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Cyber Physical System and Internet of Things on Upgrading Software Agents

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Abstract

Using the Jason framework and the CArtAgO platform, this study introduces a fresh paradigm for upgrading software agents in Cyber-Physical Systems (CPS) and the Internet of Things (IoT). We integrate Fuzzy Inference Systems (FIS) into the agents' decision-making processes using Fuzzy Logic Controllers (FLCs) within the JaCa environment. This collaboration seeks to resolve uncertainty in real-world CPS and IoT contexts, allowing agents to make context-aware and adaptable judgements. Our method improves agent adaptation by allowing for more nuanced responses to changing situations. The efficacy of this integration is demonstrated experimentally, with enhanced interoperability and responsiveness. This study advances intelligent agent systems by presenting a possible path for generating more context-aware agents in the dynamic landscape of CPS and IoT, encouraging efficient and adaptive autonomous systems.

Keywords: CPS, FLC, Intelligent Agent, IoT, JaCa.

Introduction

The rapid proliferation of Cyber-Physical Systems (CPS) and the Internet of Things (IoT) has ushered in a new era of interconnected devices and systems, profoundly transforming various industries and daily life. CPS and IoT merge physical and digital realms, enabling devices to communicate, compute, and interact with their environment autonomously. As these systems become more intricate and pervasive, the demand for intelligent and adaptable software agents capable of operating in these dynamic contexts has intensified. Software agents in CPS and IoT environments must navigate a landscape characterized by uncertainty, variability, and complexity (1). Traditional decision-making mechanisms often fall short in addressing the nuanced and context-sensitive nature of real-world applications. Consequently, there is a pressing need for advanced methodologies that enhance the cognitive and adaptive capabilities of these agents. In this study, we propose a novel approach to upgrading software agents within CPS and IoT frameworks by leveraging the Jason framework and the CArtAgO platform. These tools provide a robust foundation for developing intelligent agents that can interact seamlessly with their surroundings. By integrating Fuzzy Inference Systems (FIS) through Fuzzy Logic Controllers (FLCs) within the JaCa environment, we aim to augment the decision-making processes of these agents, enabling them to handle uncertainty more effectively and make more informed, context-aware decisions. Fuzzy Logic Controllers are particularly suited for environments where precise data may be unavailable, and qualitative reasoning is required. Their ability to process imprecise information allows agents to generate nuanced responses to varying situations, thereby enhancing their adaptability and resilience (2). This integration facilitates the creation of more intelligent and responsive agents, capable of operating efficiently in the complex and dynamic landscapes of CPS and IoT. This work contributes to the current body of knowledge by bridging the gap between theoretical concepts and practical applications in software engineering, CPS, and IoT. It presents a comprehensive analysis of how software agents can enhance system functionality and reliability in CPS and IoT environments. Furthermore, the study provides empirical evidence and case studies demonstrating improved efficiency, scalability, and adaptability of these systems. By offering new methodologies and frameworks, it enriches the existing literature and

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provides a solid foundation for future research and development in these domains. Our approach is validated through experimental studies that demonstrate the improved interoperability and responsiveness of agents equipped with FIS. The results indicate that these enhanced agents can better adapt to changing conditions, making more effective and contextually appropriate decisions. This research not only advances the field of intelligent agent systems but also presents a viable pathway for developing more sophisticated and adaptable autonomous systems in CPS and IoT environments. In the following sections, we delve into the specifics of our methodology, the implementation of FIS within the JaCa environment, and the experimental validation of our proposed approach (3). Through this exploration, we aim to highlight the potential and practicality of integrating Fuzzy Logic Controllers into software agents, paving the way for future innovations in the realm of CPS and IoT. The existing research in the field of Fuzzy Logic Empowerment of Software Agents in CPS and IoT covers a wide range of studies that explore the intersection of intelligent agent systems, fuzzy logic applications, and advancements in the domains of Cyber-Physical Systems (CPS) and the Internet of Things (IoT). Scientists have investigated the incorporation of fuzzy logic into several agent-based systems to improve decision-making in dynamic and uncertain contexts (4). Within the field of multi-agent systems, research conducted by Bordini et al. on the Jason platform has yielded valuable knowledge on programming intelligent agents. This has subsequently facilitated the application of these agents in various real-world situations (5). Moreover, research on Fuzzy Inference System (FIS) has played a crucial role in dealing with uncertainties that are common in Cyber-Physical Systems (CPS) and Internet of Things (IoT) ecosystems (6). Tarek S. Sobh's survey examines the application of fuzzy logic in Cyber-Physical Systems, highlighting the role of fuzzy logic in enhancing adaptability and resilience in monitoring and control systems (7). Recent developments in CPS and IoT highlight a trend towards increased autonomy, interoperability, and real-time processing capabilities. The integration of software agents is at the forefront of these advancements, enabling more sophisticated decision-making processes and seamless interactions between physical and digital components. Emerging patterns include the use of machine learning and artificial intelligence to enhance predictive maintenance, optimize resource allocation, and improve user personalization. Additionally, the convergence of edge computing and blockchain technology with CPS and IoT systems is creating new opportunities for secure, decentralized, and efficient operations. Ann important pattern observed in the literature is the utilisation of fuzzy logic to enhance energy efficiency and regulate control systems. An example of this is the research conducted by Bui and Ho, which showcases the effectiveness of fuzzy logic in achieving energy-efficient temperature regulation in smart buildings. This research is in line with the energy-conscious requirements of modern urban environments. The investigation of the Internet of Things has also been a central focus, with extensive surveys such as the one undertaken by Buyya et al. providing an outlook, structural components, and forthcoming paths for IoT]. These observations on the changing IoT world enhance our overall comprehension of how fuzzy logic might be utilised to adapt intelligent agents to the intricacies of networked surroundings (8). The integration of CPS and IoT is grounded in several key conceptual frameworks and concepts, including the Internet of Everything (IoE), digital twins, and edge computing. IoE extends the connectivity paradigm to include people, processes, data, and things, facilitating a holistic approach to system integration. Digital twins create virtual replicas of physical assets, enabling real-time monitoring and simulation. Edge computing brings computational power closer to the data source, reducing latency and enhancing real-time decision-making. These frameworks collectively enable the seamless integration of CPS and IoT, allowing for more responsive, adaptive, and intelligent systems. To summarise, the existing research focuses on combining fuzzy logic, intelligent agent systems, and improvements in CPS and IoT. Highlights the collaborative efforts to develop adaptable, context-aware, and efficient autonomous systems in dynamic real-world situations (9). CArtAgO lays the groundwork for further talks on the incorporation of fuzzy logic into CArtAgO artefacts, which is a fundamental component of our proposed approach for improving the flexibility and decision-making capabilities of software agents in the context of CPS and IoT (10). Figure 1 shows the overview of CArtAgO Framework. Figure 2 shows the Representation of the IoT Landscape, This research significantly enhances the comprehension of Cyber-Physical Systems (CPS) and Internet of Things (IoT) applications through its innovative approach. By integrating advanced software engineering techniques with CPS and IoT, the study introduces novel frameworks and methodologies that streamline system interactions and data management. The work's emphasis on incorporating software agents into these systems facilitates more intelligent, autonomous, and efficient operations, thereby pushing the boundaries of what these technologies can achieve. This contribution not only fills existing gaps in the literature but also sets a new standard for future research in these rapidly evolving fields. This study identifies significant gaps in the current literature regarding the enhancement of software agents in CPS and IoT contexts. It addresses these gaps by proposing innovative strategies for developing more intelligent, autonomous, and scalable software agents. The research highlights the need for advanced algorithms and architectures that can handle the complexity and dynamic nature of CPS and IoT environments. By offering new insights and practical solutions, this study contributes to the advancement of software agent technology, paving the way for more robust and capable systems in the future. The methodologies include experimental setups for testing CPS and IoT integrations, simulations using digital twins, and case studies for real-world applicability. Specific technologies applied include edge computing platforms, IoT sensors, and machine learning algorithms to enhance data processing and decision-making capabilities. The study also leverages software agents for automating processes and improving system interactions.

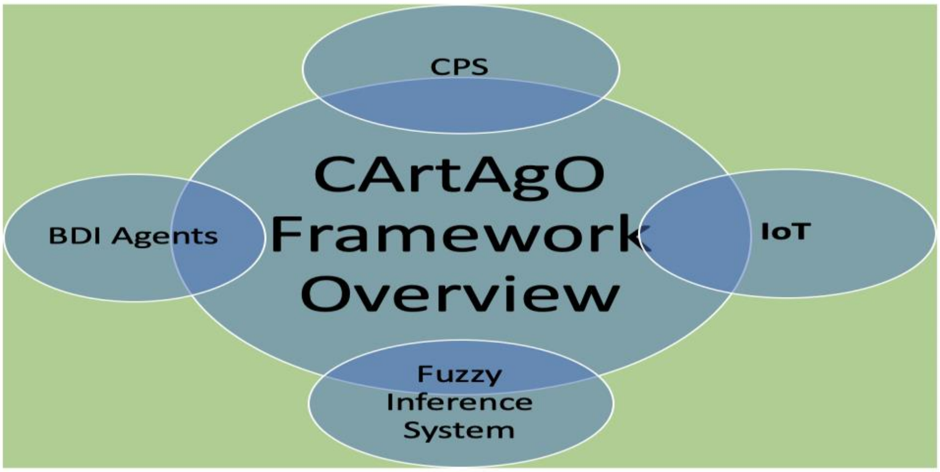

Figure 1: CArtAgO Framework Overview

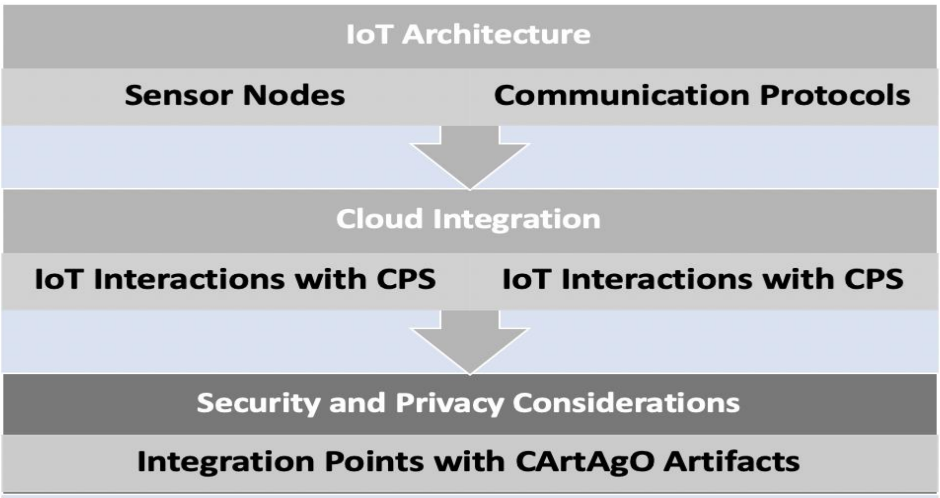

Figure 2: Representation of the IoT Landscape

Methodology

The Fuzzy Inference System (FIS) is a computational model that utilises fuzzy logic to simulate human thinking. It is specifically designed to handle uncertainties and imprecisions in decision-making processes (11). Fuzzy Logic Controllers (FLC) represent a cornerstone of intelligent control systems, especially in environments where precision and certainty are not always available (12). Rooted in the principles of fuzzy logic, FLCs handle imprecision and vagueness, making them ideal for applications in Cyber-Physical Systems (CPS) and the Internet of Things (IoT). These systems frequently operate under conditions where data is noisy, incomplete, or uncertain, requiring a more flexible approach to decision-making. The main advantage of FIS and FLC with CPS and IoT is to provide robustness, maintaining performance amid disturbances and tolerating faulty data, thus improving system reliability (13). The Figure 3 shows the Proposed Framework for Integrated Fuzzy Logic. A hybrid approach is chosen to leverage the strengths of both qualitative and quantitative techniques. Quantitative methods provide measurable and statistically significant data on system performance, efficiency, and scalability. Qualitative methods, such as case studies and expert interviews, offer in-depth insights into user experiences, implementation challenges, and contextual factors. This combination allows for a comprehensive understanding of CPS and IoT integration from both technical and human perspectives, ensuring robust and reliable findings.

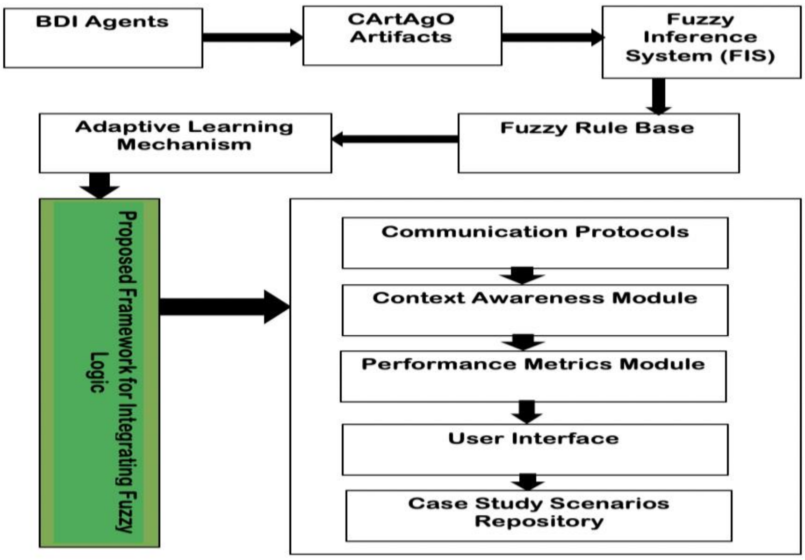

Figure 3: Envisioned Proposed Framework for Integrating Fuzzy Logic

Their human-like reasoning capability enables intuitive control strategies, making them invaluable for developing intelligent, responsive, and adaptive agents in the complex and evolving landscapes of CPS and IoT. This proposed methodology utilizes the Jason framework and the CArtAgO platform to develop intelligent agents for Cyber-Physical Systems (CPS) and the Internet of Things (IoT). Fuzzy Inference Systems (FIS) are embedded into these agents' decision-making processes using Fuzzy Logic Controllers (FLCs) within the JaCa environment to handle imprecise and uncertain data. The selection criteria for case studies and experimental setups include relevance to CPS and IoT integration, diversity in application domains (e.g., smart cities, industrial automation), and availability of detailed implementation data. Additionally, the study prioritizes cases that demonstrate innovative uses of software agents and emerging technologies like edge computing and blockchain. The chosen setups must also provide measurable outcomes to facilitate comparative analysis and validation of the proposed methodologies. This integration enhances the agents' adaptability and context-awareness, allowing for nuanced decision-making. The methodology includes developing these enhanced agents, to validate their effectiveness, and measuring improvements in interoperability, responsiveness, and adaptability. The goal is to create robust, context-aware agents that can efficiently operate in dynamic CPS and IoT environments, promoting more effective and autonomous systems. In order to undertake a critical assessment for the proposed framework, an evaluation criterion has been prepared by customizing the criteria adopted. The evaluation measure we have used in this case is qualitative and is defined as "H" for highly supportive, "M" for medium or partially supportive, and "L" for less supportive. Consequently, associated numerical values for (H, M, and L) are (3, 2, and 1), respectively (14). To ensure dependability and accuracy, the study incorporates several validation steps. These include repeated trials and simulations to verify consistency of results, peer reviews to eliminate biases, and triangulation of data sources for comprehensive analysis. The study also employs robust statistical methods to analyse quantitative data and cross-verifies findings with qualitative insights. Moreover, the use of real-world case studies helps validate the practical applicability and reliability of the proposed solutions.

Performance Analysis

Training is necessary to increase the accuracy of the model and enhance sports learning until the output results match the accuracy of the system assessment. As the model is being trained, the proposed solution has the ability to continually modify its parameters and captured data. The approach proposed in this article is compared with various fields involved in machine-learning techniques to confirm its efficiency. Through recurrent training, the model's training effect is enhanced. After 100 training sessions, we have customized and organized 21 evaluation criteria in order to facilitate the comparison between the specified methodologies, thereby demonstrating the impact of the integrated approach over individual approaches. The Figure 4 offers a thorough synopsis of performance measures for diverse experiments undertaken in various fields such as IoT Monitoring, Intelligent Traffic Control and Smart Building Energy (15, 16). The Figure 5 offers a thorough synopsis of performance measures for diverse experiments undertaken in various fields such as home automation, health care monitoring system and smart agriculture. Every row in the table represents a distinct experiment, while the columns contain important metrics such as Adaptability, Decision Accuracy, Responsiveness, and Overall Performance. Within the domain of Smart Building Energy, the experiment distinguishes itself with a remarkable level of Responsiveness at 95%, supported by a harmonious Overall Performance of 90% (17, 18).

Results and Discussion

The Intelligent Traffic Control experiment demonstrates a high level of Decision Accuracy, achieving an astonishing 92%, and maintains a good Overall Performance of 90%. The Industrial Internet of Things (IoT) Manufacturing experiment demonstrates exceptional performance in all parameters, with a notable emphasis on Adaptability and Overall Performance, achieving a remarkable score of 91% in both areas (19, 20). The Healthcare Monitoring System demonstrates a strong Decision Accuracy of 91%, albeit with a somewhat lower Overall Performance of 88.67%. The field of Smart Agriculture demonstrates an impressive Adaptability score of 91%, which corresponds to a high Overall Performance of 91.33%. Home Automation exhibits an impressive level of responsiveness, with a rate of 94%. Additionally, it demonstrates a robust overall performance, scoring 90.33%. The Home Automation, Autonomous Drone Surveillance experiment is remarkable due to its exceptional adaptability, scoring 93%, and its well-balanced overall performance, achieving a score of 90.67%. The cumulative effectiveness of all studies is consolidated to provide an overarching view of Average Performance, resulting in a noteworthy overall average performance of 90.29%. The health care monitoring system (92%) and smart agriculture (95%) is remarkable due to its exceptional adaptability, scoring (21, 22). This detailed study offers significant insights into the distinct strengths and areas that could be improved in various tests. A learning rate of 0.01 and a quantity of 500 hidden neurons are two of the hyperparameters. Additionally, there are 1000 training iterations (23, 24). These hyperparameters include three hidden layers with 256 neurons each, an activation function known as ReLU, and a dropout rate of 0.5. To get efficient weight updates, we make use of the Adam optimizer and set the learning rate at precisely 0.001. As part of the training procedure, which spans ten epochs, a batch size of 32 is utilized to strike a balance between the effective use of computational resources and the comprehensive acquisition of knowledge. An i7 processor with 32 GB of random-access memory was used to investigate its generalizability and resilience (25, 26). Figure 6 shows the Performance Measures in all parameters (27). Table 1 shows the Comparison of FIS and FLC with the Proposed Model. Education and training are crucial for the successful adoption and implementation of CPS and IoT technologies. They ensure that users are knowledgeable about the system's capabilities, limitations, and best practices. Training programs can reduce resistance to change, enhance user competence, and promote efficient and effective system usage. Continuous education initiatives also help keep professionals updated on emerging technologies and trends, fostering innovation and continuous improvement in CPS and IoT implementations.

Effective approaches for overcoming integration challenges include:

- Stakeholder Engagement: Involve all stakeholders early in the process to gather diverse perspectives and requirements.
- Iterative Development: Use an iterative development process to gradually integrate components and address issues promptly.
- Interoperability Standards: Adopt interoperability standards to ensure seamless communication between different system components.
- Risk Management: Implement a risk management plan to identify and mitigate potential issues.
- Scalability Planning: Design the system with scalability in mind to accommodate future expansions and technological advancements

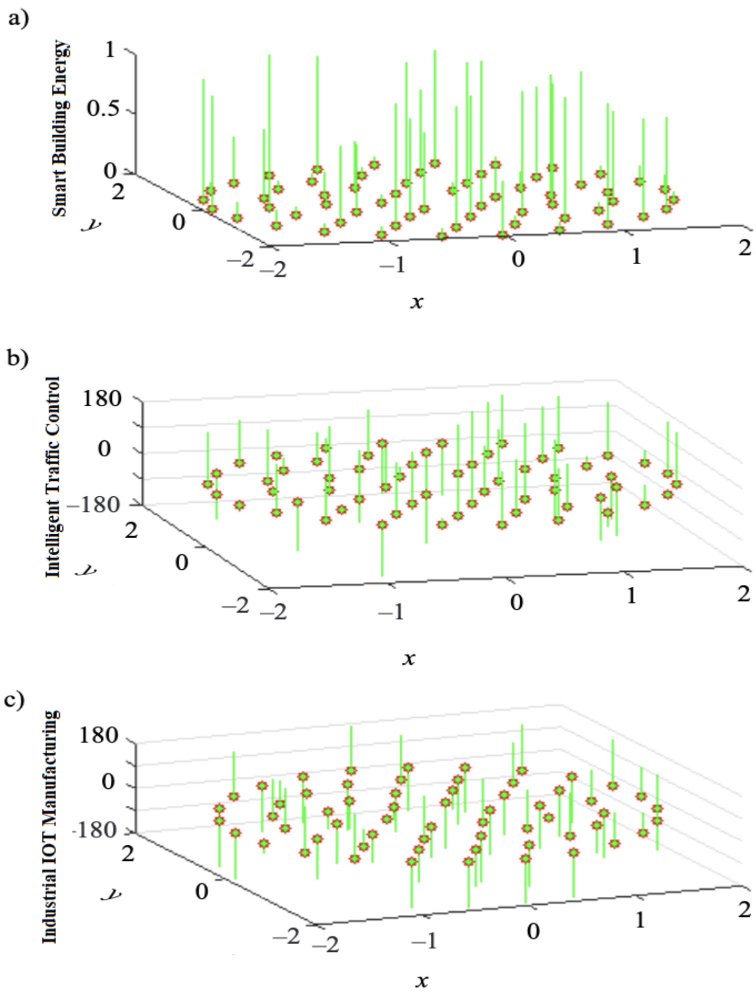

Figure 4: Performance measures for Fields like, a) IoT Monitoring, b) Intelligent Traffic Control and c) Smart Building Energy

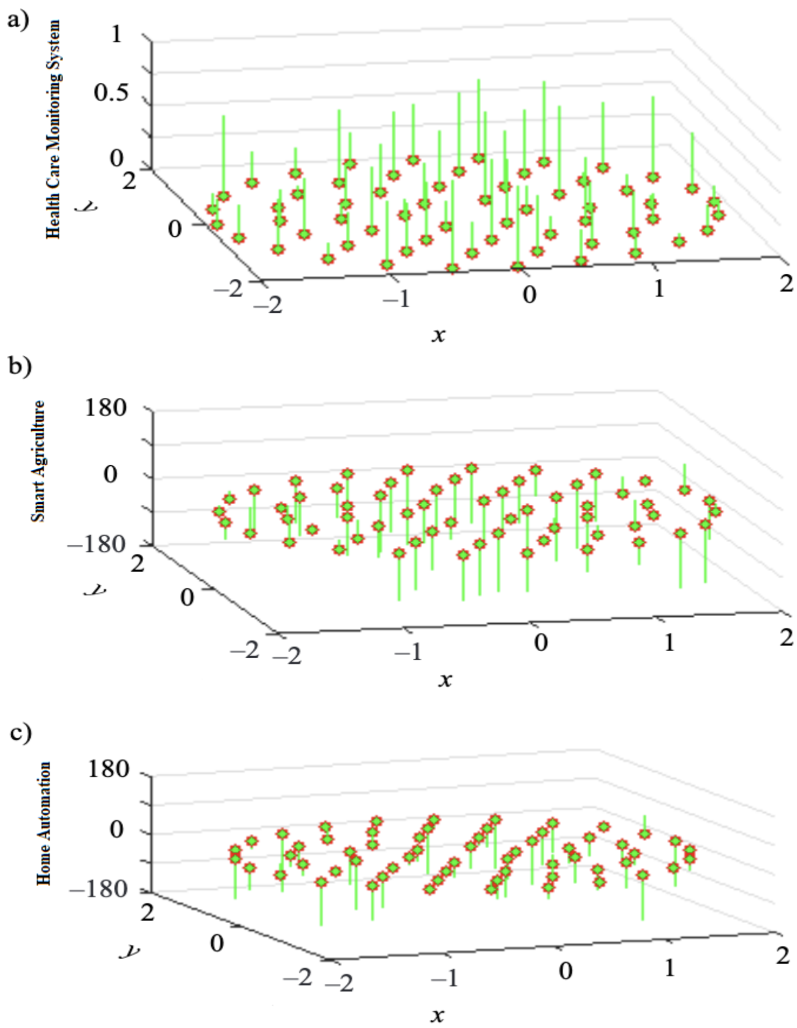

Figure 5: Performance Measures for Fields Like, A) Home Automation, B) Health Care Monitoring System and C) Smart Agriculture

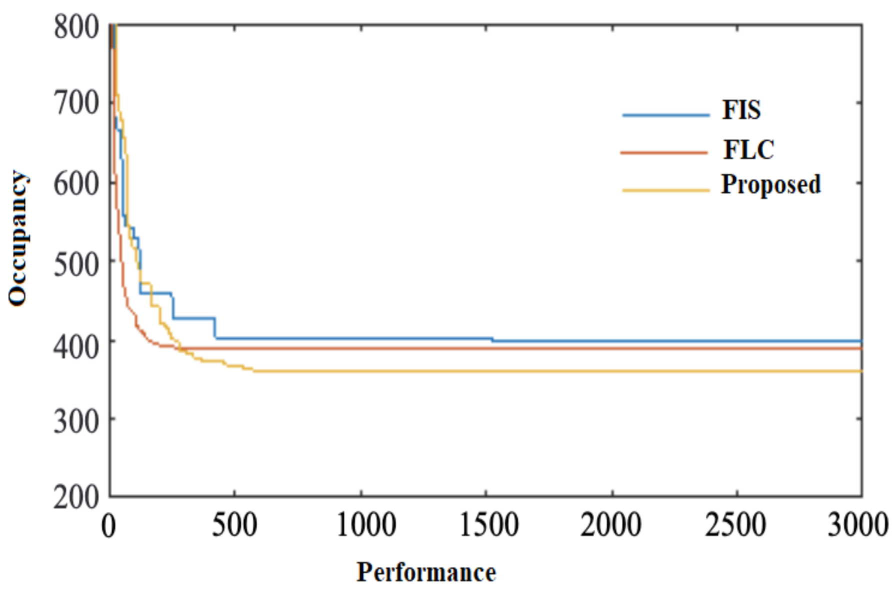

Figure 6: Performance Measures in All Parameters

Table 1: Comparison of FIS and FLC with Proposed Mode

Degrees	Parameters	FIS	FLC	Proposed
	Expected	-22.00	-22.00	-22.00
	Achieved	-17.07	-14.75	-17.07
0	Expected	0	0	0
	Achieved	21.86	20.85	21.83
	Expected	-22.08	-22.08	-22.08
	Achieved	-16.82	-14.76	-15.87
5	Expected	0	0	0
	Achieved	23.40	23.59	23.54
	Expected	-20.65	-20.65	-20.65
10	Achieved	-16.75	-16.54	-15.67
	Expected	0	0	0
	Achieved	16.25	17.35	16.25

Conclusion

This study proposed an optimized learning methodology and reinforced gradient boosting technique-based machine learning model to assess the software upgrade quality in various fields. This research significantly improved the quality and effectiveness of the software system in several areas, such as the IoT Monitoring, Intelligent Traffic Control and Smart Building Energy, home automation, health care monitoring system and smart agriculture. The proposed method is compared with the existing models such as FIS and FLC in terms of Performance. IoT Monitoring (90%) Intelligent Traffic Control experiment (92%), Smart Building Energy (95%), home automation(93%), health care monitoring system (92%) and smart agriculture (95%) As a result, incorporating a machine learning model into this fields can enhance results and more effectively prepare people to face future difficulties. Implementation difficulties, such as lack of resources and connectivity problems, also influence the real-life applicability of the advanced methods. Furthermore, the developed technique attains the best performance.

Abbreviations

CPS: Cyber Physical System
IoT: Internet of Things
HMS : Healthcare Monitoring System
FIS : Fuzzy Inference System
FLCs : Fuzzy Logic Controllers
BDI : Belief-Desire-Intention
JaCa: Java Runtime Environment
HVAC: Heating, Ventilation, and Air Conditioning.

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Author Contributions

All authors contributed to the study conception and design.

Conflict of Interests

The authors declare that they have no competing interests.

Ethics Approval

Not applicable.

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