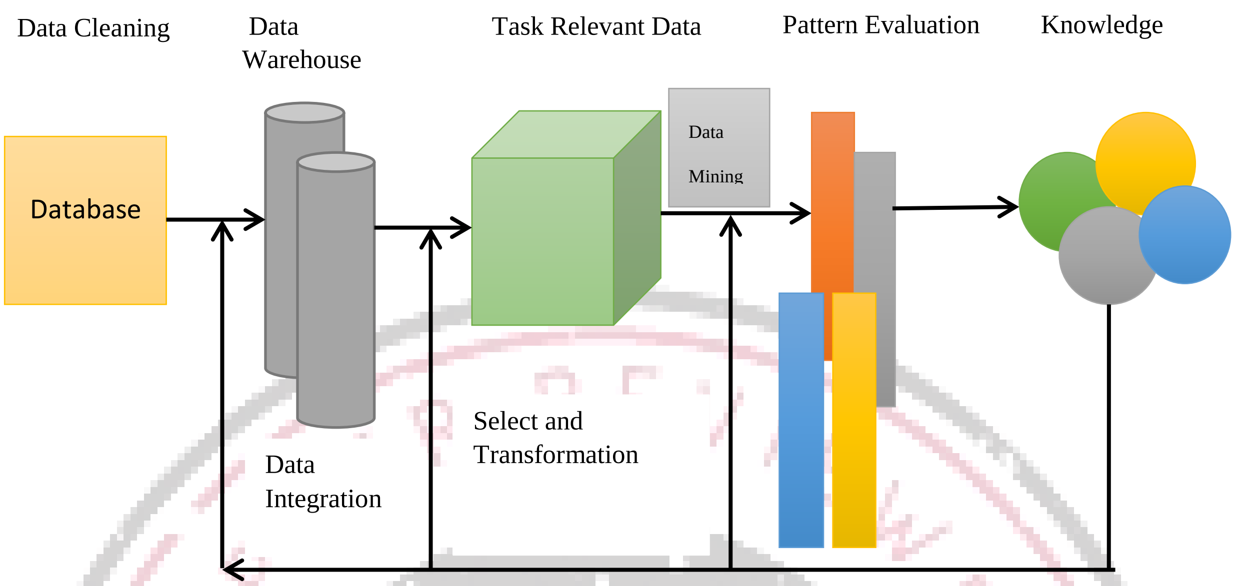

Figure 1: Association Rule Mining

The goal of association rule mining is the search for relations between different features in transaction databases. Rule mining, post-processing that contains visualization of the results, and pre-processing approaches comprise the complex process of search for new rules [2]. In many ways, big data can be thought of as a mine full of insightful secrets that are waiting to be unearthed. In order to advance science and medicine, these secrets must be found. The method of data mining (DM) can provide many worthwhile discoveries. Specifically, Association Rule Mining (ARM) is a popular kind of data mining that finds correlations between item sets by identifying patterns in the dataset that appear frequently [3]. If sickness can be identified early on, many lives can be saved. Diagnosing by invasive procedures is expensive and time-consuming. If we use a sophisticated Machine Learning (ML) approach to accurately diagnose diseases, the medical industry stands to gain a great deal [4]. Congenital heart disease (CHD) is a multifactorial disorder that affects people of all ages. Its numerous anatomical abnormalities can affect as many as 4 to 5 out of every 1,000 live births [5]. The Internet of Medical Things (IoMT) revolution has changed the healthcare sector in order to raise the standard of living for people. Wearable sensors and other IoMT devices are commonly used in the smart healthcare environment to gather medical data for intelligent data analytics powered by artificial intelligence (AI). This allows for the realisation of a wide range of fascinating smart healthcare applications, including disease prediction and remote health monitoring [6]. There are many interrelated causes that contribute to the present nursing shortage. For instance, the introduction of managed care—a healthcare system in the USA that places a strong emphasis on preventative medicine and home treatment—in the 1990s resulted in a near-freeze in average wages, a major reduction in the number of nurses on staff, and an increase in the number of patients on a nurse's caseload [7].

II. Challenges and Opportunities in Distributed Healthcare Data

Anatomical, histological, and molecular data together yield a valuable "digital bio bank" for each patient and provide a detailed description of the state of a cancer. However, as of right now, very few innovations have been reported that make use of the computational potential of large-scale, multi-modal integration for research findings, and even when these data are available, they are rarely integrated. Artificial intelligence (AI) and machine learning (ML) approaches hold great potential for driving clinical and biological discoveries by transforming data into a new generation of diagnostic and prognostic models. Nevertheless, the potential of these strategies is frequently unrealised in biological contexts, where research-ready datasets are sparse [8]. The healthcare industry faces a significant issue in securely storing and retrieving the enormous volumes of personal health data produced by standard business operations and service delivery. Healthcare monitoring technologies, like wearables, also create massive volumes of personal health data. Most health data is not standardised across systems, making it challenging to use, trade, and evaluate. They are hard to manage and disseminate since they are collected from multiple sources and stored in centralised IT systems. Time and resources are required for patient data requests, transmissions, receipts, and compilations.

The health care industry in the United States is the largest in the world, with an estimated $1.7 trillion in revenue annually. Compared to other countries, the average annual cost of healthcare in the United States is $10,739 per person. Approximately 18% of the GDP is allocated to healthcare. In 2027, the healthcare industry is expected to contribute about 20% of the US GDP, assuming no changes. The healthcare industry is addressing the increase in medical and prescription costs while implementing strategies and plans to provide patients with better care [9].

Clinicians' decisions are more evidence-based, meaning they rely more on large volumes of research and clinical data than on their professional judgement and training. "Big data" in the context of healthcare refers to larger and more complex electronic health datasets that are hard or almost impossible to handle with standard, traditional methods, tools, or software. Healthcare records are the sources of big data in the healthcare industry. These records include patient files, disease surveillance, hospital records, medication records, health management records, physician records, clinical decision support, or feedback of patient and clinical data, including imaging, personal financial records, genetic and pharmaceutical data, Electronic Medical Records (EMR) etc.]. "Real-world data" (RWD) is defined as "data relating to patient health status and/or the delivery of health care routinely collected from a variety of sources" in the context of medicine and healthcare. The increasing use of social media, wearable technology, mobile devices, electronic health records (EHRs), product and disease registries, e-health services, and other technology-driven offerings, along with increased data storage capacity, have all contributed to the production and availability of digital RWD more quickly than ever before [11].

III. Advanced Algorithms and Techniques for Association Rule Mining

Databases, relational databases, and other information repositories use if/then expressions, sometimes referred to as association rules, to assist link seemingly unrelated pieces of data. Association rules are used to find the associations between frequently used things. Applications of association rules include classification, cross-marketing, clustering, loss-leader analysis, basket data analysis, and catalogue design. For example, in addition to bread, the customer may buy butter. A memory card can be purchased by the customer in addition to the laptop. Association regulations rely on two essential components: confidence and support. It locates the relationships and rules that emerge from searching for recurring if/then patterns in data. Most of the time, association rules must satisfy the user-specified minimum support and minimum confidence requirements at the same time [12].

To establish the relationship between a huge number of data objects, association rule mining, or ARM, is utilised. Many businesses are worried about their database mining association guidelines because of the enormous amount of data stored in repositories. For example, identifying the intriguing connected links among massive amounts of transaction data can help with catalogue design, cross-marketing, and other commercial decision-making processes. One common application of ARM is market basket analysis. This technique looks for correlations between different things that customers include in their packs to investigate their purchase patterns. By providing a summary of the things that they typically purchase together, the identification of such alliances will allow marketers to expand their communication initiatives [13].

Upon entering transactional databases, the ARM approach known as Apriori eliminates any items that are regularly encountered from the transaction. In this instance, a number of often occurring risk variables are produced and specific indicators for the development of diabetes are identified, given that the electronic medical record in Apriori is available. Elcat is comparable to the Apriori algorithm's recursive function. It makes use of a tree like the Tidset structure. Consequently, the EMR generates the typical diabetes risk variables. Every now and then, all hazards are present in the database when the tidset begins. The program searches thoroughly to determine the risk element in every circumstance. Algorithm for Growth used to address the program's apriori shortcomings. This document just needs to be searched twice. This algorithm requires the creation of an FP tree, hence two passes are required [14].

IV. Innovative Approaches in Association Rule Mining for Heart Disease Prediction

Heart disease is thought to be the leading cause of death worldwide. The process of identifying or forecasting heart illness using patient records is known as the diagnosis of heart disease. Physicians may find it difficult to accurately identify patients quickly, particularly if they have many illnesses. As a result, diagnosing heart disease is a difficult process that calls significant expertise. A wrong diagnosis could leave the patient disabled or dead. Medical experts and practitioners can use disease prediction models to assist in the prediction of heart disease. Data mining techniques can be used to diagnose patients and forecast diseases based on the vast quantity of data that can be gathered via digital devices, either by the patient or at a hospital. The present study examines diverse classification and prediction methodologies employed in the prognosis of cardiac disease. Additionally, provide a hybrid strategy that combines all methods into a single one in order to integrate all features and generate precise diagnoses [15].

Data mining is one of the important branches of data management which focuses on extracting knowledge from massive amounts of unprocessed data. It employs two key models-the Descriptive Model, where data is analyzed without focusing on any specific variable that uses techniques such as factor analysis and cluster analysis, and the Predictive Model, which uses techniques like predictive modeling in order to predict a few definite outcomes. Techniques of data mining like Decision Trees (DT), Multi-layer Perceptrons (MLP), Naïve Bayes (NB), K-nearest neighbour (K-NN), and Support Vector Machines (SVM) are typically used to enable meaningful inferences over large datasets. Techniques of data mining applied in the healthcare industry include clustering, regression, classification, and outlier identification for discovering the patterns in the medical data that are unknown. With intelligent models like DSS and CDSS, healthcare professionals can improve clinical decisions. Computational intelligence greatly contributes to the prediction of cardiac disease with the identification of correlations between patient's characteristics and disease. Feature selection, sometimes referred to as variable or attribute selection, is an important technique that features in cardiac disease prediction, aimed at removing unnecessary data. Being in contrast to other dimensionality reduction techniques where original attributes were employed to create new ones, feature selection aims to enhance the predictive accuracy by removing irrelevant attributes [16].

Heart disease is a complex condition that depends on various lifestyle, environmental, and genetic factors. The conventional diagnosis methods rely on the observations of symptoms and medical check-up, and although such approaches can be taken, early manifestations of the disease might not be noticed. Data mining techniques enable an earlier analysis of the data for a pre-symptomatic prediction of the disease. Healthcare professionals will be better able to understand how different types of risk factors lead to heart disease using data mining tools such as Decision Trees, Naïve Bayes, and SVM. This will bring in early interventions and customized treatment plans. Even though the person's current clinical signs may be well within the normal ranges, the data mining-based predictive model might flag an individual with a higher risk for further testing. Furthermore, putting this data-driven knowledge into Clinical Decision Support Systems will support doctors to make better judgment calls in general by arming them with more knowledge. With data mining-based predictive models installed into CDSS, it will be able to assess fresh patient data continuously to ensure that risk evaluations prove effective over time and interventions occur on schedule [17].

A study of an IoT framework for the prediction of heart disease by the use of a CNN classifier, MDCNN, (2020) identifies some significant obstacles to the successful deployment of such systems. Data heterogeneity is one of them since IoT devices gather enormous volumes of data from various sources, most of which are inconsistent or incomplete and thus make the training difficult in models. Real-time prediction is also challenging as deep learning models such as MDCNN have heavy computation, requiring much processing power- this can be critical in resource-limited contexts. In addition, some of the issues related to medical data: privacy and security issues arise because it is hard to protect the data stringently without compromising the efficiency of the system. Another challenge to this is that good predictions require the non-jerky integration of data among healthcare systems. Further, interoperability between various IoT platforms will also create a problem since ultimately, the models must adapt to numerous data inputs, and hence, the scope of the prediction model to various disparate patient groups without losing out on the accuracy remains a big challenge. This therefore underscores the complexity of implementing large-scale cardiac disease prediction through IoT and machine learning systems [18].

Important Challenges Diminished by the Work of David and Belcy The work of David and Belcy on applying data mining techniques towards the forecasting of cardiac diseases enlightens numerous important obstacles. Management of the complexity and high dimensionality of medical datasets was one of the major challenges involved. Such datasets contain a large number of variables, and in the event that features are not chosen carefully, models may overfit and become less accurate. Another challenge comprises the integration of diverse and heterogeneous data from multiple sources, for instance, histories of patients and electronic health records. There is also a problem of interpretability of the models of machine learning since physicians should be able to trust the results in order to make sense and make accurate predictions. Striking a balance between explainability and accuracy remains difficult in practice. Other factors include data privacy, computational efficiency, and also applying data mining technology in healthcare environments [19].

Zriqat, Altamimi, and Azzeh work on a different study by addressing a large number of issues concerning the application of data mining classification techniques for heart disease prediction. Among the many problems identified, one major challenge is that choosing the best method for the classification of the given dataset is quite tough because different algorithms offer a different level of accuracy according to the type of data. Another problem is handling imbalanced datasets, which produce skewed results since there are more non-disease cases than disease cases. It is, therefore important for practical applications to maintain confidentiality and data security when dealing with private health information. The last significant problem is that feature selection and reduction are very complicated in high-dimensional data [20].

V. Key Findings from Past Studies

This table gives a comparative analysis of varied research studies on the prediction of heart disease using data mining techniques and analyzing healthcare information. With a summarized version from each study, the table identifies the main objectives, methodology, findings, and contribution of each diverse study that reflected advancement in machine learning, association rule mining, electronic health data usage, and hybrid approaches in healthcare analytics. The paper presents an overview of advancement in predictive modeling and data mining techniques along with their applications in the context of health care. Such diversified approaches carried on in research studies from traditional classifiers to advanced machine learning and hybrid models show the landscape evolvement in health care.

Table 1: Comparative Analysis of Data Mining Techniques for Heart Disease Prediction and Healthcare Data Analysis

Study	Objective	Methodologies	Key Findings	Contributions
Darrab et al. (2024) [21]	Enhance understanding and predictability of heart disease using rare association rule mining	Rare association rule mining integrated with feature engineering (EPFHD-RARMING)	Identifies high-risk patterns in seemingly healthy individuals; facilitates early intervention	Demonstrates superior performance in terms of explainability and comprehensiveness compared to traditional models; applicable beyond healthcare in fields like finance and cybersecurity
Soni et al. (2011) [22]	Survey current data mining techniques for heart disease prediction	Decision Trees, Bayesian Classification, K-Nearest Neighbors (KNN), Neural Networks, Genetic Algorithms	Decision Tree outperforms; Bayesian Classification shows similar accuracy; Genetic Algorithms enhance accuracy by reducing dataset size	Highlights effective predictive techniques; Genetic Algorithms improve accuracy and data processing efficiency
Srinivas et al. (2010) [23]	Explore classification techniques for heart attack prediction using large healthcare datasets	Rule-Based Classification, Decision Trees, Naïve Bayes, Artificial Neural Networks, One Dependency Augmented Naïve Bayes (ODANB), Naive Credal Classifier 2 (NCC2)	ODANB and NCC2 provide robust classifications with small or incomplete datasets; patterns identified using medical profiles	Establishes the utility of ODANB and NCC2 for dealing with incomplete data; identifies hidden patterns in heart disease data
Hossain et al. (2019) [24]	Review electronic health data-based risk prediction models for different diseases	Literature review, Electronic Health Data Analysis, Various Disease Prediction Models	High accuracy in disease prediction using electronic health data; models inform clinical decision-making	Offers a comprehensive comparison of risk prediction models; discusses advantages, disadvantages, and performance metrics

Altaf et al. (2017) [25]	Review applications of association rule mining in health informatics	Association Rule Mining (ARM), Apriori Algorithm	Apriori remains widely used despite more efficient alternatives; limitations identified and recommendations provided	Provides insights into ARM's role in health informatics; calls for more efficient ARM algorithms and future research directions
Sornalakshmi et al. (2020) [26]	Develop a hybrid method for improving association rule mining in healthcare	Enhanced Apriori Algorithm (EAA) with Sequential Minimal Optimization (SMO)	EAA-SMO improves accuracy by 2% and reduces execution time by 25% compared to traditional Apriori	Proposes EAA-SMO for more efficient rule mining; addresses limitations of conventional ARM techniques
Banaee et al. (2013) [27]	Review data mining methods for wearable sensor data analysis in health monitoring	Anomaly Detection, Prediction, Decision Making, Continuous Time Series Analysis	Various methods effectively process physiological data from wearable sensors; challenges identified for data mining in health monitoring	Highlights data mining challenges for continuous data; provides a framework for future research in sensor data processing
Ali et al. (2020) [28]	Propose a smart system for heart disease prediction using deep learning	Ensemble Deep Learning, Feature Fusion, Information Gain, Conditional Probability	Achieves 98.5% accuracy; outperforms traditional classifiers	Introduces a smart healthcare system with high predictive accuracy; demonstrates the effectiveness of feature fusion and weighting techniques

VI. Conclusion

This involves the health sector, especially the prediction of heart disease, promises to boom with advanced algorithms in association rule mining (ARM). Although the Apriori algorithm is fundamental to ARM, there are several reasons for which it runs into problems about producing too many rules and calls for advanced methods to make it more effective. Precise use cases in the medical domain, better suited, could be achieved with innovative approaches such as hybrid approaches that fuse ARM with machine learning strategies such as Naïve Bayes and Decision Trees. These developments are based on gigantic datasets from wearable sensors and electronic health records otherwise hidden from the world. Data heterogeneity, computational complexity, and privacy remain huge concerns. IoT devices do provide immense volumes of data while also offering inconsistencies and issues with privacy that have rendered development and implementation of models much harder. The power requires strong systems that integrate data, security, as well as real-time processing for effective resolution of these problems. This will probably revolutionize healthcare practices with the growing capability to forecast heart diseases at an early and more precise stage, which is highly expressed in the development of data mining techniques, especially hybrid approaches and improved classifiers. Moreover, the comparative evaluation of different research highlights the range of methods used to improve the prediction of heart disease. Methods like Ensemble Deep Learning and the Enhanced Apriori Algorithm (EAA) have shown to be more accurate and efficient. These developments show how important it is to do continuing research and development to improve data mining techniques so that they can continue to be relevant and useful for enhancing healthcare outcomes. To summarise, there is considerable potential for improving the prognosis and management of cardiac disease through the incorporation of sophisticated ARM approaches with contemporary machine learning models. These techniques' continued development will be essential to the advancement of healthcare analytics, which will ultimately result in improved patient care and more knowledgeable clinical judgements.

References

[1] Santoso, M. H. (2021). Application of association rule method using apriori algorithm to find sales patterns case study of indomaret tanjung anom. *Brilliance: Research of Artificial Intelligence*, *1*(2), 54-66.

[2] Fister Jr, I., Fister, I., Fister, D., Podgorelec, V., & Salcedo-Sanz, S. (2023). A comprehensive review of visualization methods for association rule mining: Taxonomy, challenges, open problems and future ideas. Expert Systems with Applications, 120901.

[3] Aljehani, S. S., & Alotaibi, Y. A. (2024). Preserving Privacy in Association Rule Mining Using Metaheuristic-Based Algorithms: A Systematic Literature Review. IEEE Access.

[4] Yewale, D., & Vijayragavan, S. P. (2022, May). Comprehensive review on machine learning approach for heart disease prediction: Current status and future prospects. In AIP Conference Proceedings (Vol. 2463, No. 1). AIP Publishing.

[5] Mohsin, S. N., Gapizov, A., Ekhator, C., Ain, N. U., Ahmad, S., Khan, M. & Nagaraj, R. H. (2023). The role of artificial intelligence in prediction, risk stratification, and personalized treatment planning for congenital heart diseases. Cureus, 15(8).

[6] Nguyen, D. C., Pham, Q. V., Pathirana, P. N., Ding, M., Seneviratne, A., Lin, Z., ... & Hwang, W. J. (2022). Federated learning for smart healthcare: A survey. ACM Computing Surveys (Csur), 55(3), 1-37.

[7] [6].Al Yahyaei, A., Hewison, A., Efstathiou, N., & Carrick-Sen, D. (2022). Nurses' intention to stay in the work environment in acute healthcare: a systematic review. Journal of Research in Nursing, 27(4), 374-397.

[8] Boehm, K. M., Khosravi, P., Vanguri, R., Gao, J., & Shah, S. P. (2022). Harnessing multimodal data integration to advance precision oncology. Nature Reviews Cancer, 22(2), 114-126.

[9] Attaran, M. (2022). Blockchain technology in healthcare: Challenges and opportunities. International Journal of Healthcare Management, 15(1), 70-83.

[10] Rehman, A., Naz, S., & Razzak, I. (2022). Leveraging big data analytics in healthcare enhancement: trends, challenges and opportunities. Multimedia Systems, 28(4), 1339-1371.

[11] Liu, F., & Panagiotakos, D. (2022). Real-world data: a brief review of the methods, applications, challenges and opportunities. BMC Medical Research Methodology, 22(1), 287.

[12] Kumbhare, T. A., & Chobe, S. V. (2014). An overview of association rule mining algorithms. International Journal of Computer Science and Information Technologies, 5(1), 927-930.

[13] Gupta, S., & Mamtora, R. (2014). A survey on association rule mining in market basket analysis. International Journal of Information and Computation Technology, 4(4), 409-414.

[14] Saxena, A., & Rajpoot, V. (2021, March). A comparative analysis of association rule mining algorithms. In IOP conference series: materials science and engineering (Vol. 1099, No. 1, p. 012032). IOP Publishing.

[15] Tarawneh, M., & Embarak, O. (2019). Hybrid approach for heart disease prediction using data mining techniques. In advances in internet, data and web technologies: the 7th international conference on emerging internet, data and web technologies (EIDWT-2019) (pp. 447-454). Springer International Publishing.

[16] Bashir, S., Khan, Z. S., Khan, F. H., Anjum, A., & Bashir, K. (2019, January). Improving heart disease prediction using feature selection approaches. In 2019 16th international bhurban conference on applied sciences and technology (IBCAST) (pp. 619-623). IEEE.

[17] Babu, S., Vivek, E. M., Famina, K. P., Fida, K., Aswathi, P., Shanid, M., & Hena, M. (2017, April). Heart disease diagnosis using data mining technique. In 2017 international conference of electronics, communication and aerospace technology (ICECA) (Vol. 1, pp. 750-753). IEEE.

[18] Khan, M. A. (2020). An IoT framework for heart disease prediction based on MDCNN classifier. Ieee Access, 8, 34717-34727.

[19] David, H., & Belcy, S. A. (2018). HEART DISEASE PREDICTION USING DATA MINING TECHNIQUES. ICTACT Journal on Soft Computing, 9(1).

[20] Zriqat, I. A., Altamimi, A. M., & Azzeh, M. (2017). A comparative study for predicting heart diseases using data mining classification methods. arXiv preprint arXiv:1704.02799.

[21] Darrab, S., Broneske, D., & Saake, G. (2024). Exploring the predictive factors of heart disease using rare association rule mining. Scientific Reports, 14(1), 18178.

[22] Soni, J., Ansari, U., Sharma, D., & Soni, S. (2011). Predictive data mining for medical diagnosis: An overview of heart disease prediction. International Journal of Computer Applications, 17(8), 43-48.

[23] Srinivas, K., Rani, B. K., & Govrdhan, A. (2010). Applications of data mining techniques in healthcare and prediction of heart attacks. International Journal on Computer Science and Engineering (IJCSE), 2(02), 250-255.

[24] Hossain, M. E., Khan, A., Moni, M. A., & Uddin, S. (2019). Use of electronic health data for disease prediction: A comprehensive literature review. IEEE/ACM transactions on computational biology and bioinformatics, 18(2), 745-758.
[25] Altaf, W., Shahbaz, M., & Guergachi, A. (2017). Applications of association rule mining in health informatics: a survey. Artificial Intelligence Review, 47, 313-340.
[26] Sornalakshmi, M., Balamurali, S., Venkatesulu, M., Navaneetha Krishnan, M., Ramasamy, L. K., Kadry, S., & Muthu, B. A. (2020). Hybrid method for mining rules based on enhanced Apriori algorithm with sequential minimal optimization in healthcare industry. Neural Computing and Applications, 1-14.
[27] Banaee, H., Ahmed, M. U., & Loutfi, A. (2013). Data mining for wearable sensors in health monitoring systems: a review of recent trends and challenges. Sensors, 13(12), 17472-17500.
[28] Ali, F., El-Sappagh, S., Islam, S. R., Kwak, D., Ali, A., Imran, M., & Kwak, K. S. (2020). A smart healthcare monitoring system for heart disease prediction based on ensemble deep learning and feature fusion. Information Fusion, 63, 208-222.