Bioinspired Intelligence in IoT: A Comprehensive Survey

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Abstract

Recent developments in the Internet of Things, Artificial Intelligence, and cloud computing are transforming healthcare into a personalized and data-driven ecosystem. IoT-based healthcare systems, also known as the Internet of Medical Things, facilitate real-time monitoring through interconnected medical devices. However, the dynamic nature of healthcare environments demands adaptive systems capable of evolving over time. This research explores adaptive IoT systems inspired by Evolutionary Algorithms such as Genetic Algorithms, Ant Colony Optimiza- tion, and Particle Swarm Optimization. These bio-inspired models dynamically adjust device configurations and improve data processing, improving diagnostic accuracy and system performance. By using natural selection and evolutionary principles, the proposed framework integrates machine learning techniques, including Convolutional Neural Networks and Long Short-Term Memory networks, to analyse patient data and enhance decision-making accuracy. The application of these models addresses key challenges in scalability, energy efficiency especially for chronic disease management and elderly care, while also reducing costs and enhancing patient outcomes. This research is a mirror to the revolutionary changes that could be made by adaptive systems in the medical field. Keywords: Internet Of Things, Evolutionary Algorithms, Bio-inspired models, Data driven healthcare.

I. INTRODUCTION

Widespread connectedness and IoT has transformed the dynamics of patient care in the most beneficial way, allowing patient's health to be constantly monitored, diagnostics to be conducted, and data be processed instantly. All these connected devices, that form a whole ecosystem, are commonly referred to as the Internet of Medical Things. While there are great benefits provided by the IoMT, it also poses challenges such as: energy limitation, a necessity for quick and efficient data processing and certain data security and accuracy requirements. As one of the possible solutions to the posed issues, bio-inspired algorithms stand out with great effectiveness. These algorithms take their essence from natural models that include swarm intelligence, immune response systems, and processes of evolution which allow them to be flexible, efficient, and robust enough to meet various needs of IoT in the sphere of healthcare.

The use of bio-inspired algorithms in IoT is intricately tied to a number of biological systems, which offer possible solutions to a number of complicated issues. For instance, swarm intelligence models imitate the distributed decision making in colonies of ants and bees in order to enhance the routing and load balancing in the network. The utilization of devices that 'expect' to manage data and consume power more effectively as they 'benefit' from a process similar to natural selection are termed Genetic algorithms (GAs) [6]. These models not only optimize resource allocation but also provide information with several benefits in IoMT such as improving energy efficiency, allowing for a level of monitoring that dynamically changes and keeping the data safe. Usually, there are three layers of Healthcare IoT architectures: Device layer, edge/fog layer and cloud layer. [16] Each of these layers is responsible for different tasks for example collecting patient data to local processing for later centralized storage. Bio inspired algorithms supplement each layer with effective data processing, minimum latency, and optimal storage and retrieval on the move. Such flexibility is important in healthcare settings where, quite often, even the smallest of delays in processing the data can affect the care given to patients. [16]

II. BIO-INSPIRED IOT ARCHITECTURE IN HEALTHCARE SYSTEMS

Usually, the bio-inspired IoT healthcare architecture is organized into three interacting layers: the device layer, the edge/fog layer and the cloud layer. [16] The purpose of each layer is mainly to process patient related information, manage data efficiently and protect personal information securely.

A. Device Layer

The device layer consists of wearables and IoT sensors, which monitor patients' heart rate, blood pressure, glucose levels, etc., in real time. However, there are many self-powered units in the field which need effective energy management to support continuous monitoring of patients over a long period of time. Bio-inspired algorithms are one of these competing solutions to the energy constraint since they replicate energy efficient behaviour evident in animals. For example, some sensors lose activity when patients are passive, which is similar to how most living things behave to conserve their energy. [17] Other algorithms, such as Ant colony optimization ACO, Particle swarm optimization (PSO) which have swarm intelligence ideas assist in determining the best routing of data within the device during layer which helps in allowing all the sensors to send data through the least power consuming route in order to cut energy.

B. Edge/Fog Layer

There is a need for an edge/fog layer as it has been pointed out that the data is processed closer to the source, both of which reduce latency in the health sector. Despite the fact that IoMT handles an enormous amount of data, this data must, first and foremost, be processed right away, especially for monitoring devices that require instantaneous notifications to healthcare professionals in the event of an emergency [9]. This layer makes use of swarm intelligence algorithms, for instance ACO, that assist in dispatching data packets by calculating the most efficient routs for data packets. It reduces constraints and adjusts the data loads in real time according to the network circumstances and the patient condition's dynamics. [5] The edge layer has further been successfully integrated with bio inspired algorithms that are distributed, consequently the need of transmitting large amounts of information to the central processing units has been eliminated allowing faster responses.

C. Cloud Layer

All patient data is kept in the cloud layer for collection and continuous analysis, as well as long-term storage of data. There are bio inspired algorithms such as Genetic Algorithms that help to organize data hierarchically in this layer with the aim of seamless storage and retrieval processes and avoiding congestion in the data flow. [11] GAs use natural selection methods to evolve designs that enhance different aspects that are incorporated in the data structure. This is very important in an industry like healthcare where there is need for immediate and successive analysis of data to uncover new insights that are actionable. [3]

III. APPLICATIONS OF BIO-INSPIRED IOT IN HEALTHCARE

Healthcare in particular, bio-inspired IoT systems are significant bio-inspired algorithms that hold great potential for innovative applications in various aspects of healthcare IoT systems as they allow for dynamic, adaptive, and efficient use of resources. Bio-inspired IoT applications in healthcare can be used for patient's continuous monitoring, remote monitoring diagnosis, remote emergency treatment, or patient's data analysis and anomaly detection. [14] The use of these algorithms enables IoT systems to tackle intricate activities through the emulation of swarm intelligence, genetic evolution, as well as immune response and each activity can be executed with utmost energy efficiency which also minimizes resource wastage. [19]

A. Real-Time Patient Monitoring and Anomaly Detection

Real time patient monitoring is considered to be one of the practical examples of the IoT which has application in healthcare, which is the continuous tracking of vitals and active monitoring of patients when required. Algorithms that are bio-inspired, and in this case commercialized by swarm intelligence, assist in this task by enabling IoTs to perform the task based on the data at hand. In swarm intelligence algorithms such as Ant Colony Optimization and Particle Swarm Optimization, the devices of the system imitate the ant or bird flock's decentralized behaviours. [13] Each individual device monitors definite vitals while each device gets the assistance of the other devices in the network to establish the complete patient status. For instance, in performing cardiac monitoring, the wearable devices can employ Ant Colony Optimization to transmit signals through the most efficient paths and ensure timely transfer of critical information such as abnormal heartbeat rate to physicians. [13] The same situation applies for Particle Swarm Optimization, in this case energy used can be managed to the degree of the health message being sent so that batteries can be preserved while matters requiring immediate attention are sent first. [20]

- *Case Study: Chronic Disease Management Using Wearable Devices*

PSO technology was integrated into machine learning and combined with a continuous monitoring system for heart patients. Energy efficiency was improved through adaptive sampling frequency based on heart rate patterns. It was trained to understand the historical data and evaluate each anomaly's level. [2] Clinicians received timely notifications of critical events. The system reduced false alarms, improving sensitivity to critical events. This implementation was illustrative of the benefits of AIoT based systems in the management of cardiac patients and how energy efficient AI classification and PSO features of the device enhanced both safety and shelf life of the device respectively. [20] The AIoT equipped wearables have been reported to have a considerable impact on averting emergency cases as early actions were activated. A six-month trial showed a 30% reduction in emergency admissions. This showcases the potential of AIoT in chronic patient care.

B. AI in the Optimization of Emergency Resources

Available must be optimally utilized. It has been shown that Genetic Algorithms (GAs) which have been enhanced with AI technology are of great benefit in managing resources in such emergency situations. [9] Through machine learning, GAs can predict demand trends, adjust, and distribute resources instantly whenever the need arises. With the incorporation of AIoT technology in EDs and ICUs, there is an assurance that resources including treatments, medical personnel and equipment are available at the required time or place.

- AIoT Sensor Exploration and Use : GAs utilize machine learning models that optimize historical ED and ICU data to predict peak operating times and likelihood of patient traffic. Remsoft AIoT has a yet-to-be announced ability for real time resource allocation which takes into consideration patient urgency, equipment availability, and staff availability. This ability allows healthcare institutions to utilize their resources economically while making sure that specialized care for severe situations is not missed. [20]

- Research Strategy: Use Case of AIoT Management of Resources in a Must-Win ED. One urban healthcare institution engaged GA that was based on AIoT to be implemented for effective management of the resources in the emergency department which is already busy. In the development of this system, its AI component learned during the process from 3 years of historical data containing the total volume of the patient's institution, their triage and created a schedule of work for the resources in rush hours. This helped the AIoT system to manage resources by predicting high-usage periods and evenly distributing resources depending on the condition of the patients and the quantity already in use. [8]

C. *Remote Health Monitoring*

Remote patient monitoring was, and continues to be an important IoT application in the field of healthcare but has gained attention post pandemic where access to medical facilities are scarce within many rural or underserved regions.

Remote health monitoring systems can optimize the use of data transfer, increase energy utilization efficiency and reduce response time using bio-inspired based algorithms. Consider setups where bio-inspired models like ACO and PSO enable assured device communications towards the central monitoring hubs with minimized power consumption and data preservation over a long distance problem. [5]

In remote monitoring systems, for example, ACO algorithms focus on prioritizing data according to urgency, so that urgent health data is sent first. This efficiency is an improvement of remote monitoring as PSO algorithms separate tasks across devices by minimizing energy consumption. With the help of these adaptive approaches, wearables can wakeup to raise alerts when specific health parameters exceed certain threshold values, which empowers healthcare providers with time critical information during emergencies while also reducing device battery consumption. [20]

- *Case Study: AIoT Supported Rural Telemedicine for Chronic Disease Patients*

For the rural healthcare program that aims to assist diabetic and hypertensive patients, an AIoT-enabled wearable device is used to relay the health data using low bandwidth connections. Connected Care allowed the patients to engage with health care providers remotely. However, the problem of limited electricity still existed. In order to alleviate the charging problem, the device reduced the transmission frequency during stable periods, thus extending the battery life to 2 weeks. [17] It resulted in a 40% decrease in emergency hospitalization because of timely inter- ventions and proactive aid. This AIoT based approach certainly disrupted previously existing practices of healthcare and made remote monitoring much more accessible. Improving accessibility to healthcare was one of the major points of consideration, for working through this issue, it was ensured that the devices used were both cost effective and allowed for the patients to have timely interventions. [9]

From wearables to ICU management, AI-enhanced bio-inspired IoT has made tangible advances in patient results, op- erational efficiency, and resource management. With bio-inspired algorithms and AI predictive power fused together, AIoT gives personalized, efficient and resilient solutions to address the healthcare challenges worldwide.

IV. COMPARATIVE ANALYSIS OF BIO-INSPIRED ALGORITHMS IN IOT HEALTHCARE

Bio-inspired algorithms are growing an immaculate importance in the sphere of IoT supported healthcare technologies with their natural capability to adjust, resist, and endure transmutations in evolving scenarios which allows them to prosper. Nonetheless, all algorithms, be it Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO), Genetic Algorithms (GAs), Artificial Immune Systems (AIS) have their own merits and demerits. In this segment, we will discuss these algorithms and their functioning in IoT healthcare with the working of each, along with some details about applications and advantages vs challenges.

A. *Ant Colony Optimization (ACO)*

Ant Colony Optimization (ACO) simulates the behaviour of ants as they find ways to best sources of food. When it comes to IoT healthcare use cases, ACO allows devices to choose the best paths for transmitting data, which in turn reduces delays and saves energy when constant patient monitoring is needed. In ACO, ways in which ants communicate by pheromone trails to find shortest paths are mimicked, while in the IoT digital "pheromones" are created that guide data packets as they flow across network nodes. Such behaviour guarantees that the most critical data (like vitals which are provided by wearables, live) relays quickly and goes to the healthcare professionals on time.

- Use cases and Advantages: ACO perfectly works in decentralized settings such as IoT networks where devices can operate online, quasi-independently while also contributing towards a global object. For example, in a hospital network, each IoT device-enabled with ACO can independently follow patient data flow to the edge devices or cloud storage which are nearby locations while saving energy and minimizing losses caused by dropping of data packets. Such free will permits the network to dynamically respond to disruptions, ensuring that the data remains cleaned up correctly even without disruption during periods of high demand, or verify before a widespread change in systems used. For healthcare monitoring applications, ACO also is resource conserving. Since wearable devices should work 24/7, usually are powered with a limited power source, by using ACO for those devices to choose the most energy-efficient paths are very good for long-lasting operation. This is particularly crucial in emergency response situations where rechargeable wearable devices must be able to function without having to recharge the unit for a long period of time.

- Challenges and Limitations: ACO's decentralized, adaptive nature, while a strength, can also be a potential weakness contributing inefficiencies in highly connected networks. As an example, excessive route creation in a crowded IoT system can demand duplicates or inadequate paths for controlling traffic causing delay or bottleneck. This can be solved by tuning the healthcare IoT system via ACO as pheromone trails must decay at a proper rate to avert outdated routing paths from reoccurring together in high frequency. In order to utilize ACO for the network, real-time updating of network state information is also necessary which imposes more processing burden on the IoT system. If the scenario has highly dynamic network topology, i.e. frequent re-routings cause a temporary break-down of efficient data transmission regime, then performance of the algorithm can degrade.

B. PSO (Particle Swarm Optimization)

Particle Swarm Optimization (PSO) is inspired by the social behaviour of birds or fish, following each other to a target location. In PSO, each "particle" is a potential solution that moves through the solution space according to its own experience and that of an aggregate of its neighbours. PSO is widely utilized in IoT healthcare for resource allocation and energy management issues, particularly in the context of wearable devices that must optimize battery life while monitoring patient vitals continuously.

- Applications and Benefits: PSO is used mainly in applications which need adaptive power management. For example, in healthcare wearables, PSO allows the mode of monitoring to be periodically updated according to the health condition of a monitored population and transmission frequency is increased or decreased based on the systematization technology specification (i.e., according to the health status of patients). In the case of a wearable, it may reduce data transmission when vitals are stable to preserve battery life but will increase sampling rate if changes in vitals such as an increase in heart rate or blood pressure is detected. This flexibility makes PSO very suitable for remote monitoring applications, where long lifetime of devices is critical.

Another example of PSO in healthcare IoT is the organization of the sensors within the system. This is more pertinent to the hospitals with a high number of IoT patients, as PSO allows the positioning of multiple IoT devices to minimize the signal interference and enlarge the coverage area. This guarantees that the configurations of PSO's sensors are sufficient in ensuring the proper allocation of sensor coverage, especially where important areas are in focus and energy is minimized. This is also very useful in situations that require patient monitoring such as in Intensive Care Units (ICU) with a lot of sensor points.

- Challenges and Limitations: PSO has a number of characteristics that could prevent its effective utilization in such a broad context, but particularly when one considers its efficiency for large-scale computations. Therefore, this approach assumes that there may be some discrepancies in the decision-making processes, which can lead to the worse general results as compared to larger networks that could support the PSO algorithms. [14] However, another issue that could be criticized is that PSO might sometimes fail when the goal is achieved in terms of finding all solutions and even then the system remains in a very rigid state of being. PSO, however, has other issues as it is good at dealing with complex problems with many solutions such as many different hospitals and diverse needs. The algorithm can also adapt the combination of PSO with other optimized algorithms or even hybrid models, and this is the advantage of PSO, as opposed to single optimization models. Despite these limitations, PSO remains relevant for dealing with wearable devices and energy-sensitive IoT systems in the healthcare industry.

C. GAs, or Genetic Algorithms

Genetic algorithms (GAs) mimic natural selection and evolution by using processes like crossover, mutation, and selection to generate optimal solutions across a number of rounds. [17] In IoT healthcare, GAs are used to optimise resource allocation and decision-making, particularly in emergency scenarios where resource management may affect patient outcomes. By using the survival of the fittest paradigm, GAs prioritise solutions that best meet healthcare demands, allowing IoT systems to gradually improve in efficacy.

- Uses and Advantages: In emergency departments (EDs) and critical care units (ICUs), GAs are commonly used for dynamic resource allocation. For example, a GA-based IoT system can prioritise patients depending on their severity, ensuring that critical cases receive resources like monitoring equipment or personal attention in a timely manner. This prioritising is essential when there are limited resources and a high patient volume since effective triage can mean the difference between life and death. GAs can also be used to optimise the transmission and data processing settings of Internet of Things devices. In healthcare scenarios involving data needs, GAs iteratively adjust device setups to maximise processing efficiency and minimise latency. GAs assist IoT devices in managing massive data volumes, lowering the possibility of bottlenecks in healthcare networks as they continuously evolve towards optimal solutions.
- Challenges and Limitations: Even though GAs are effective, their iterative nature can be time-consuming, which makes them less appropriate for real-time applications that require results right away. GAs may be limited in situa- tions that need for quick alterations, such emergency patient monitoring, because it takes several generations to get to the best solution. [12]In critical care conditions, this may result in unfavourable delays. Furthermore, GAs demand a lot of processing power, particularly in big healthcare systems. The technique uses more processing power than other bio-inspired algorithms since it relies on iterative mutation and selection processes, which can be a limitation in IoT situations with constrained computational resources. Even with these drawbacks, GAs are nonetheless very useful for non-time-sensitive applications where the necessity for instantaneous response is outweighed by their capacity to optimise resource allocation over time.

V. FUTURE DIRECTIONS AND CHALLENGES IN BIO-INSPIRED IOT FOR HEALTHCARE

As bio-inspired algorithms are progressively incorporated into healthcare IoT, ongoing research and development aims to address the limitations associated with computation requirements, data privacy, energy efficiency, and scalability. Future advancements in quantum computing, biomimetic encryption, and sustainable energy sources may expand the potential uses of bio-inspired IoT in healthcare. This section looks at both these positive improvements and the challenges that the healthcare IoT will face as it expands.

A. Emerging Research Areas

Advances in bio-inspired IoT in healthcare are anticipated to revolutionise diagnostics, patient monitoring, and overall healthcare administration. Important research topics include:

- Quantum Computing IntegrationBio-inspired algorithms: The use of quantum computing could make it quicker and more efficient. Because quantum processors can perform calculations at speeds that ordinary computers cannot match, they are ideal for large-scale healthcare IoT systems that need to handle complex, high-dimensional data in real-time. Combining quantum computing with models like MSSO-ANFIS, for instance, may reduce the computational load in diagnostic applications, allowing for faster and more accurate predictions with less device power. [3]
- Biomimetic Encryption for Enhanced Security: Due to the fact that IoT healthcare solutions gather sensitive patient data, robust security is essential. Biomimetic encryption, a new technique for Internet of Things data protection, is based on the genetic coding present in DNA. Because biomimetic encryption algorithms mimic the complexity and individuality of genetic systems, they can provide extremely safe, multilayer encryption methods that protect patient data from internet threats. This encryption method can assist comply with the stringent privacy regulations in the healthcare sector while enabling decentralised data transfer across IoT devices.
- Hybrid Bio-Inspired and Machine Learning Algorithms: Combining bio-inspired algorithms with machine learning could make IoT healthcare systems more adaptable. IoT devices can enhance their performance by examining historical data trends using hybrid algorithms, which combine the self-optimization potential of bio-inspired models with the predictive power of machine learning. To give a more accurate diagnosis, for example, a hybrid MSSO-ANFIS and machine learning model can continually learn from patient data and modify its parameters in real-time.

B. Data Privacy and Ethical Implications

Data privacy in the healthcare IoT is a big concern because patient data is sensitive. Although bioinspired algorithms promote decentralised data management, they also raise moral concerns regarding data privacy, transparency, and patient consent. Strong security measures that safeguard patient privacy are required to guarantee adherence to regulations like GDPR and HIPAA that deal with healthcare data.

- Data Ownership and Transparency: IoT-enabled healthcare devices that rely on continuous data collection pose questions about data transparency and ownership. Accessing their data and understanding its use should be easy for patients. Real-time bio-inspired models such as AIS that can detect irregularities may help protect patient privacy by preventing unauthorised access to data.
- Regulatory Compliance in Data Security: Bio-inspired IoT devices must stick to rules governing healthcare data, including the safe handling and processing of patient data. Algorithms like AIS must be used along with advanced encryption and compliance frameworks to ensure data security. These algorithms provide a decentralised and real-time approach to risk assessment.

C. Energy Efficiency and Sustainability

The need for continuous operation of wearables and other battery-operated sensors remains one of the primary energy efficiency issues facing IoT healthcare equipment. Energy efficiency has been improved by bio-inspired algorithms such as PSO and ACO by removing redundant data transmission and improving routing patterns; nevertheless, more advancements are needed to achieve long-term sustainability.

- Energy Harvesting Technologies: Research into renewable energy sources, such as solar or kinetic energy col- lecting, may help power IoT healthcare equipment in a sustainable manner. For example, wearables that run on solar power could do away with batteries and allow for extended observation periods. When combined with energy- efficient algorithms like PSO, energy harvesting devices can support the sustainable operation of IoT healthcare systems, particularly in distant or resource-constrained environments.
- Low-Energy Data Processing Models: New low-energy algorithms that can operate on a minimal amount of electricity are being created, drawing inspiration from nature. Through the reduction of bio-inspired IoT's energy consumption, these models could allow medical devices to continually monitor patients without requiring recharging. Healthcare IoT devices may last longer, improve patient comfort, and have a lesser environmental impact if low-energy bio-inspired algorithms are analysed.

D. Scalability in Expanding IoT Healthcare Systems

As IoT healthcare systems expand, they must be able to manage a growing number of connected devices without sacrificing functionality. Bio-inspired algorithms like ACO and PSO have been successfully used to manage small-to-medium-sized IoT networks; however, further optimisation is required for larger, more complex networks to continue to function well..

- Adaptive Resource Management for Large-Scale Networks: For the healthcare IoT to successfully scale, adaptive resource management is crucial. ACOs and GAs can assist IoT systems in managing resource demands by assigning tasks to devices based on their capabilities and current burden. It can be challenging to prevent redundant routing channels while raising ACO in bigger networks, which can lead to network congestion. Additional research is needed before these models may be used in massive healthcare networks, like hospital systems and massive telemedicine platforms.

- Distributed Processing and Edge Computing: Adaptive resource management is necessary for the healthcare IoT to scale effectively. By allocating tasks to devices according to their capabilities and present load, ACOs and GAs can help IoT systems manage resource demands. Network congestion may result from the difficulty of removing redundant routing channels when extending ACO in larger networks. To use these models in extensive healthcare networks, such as hospital systems and big telemedicine platforms, more study is required.

E. Advanced AI with Bio-Inspired Algorithms

Combining state-of-the-art AI techniques with bio-inspired algorithms in healthcare IoT opens up new possibilities for enhanced real-time, adaptive, and predictive response. Deep learning models such as convolutional neural networks (CNNs) and long short-term memory (LSTM) networks may enhance the ability of bio-inspired IoT to evaluate complex healthcare data patterns and generate more accurate predictions.

- Predictive Analytics and Deep Learning: By integrating deep learning with bio-inspired models, predictive analytics enables IoT devices to assess patient data and foresee potential health issues. Wearable technology, for example, may be able to recognise patterns that indicate a risk of heart disease and alert medical practitioners before symptoms worsen when MSSO-ANFIS and LSTMs are coupled.[cite16]
- Improved Decision-Making in Real-Time Scenarios: Decision-making can be improved by AI-enhanced bio-inspired algorithms that continuously improve operational tactics based on previous data. For instance, in emergency departments when circumstances change rapidly and swift action is required, a GA combined with reinforcement learning may optimise resource use.

Bio-inspired IoT and AI can be combined to improve the accuracy, efficiency, and flexibility of healthcare systems. Through the enhancement of proactive, customised, and patient-centered healthcare delivery, this approach has the potential to revolutionise the healthcare sector.

VI. CONCLUSION

By providing innovative solutions to the unique challenges posed by real-time patient monitoring, diagnosis, and resource management, bio-inspired algorithms are revolutionising the healthcare IoT field. Natural processes like swarm intelligence, evolutionary adaptation, and immune response provide as inspiration for these algorithms. As the Internet of Medical Things (IoMT) in healthcare advances, bio-inspired algorithms are expected to play a key role in providing the advantages of efficient resource management and dynamic patient care adaptability.

In this study, we looked at the three-tiered architecture of bio-inspired IoT in healthcare, specifically the device, edge/fog, and cloud levels. The bio-inspired algorithms that optimise data collection and processing at the device layer, enhance responsiveness at the edge/fog layer, and provide efficient long-term data analytics and cloud storage are advantageous to each layer.

Predictive diagnosis, real-time monitoring, emergency resource management, and remote health monitoring are just a few of the numerous applications of bio-inspired IoT in healthcare. The case studies covered in this paper illustrate the advantages of applying bio-inspired algorithms in real healthcare settings, demonstrating how they can improve patient outcomes and speed up medical processes. However, ACO and PSO have demonstrated potential in remote care and energy-efficient monitoring. These applications demonstrate how bio-inspired algorithms aid in the creation of patient-centered healthcare solutions that prioritise dependability and adaptability.

However, the successful implementation of bio-inspired IoT in the medical field remains impeded. Issues with scala-bility, energy sustainability, computing efficiency, and data privacy still need to be fixed to ensure broad adoption. Future directions in this field include the improvement of algorithmic performance through the integration of quantum computing, the creation of biomimetic encryption for enhanced data security, and the utilisation of renewable energy sources to support sustainable IoT operations. The delivery of healthcare could be revolutionised by bio-inspired IoT, to sum up. Nature-inspired algorithms can improve the safety, adaptability, and efficiency of healthcare IoT systems.In the end, this will enhance the provision of healthcare and patient care. In order to fully exploit the potential of bio-inspired IoT and solve existing challenges, further research and innovation are required. As these systems advance, they could enhance patient outcomes worldwide by increasing the accessibility, responsiveness, and individualisation of healthcare.

REFERENCES

[1]. Md Manjurul Ahsan, Kishor Datta Gupta, Abhijit Kumar Nag, et al. Applications and evaluations of bio-inspired approaches in cloud security: A review. *IEEE*, September 2020.

[2]. Abdullah Alabdulatif. Bio-inspired internet of things: Current status, benefits, challenges, and future directions. *MDPI*, August 2023.

[3]. Rneem I. Aldoraibi, Fatimah Alanazi, et al. Optimising delivery routes under real-world constraints: A compar- ative study of ant colony, particle swarm and genetic algorithms. *(IJACSA) International Journal of Advanced Computer Science and Applications*, 2024.

[4]. Roobaea Alroobaea. Ai-assisted bio-inspired algorithm for secure iot communication networks. *Cluster Comput- ing*, 2022.

[5]. Muladi Gwo-Jiun Horng Aripriharta, Wangzhihao and Gwo-Jia Jong. A new bio-inspired for cooperative data transmission of iot. *IEEE*, September 2020.

[6]. Kazhan Othman Mohammed Salih Tarik A. Rashid Rafid Sagban Abeer Alsaddon Nebojsa Bacanin Amit Chhabra S. Vimal Indradip Banerjee Aso M. Aladdin, Jaza M. Abdullah. *Fitness Dependent Optimizer for IoT Healthcare using Adapted Parameters: A Case Study Implementation*, chapter 3. CRC Press, Boca Raton, 2023.

[7]. Cheng-Fa Chiang. Robust iot-based nursing-care support system with smart bio-objects. *BioMedical Engineering OnLine*, November

2018.
[8]. Reyazur Rashid Irshad and Shahab Saquib Sohail. Towards enhancing security of iot-enabled healthcare system. *IEEE*, 2020.
[9]. Gulraiz J. Joyia et al. Internet of medical things (iomt): Applications, benefits and future challenges in healthcare domain. *Journal of Communications*, April 2017.
[10]. Mohammad Ayoub Khan and Fahad Algarni. A healthcare monitoring system for the diagnosis of heart disease in the iomt cloud environment using msso-anfis. *IEEE*, July 2020.
[11]. Hemantha Krishna, Aayush Agarwal, Vinay Chamola, et al. A review on the role of machine learning in enabling iot based healthcare applications. *IEEE*, February 2021.
[12]. ZIBOUDA ALIOUAT ADO ADAMOU ABBA ARI RANIDA HAMIDOUCHE, MOURADGUEROUI. An effi-cient clustering strategy avoiding buffer overflow in iot sensors: A bio-inspired based approach. *IEEE*, November 2019.
[13]. Dr-Palanivel Rajan S. In hospital and in home remote patient monitoring. *Researchgate*, 2018.
[14]. Samson Hansen Sackey. A bio-inspired technique based on knowledge discovery for routing in iot networks. *2020 International Multitopic Conference (INMIC),IEEE*, 2020.
[15]. Kashif Saleem et al. Bio-inspired network security for 5g-enabled iot applications. *IEEE*, December 2020.
[16]. Guto Leoni Santos and Demis Gomes. Maximizing the availability of an internet of medical things system using surrogate models and nature-inspired approaches. *International Journal of Grid and Utility Computing*, 2020.
[17]. Haoran Wei, Fei Tao, Zhenghua Huang, and Yanhua Long. Bioinspired artificial intelligence applications 2023. *MDPI*, January 2024.
[18]. Zhen Yang, Yaochu Jin, and Kuangrong Hao. A bio-inspired self-learning coevolutionary dynamic multiobjective optimization algorithm for internet of things services. *IEEE*, 2020.
[19]. Shusuke Yoshimoto et al. Flexible electronics for biosignal monitoring in implantable applications. *Electronics Express*, October 2017.
[20]. Adil Yousif, Mohammed Bakri Bashir, and Awad Ali. An evolutionary algorithm for task clustering and schedul- ing in iot edge computing. *MDPI*, January 2024.