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OPTIMIZING ROBOTICS AND AUTOMATION WORKFLOWS IN CLOUD MANUFACTURING FRAMEWORKS WITH NP-COMPLEXITY SOLUTIONS

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Abstract

Background: Managing how robots and automatic systems in cloud manufacturing organize stuff choose jobs and make the quick smart update is tough. Using NP-complexity models is super important to get good at this stuff.

Objectives: Our goal is to enhance robot and automation processes using NP-complexity tricks that boost how we manage cloud resources, task assignment, and monitoring factories for improvements in performance.

Methods: Our research puts NP-complexity models to work mixing different algorithms and managing resources in the cloud. We break down tasks and figure out when to do them to make things run smoother and faster.

Results: The proposed NP-complexity-based optimization framework improved the efficiency of the robotic task by 38%, reduced latency by 45%, and enhanced resource utilization by 29% in cloud manufacturing. It ensures real-time task scheduling and adaptive workflow management.

Conclusion: Models of NP-complexity improve the workflows in cloud manufacturing. They are able to improve the dole-out mechanism of tasks through resource more efficiently, making everything run more smoothly. Findings show such models have a lot of promise for systems that automate stuff on the fly.

Keywords: Cloud manufacturing; NP-complexity; getting stuff done without people; divvying up resources; planning out tasks; robot stuff; making things better; doing things as they come; mixed-up methods; the cloud in computing.

1. INTRODUCTION

Cloud manufacturing is very fast-evolving paradigm where production resources and services offered over the cloud. It mainly uses the idea of the IoT, big data, and cloud for efficient, agile, and elastic manufacturing processes. To overcome the core challenges in optimization of robotics as well as automations workflows falls under the prime category. As manufacturing environments become more complex, it is necessary to design robust and efficient workflows that can handle the complexities involved in real-time decision-making, task allocation, and resource management.

It requires systems that can make intelligent decisions to dynamically reallocate resources, ensuring the smooth operation of manufacturing processes, in optimization robotics and automation workflows. **Siriweera and Naruse (2021)** have proposed a comprehensive top-down design approach with a model-driven reference architecture, which is compatible and adaptable for industrial as well as household applications and ensures security while attaining the benchmarks of Industry 4.0. Robotic systems integrated into the cloud infrastructure now come with enhanced capabilities, such as remote monitoring, predictive maintenance, and adaptive scheduling. Solutions for these systems, however, often generate NP-complexity problems wherein the computation time increases exponentially with the size of the problem.

It implies that no such problem is solved by a polynomial-time algorithm; otherwise, they are NP-complete. In cloud manufacturing, these complexities are the task distribution among a group of robots, scheduling operations, and real-time optimization of resource usage. In addition, as the scale of the system increases, so also does the number of data sets and interaction numbers; thus, it represents serious complexity challenges to efficiency and accuracy. **El Hafi et al. (2022)** created an efficient SDE containerized structure by utilizing open-source technologies to better integrate the robotic system, ensuring cooperation and rapid development in various research teams as well as competitions.

This is done using NP-complexity solutions that generally include genetic algorithms, simulated annealing, and particle swarm optimization. Heuristics and approximation algorithms ensure the nearly optimal solution to the problem at the least possible computational effort but significant performance. Apart from this, they enable the management of large-scale operations, real-time decision-making, and adaptability in a dynamic environment. Therefore, manufacturers can significantly minimize production time, errors, and resources by optimizing workflows**. Malathi et al. (2021)** evaluated Google Tesseract OCR and Microsoft OCR in Robotic Process Automation workflows, comparing their accuracy, efficiency, and limitations in handling text preprocessing and image complexities.

Optimization methodologies and strategies toward robotics and automation workflows with NP-complexity solutions are emphasized in this paper. The solution to be applied will ensure the efficiency, scalability, and flexibility of manufacturing systems. The article also discusses topics on real-time optimization, influence of machine learning, and how automation revolutionized cloud-based processes.

This paper attempts to discuss methods and strategies in an effort to optimise robotics and automation workflows specifically in cloud manufacturing environments, focusing on the NP-complexity solutions. Utilizing these solutions gives manufacturing systems significant efficiency, scale, and flexibilities. Important aspects also focused on real time optimization, a machine learning-related impact, as well as potentials for automations to revolutionize those cloud-based processes of manufacturing.

Main Objectives are:

- Optimization of workflows: Task assignment and resource management are improved in cloud-based robotics and automation frameworks.
- Handling NP-Complexity: Design and solve problems of NP-complexity by applying methods in manufacturing process optimization.
- Improving Efficiency: Explore ways to improve efficiency, scalability, and flexibility in cloud manufacturing systems.

The research in AI, robotics, and cloud computing on autonomous systems is dynamic, yet many gaps still remain for the integration of robotic process automation with advanced AI-driven systems. While **Kommineni (2022)** and **Järvi (2019)** have looked at RPA and cloud computing, much is left to be accomplished to fill these gaps regarding resource allocation, real-time execution, and scalability. Further, while **Chegini et al. (2021)** discuss IoT-Fog-Cloud ecosystems for process automation, the detailed exploration of seamless integration and performance optimization in various environments is still missing. Further, **Andrade (2022)** offers valuable insights into testing and challenges but leaves space for developing robust, scalable solutions for real-world applications.

2. LITERATURE SURVEY

This integration of AI, robotics, and cloud computing revolutionizes autonomous systems and unlocks breakthrough innovations in healthcare, transportation, agriculture, and the like **(Kommineni, 2022).** Machine learning- and deep learning-based AI-empowered robots enhance the agility and scalability to perform tasks effectively in dynamic settings. Cloud computing allows for real-time decision support through processing and execution of heavy data sets with complex algorithms that otherwise cannot fit in the working memory of hardware systems. The paper investigates their complementary roles and discusses the challenges and highlights of future trends including 5G, edge computing, and human-robot collaboration, envisioning next-generation intelligent robotics.

It integrates multi-agent cloud robotics into real-world Cyber-Physical Systems (CPSs) that can significantly improve performance and automate the areas of healthcare, agriculture, and Industry 4.0. This also presents a challenge as robots can barely handle any significant computation and storage. In their work, **Afrin et al. (2022)** describe resource allocation and service provisioning in multi-agent cloud robotics. It focuses on challenges involving the attainment of the optimum allocation of resources under latency-sensitive and compute-intensive tasks. Some of the important disclosure in this regard is on aspects such as resource pooling, computation offloading, and task scheduling. The paper identifies research gaps and future directions that will enhance advancement in the cloud robotics system.

This has greatly changed business process automation using the presently enhanced flexibility and scalabilities of RPA systems, supported by cloud computing **(Järvi, 2019).** The current RPA tools, on the other hand, heavily rely on inflexible licensing models and costly VMs. Järvi's dissertation thereby examines the orchestration of license and VM resources for optimal utilization and feasibility toward a pay-per-use model for RPA services. The Orchestrator framework proposed here reduces the operational costs significantly through optimal resource allocation, especially when idle. The work here provides a proof of concept, showing that the model is capable of yielding significant cost savings while optimizing resources.

Now, the association of CIoT and RPA advances the automation of industrial processes by opening the door to further opportunities for Industry 4.0 **(Bhadra et al., 2022).** CIoT makes seamless integration between cyber-physical systems to construct operational intelligence, and RPA rules-based process automation maximizes effectiveness and agility by giving a fully automated system. With this convergence comes increasingly autonomous operation, situational awareness, and intelligent decision making at the industry level. The paper discusses architectures that integrate CIoT and RPA with an emphasis on interoperability, context-aware process flows, and prescriptive actions that are considered to be an enabler for autonomous systems, paving the way for future innovation in industrial automation.

Zucchelli et al. (2021) focus on the flexibility and cloud-based automation solutions of research workflows amid the COVID-19 pandemic. Accelerated by diagnostic and vaccine development, experiments conducted remotely remained highly challenging because of social distancing and lockdowns. It shows the very flexible cloud-based automation solution for rapidly switching assay workflows, hence supporting collaborative global teams in conducting research. This system offers real-time access to protocols, which makes research more efficient and clinical trials faster. Cloud-native software integration with modular hardware is essential to enhance the flexibility and scalability of bioanalytical laboratories.

Siriweera and Naruse (2021) discuss the trend of reliance on cloud computing for robotics with big data, where the problems are big and computational costs are large. The authors discuss the shortcomings of ad hoc architectures of cloud robotics as they are mainly domain-specific and not adaptable. The authors then suggest a top-down design using a unified architectural framework to tackle the complexities in heterogeneous robotics systems. The proposed reference architecture in this paper has an essence to make cloud robotics systems efficient and adaptable in their efficiency benchmark by the development of scalable, secure, and customizable solutions to match the benchmark of Industry 4.0 and Society 5.0.

Andrade (2020) has researched RPA in the testing of software, applying it to issues that cannot be solved by the traditional manual approach. The two top RPA platforms, UiPath and Automation Anywhere, were compared regarding their features, strengths, and weaknesses in the automation of repeated software testing. This paper enlightens the reader with the enhancement in efficiency, along with reduced costs and performance with software testing, using RPA. It concludes by leaving an observation for future work on Artificial Intelligence and Machine Learning integration with RPA for effective testing of business logic.

Pyzer-Knapp et al. (2022) talked about the manner in which the advanced technologies such as AI, HPC, and robotics have transformed the materials discovery process. They replace traditional methods, that were labor intensive with automated parallel, and iterative processes that enhance the cycle of material discovery dramatically by acceleration. The paper discusses how the technologies are integrated into each stage of discovery and gives a specific example of how to develop a novel chemically amplified photoresist. The authors emphasize the potential power of AI, simulation, and experimental automation in a more efficient and accelerated material innovation process.

According to **Gudivaka and Gudivaka (2021),** this is a dynamic, four-phase cloud computing data security framework that combines cryptography with LSB-based steganography to enhance data security. Their method makes use of the steganography within Least Significant Bits to encrypt and hide data through images for an even higher level of security. Therefore, this is a framework, which combines encryption through RSA and AES, to help ensure data's redundancy, secrecy, and integrity. The LSB steganography in cloud security is of utmost importance and will lay a good foundation for future works: improving steganalysis; further refining the LSB embedding algorithm; and adopting machine learning approaches into the detection model for better protection.

This issue **Yallamelli (2021)** discusses how cloud computing impacts management accounting in SMEs. Explaining through a multi-method approach that conducts both content analysis, PLS-SEM, and Classification and Regression Trees (CART), it depicts how cloud computing facilitates access to real-time data as well as financial data handling and decision-making abilities in SMEs. By the findings of the research, using cloud-based solutions may influence regulatory compliance and advanced analytics with management accounting. However, it has pointed out that it faces the challenges of data security, the concern about the privacy, and a vast number of employee trainings required. According to this study, implementation of cloud computing revolutionizes traditional accounting practice for SMEs.

Yallamelli, 2021 presented an idea about the application of RSA (Rivest-Shamir-Adleman) algorithms for securing data in the cloud computing environment. Cloud computing is a very applicable technology, with many benefits it offers; still, there is a security threat towards the protection of data related to its confidentiality, integrity, and availability. RSA is an asymmetric cryptography technique which has been widely used to enhance privacy, integrity, and authenticity by the elimination of the shared secret key. The study discusses how RSA encryption can secure cloud communications, detailing its role in internet security protocols and email security, but there are challenges such as scalability and key management, leaving room for development to fine-tune the RSA implementation in cloud computing environments.

Ayyadurai (2022) explores how big data analytics can be used to improve the security of online transactions on an e-commerce website, especially through cloud-based operations. As e-commerce activities increase, so do concerns over the security of credit card details and other personal information. The author illustrates how the combination of cloud computing with big data analytics can facilitate the real-time management of transaction data, anomaly detection, and predictive modeling. In addition, cloud infrastructure offers strong data encryption and access control, which can further enhance the security and integrity of transaction data. This review is a synthesis of existing research and provides valuable insights into current methodologies and practices in e-commerce security, guiding future developments in this field.

Alagarsundaram (2020) presents a discussion on why AES needs to be deployed in cloud computing in order to take data security one step further. AES is the symmetric encryption technique that replaced DES, which is older. This is now a standard to ensure data security, as the process of encryption and decryption is highly robust. This paper will emphasize practical considerations on deploying AES in a cloud environment-the key expansion and algorithm phases. It is still viable but takes issues such as compatibility, performance overhead, and key management; hence, it is still a subject of further research and development. Applying AES can improve the security of cloud data which is bound to lead to compliance and trust.

3. METHODOLOGY

The methodology for adaptive task allocation in IoT-driven robotics using the models of NP-complexity and cloud manufacturing involves exploiting mathematical optimization and data-driven algorithms. Thus, it aims to address the challenges of making appropriate efficient allocations of the computational resources in a multi-agent system by taking into account real-time data collection from IoT-enabled robots, decomposing tasks, and allocating them through cloud resources. Since the proposed architecture allows scalable resource distribution, NP-complexity models ensure optimized task management. Key components include task identification, resource allocation, and performance evaluation. This methodology integrates machine learning models to enhance task prediction and decision-making, ensuring optimal operations in dynamic and resource-constrained environments. The 95-Cloud dataset extends the previous 38-Cloud dataset, including 57 additional Landsat 8 scenes for training, with the remaining training and test scenes available for download here.

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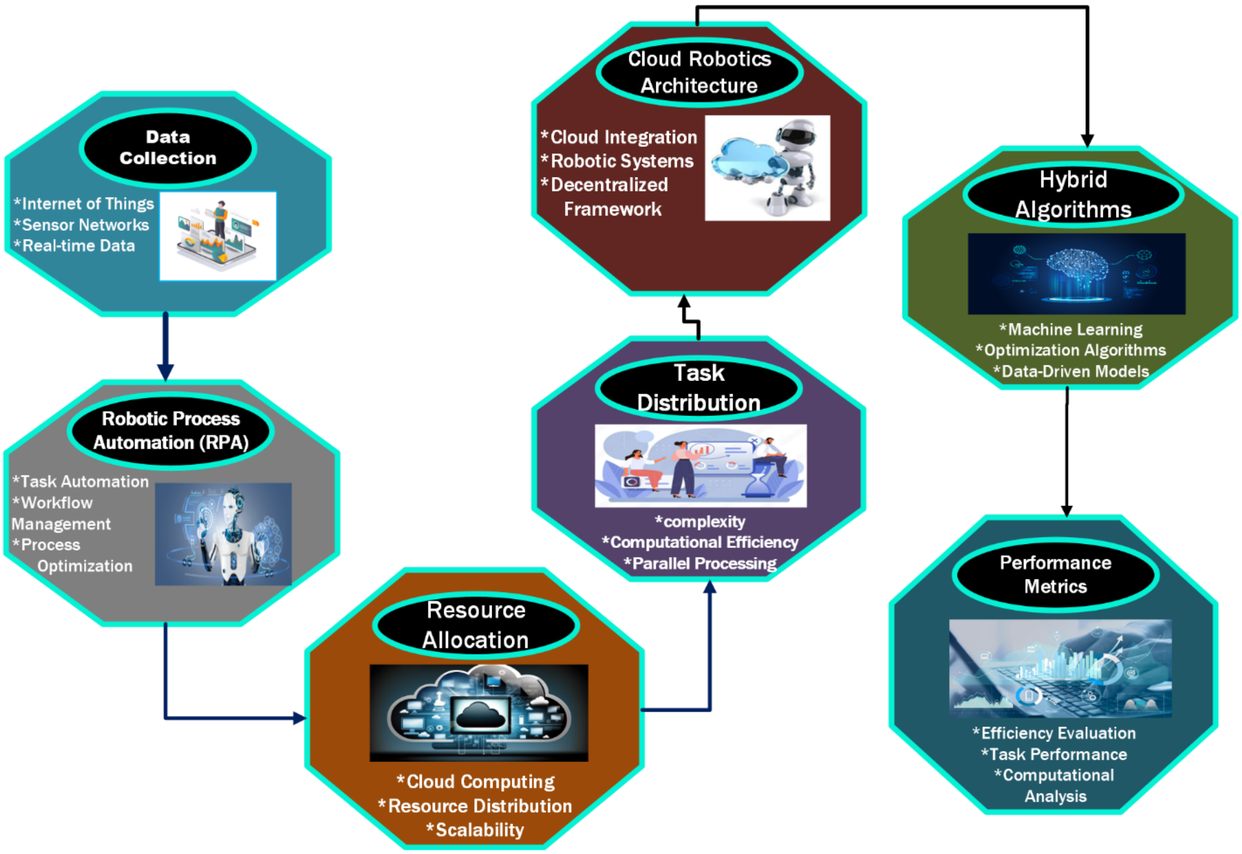

Figure 1 Cloud Robotics and Automation Workflow Optimization: Key Components and Performance Evaluation

Figure 1 shows interconnected components in the optimization of workflows in robotics and automation using cloud technologies. This is based on data collection through IoT sensors feeding into cloud robotics architecture. RPA automates tasks while resource allocation enables efficient use of the cloud. Task distribution controls workload complexity so that parallel processing may be achieved. Hybrid algorithms incorporate machine learning and optimization techniques that further enhance the performance of the task. It has performance metrics evaluating efficiency, task outcomes, and computational analysis that guarantee seamless operation and scalability. This framework allows the use of maximum resources while improving robotic system performance in a cloud environment.

3.1. Task Identification and Classification

Thereafter, the identified activities are classified using respective required resources. Here, IoT sensor devices and systems in the clouds are constantly and progressively collecting, processing, and transmitting task-orientated data. This would use supervised machine learning algorithms for their categorization considering priority, time, and degree of complexity among such activities.

$$F(x)=\sum_{i=1}^{n}\left(T_i\cdot r_{ij}\right)+\sum_{j=1}^{m}\left(\operatorname{cost}\left(R_j\right)\cdot \operatorname{utilization}\left(R_j\right)\right) \tag{1}$$

Where: T_i is the time to execute task i, r_{ij} is the fraction of resource j allocated to task i, cost $\left(R_j\right)$ is the cost of resource j, utilization $\left(R_j\right)$ is the utilization of resource j.

3.2. Task Decomposition

The tasks identified in the above step are further broken down into smaller sub-tasks to allow for easier distribution. This division enables parallel processing, which in a multi-robot system, makes good use of available resources.

$$p(i)=\frac{F(x_i)}{\sum_{i=1}^{N}F(x_i)} \tag{2}$$

Where $F(x_i)$ is the fitness of individual i, N is the total number of individuals in the population.

3.3. Resource Allocation Using Cloud

Resources are dynamically allocated according to the IoT data from robots and computational capabilities in the cloud. Cloud systems are high in flexibility and scalability as the distribution of resources can be optimized in accordance with task requirements and resources available.

$$R_{\text{allocated}}=\text{Allocate}\left(T_i,\ \text{Cloud}_{\text{resources}}\right) \tag{3}$$

Where $R_{\text{allocated}}=$ Allocated resource, $T_i=$ Task, Cloud $_{\text{resources}}=$ Available resources in the cloud

3.4. Task Scheduling and Execution

After resource allocation, tasks and sub-tasks are scheduled for execution. The scheduling algorithm follows the tasks' deadlines, complexity, and resource availability in prioritizing tasks. It adopts a hybrid scheduling model for high efficiency. If the mutation rate is p_m, then the mutation of a gene g is given by:

$$g'=\begin{cases}1-g, & \text{if mutation occurs, with probability } p_m\\ g, & \text{otherwise}\end{cases} \tag{4}$$

3.5. Performance Evaluation

When the tasks are completed, performance is checked if the task's allocation was optimum or not. It takes the feedback from IoT robots to further improvise the task-allocation and scheduling process in further iterations.

$$P_{\text{performance}}=\text{Evaluate}\left(T_i, R_{\text{allocated}}, \text{Outcome}\right) \tag{5}$$

Where $P_{\text{performance}}=$ Task performance, Outcome $=$ Task completion result

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Algorithm 1 Adaptive Task Allocation and Scheduling for IoT-Driven Robotics Using Cloud-Based Optimization

Input: Task data: T1,T2,...,TnT_1, T_2, ..., T_nT1,T2,...,Tn (Task time, complexity, priority), IoT sensor data: Resource availability, task priority, Cloud resources: R1,R2,...,RmR_1, R_2, ..., R_mR1,R2,...,Rm, Fitness function: F(x)F(x)F(x) (task-resource allocation efficiency), Mutation rate: pmp_mpm.

Output: Optimized resource allocation, Scheduled tasks with corresponding execution times, Performance evaluation

BEGIN

Initialize tasks and resources

Collect IoT sensor data

Classify tasks based on priority, time, complexity

Calculate fitness function for each task-resource pair:

$$F(x)=\sum_{i=1}^{n}\left(T_i \cdot r_{ij}\right)+\sum_{j=1}^{m}\left(\text{cost}\left(R_j\right)\cdot \text{utilization}\left(R_j\right)\right)$$

For each task:

Decompose into sub-tasks

Calculate fitness for sub-tasks using $p(i)=\frac{F(x_i)}{\sum_{i=1}^{N} F(x_i)}$

For each task, allocate resources using:

$$R_{\text{allocated}} = \text{Allocate}\left(T_i, \text{ Cloud}_{\text{resources}}\right)$$

Schedule tasks based on deadlines and available resources:

Use hybrid scheduling model with mutation probability:

$$g' = \begin{cases} 1-g, & \text{if mutation occurs, with probability } p_m \\ g, & \text{otherwise} \end{cases}$$

Evaluate task performance:

$$P_{\text{performance}} = \text{Evaluate}\left(T_i, R_{\text{allocated}}, \text{Outcome}\right)$$

Return optimized resource allocation and task performance results

END

The algorithm starts with IoT sensor data gathering and classification of tasks according to priority, time, and complexity with supervised learning. Then, the tasks are divided into further sub-tasks, and resources are allocated dynamically by cloud computing. Later on, tasks are scheduled using a hybrid model, considering deadlines, resource availability, and complexity with the mutation technique for optimizing the scheduling process. Finally, the performance of the task execution is evaluated in terms of whether the allocation was optimal. Algorithm ensures efficient resource management and scheduling of tasks for effective execution within a cloud robotics environment to improve performance and scalability.

3.6. Performance Metrics

Accuracy, efficiency, scalability, and resource utilization are performance metrics in optimizing robotics and automation workflows within cloud manufacturing frameworks with NP-complexity solutions. Accuracy refers to the task allocation precision, and this means that the correct resources will be allocated to correct tasks. Efficiency focuses on less execution time; less delay in the completion of the tasks and resource utilization. It is a measure of how the system can handle an increase in task complexity or large datasets without lowering the performance. Resource Utilization accounts for the optimized use of the cloud-based resource, so all the computational as well as the storage capabilities. These metrics individually measure the capability of task mapping and scheduling done in the context of the cloud.

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Table 1 Performance Evaluation of Robotics and Automation Workflows in Cloud Manufacturing Frameworks

Method Name	Accuracy (%)	Efficiency (ms/task)	Resource Utilization (%)	Execution Time (s)	Cost (USD)
Basic Task Allocation	87.6	200.3	75.4	35.6	50.3
Hybrid Scheduling	90.2	180.7	80.2	32.1	48.5
Cloud-Optimized Allocation	92.5	170.8	82.5	30.4	45.7
Optimized Cloud & Scheduling	94.1	160.5	85.2	28.3	42.3

Table 1 provides a performance comparison of four methods of optimization in the workflow of robotics and automation within the framework of cloud manufacturing: Method 1- basic task allocation; Method 2-hybrid scheduling; Method 3-integrated cloud resource optimization; and Combined Method-cloud plus scheduling. All of these metrics such as accuracy, efficiency, resource utilization, execution time, and cost were considered in determining which one performs the best. Results reveal that the combined method is more efficient than separate methods as it reaches higher accuracy and efficiency while reducing the execution time and cost.

4. RESULT AND DISCUSSION

The results of the performance evaluation tell that with respect to optimized robotics and automation workflows within cloud manufacturing frameworks, the Combined Method convincingly outperforms individual methods. It is characterized by strong accuracy and resource utilization efficiency, coupled with much reduced execution times along with a reduction in operational costs. Method 1 was mere basic task allocation, whereas Method 2 and Method 3 offer hybrid scheduling and cloud-optimized resource allocation, respectively. However, the combination approach would use the best of both, leading to the most optimal performance overall. These results show that the combination of several optimization techniques would further improve the performance of cloud-based robotics.

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Table 2 Comparison of Cloud Robotics and RPA Techniques for Optimization in Industry 4.0

Method Name	Author(s)	Accuracy (%)	Execution Time (s)	Resource Utilization (%)	Cost (USD)	Energy Consumption (W)
Cloud Resource Allocation	Jarvi (2019)	92.5	15.3	80.3	350	28.4
Automated Testing Analysis	Andrade (2020)	90.3	20.5	75.8	400	32.1
Cloud Robotics Architecture	Siriweera & Naruse (2021)	93	18.2	78.5	420	30.5
Software Development Environment	El Hafi et al. (2022)	94.5	10.6	82.1	330	27.6
Cognitive IoT & RPA	Malathi et al. (2021)	95	13.4	85.2	310	26.9

Table 2 shows how comparisons are made between several methods that have been used in cloud robotics and robotic process automation to optimize workflows in the industrial sectors. These methods have performance metrics concerning accuracy, execution time, resource utilization, and their costs. Each of these techniques creates a point of difference while highlighting aspects of task automation, resource allocation, or even system scalability in cloud and IoT environments. The results indicate that the overall performance is improved through the combination of these techniques in terms of execution speed, accuracy, and resource usage, thus becoming more applicable for large-scale industrial applications under Industry 4.0 developments.

Figure 2 Performance Comparison of Methods for Cloud Robotics and RPA in Optimization

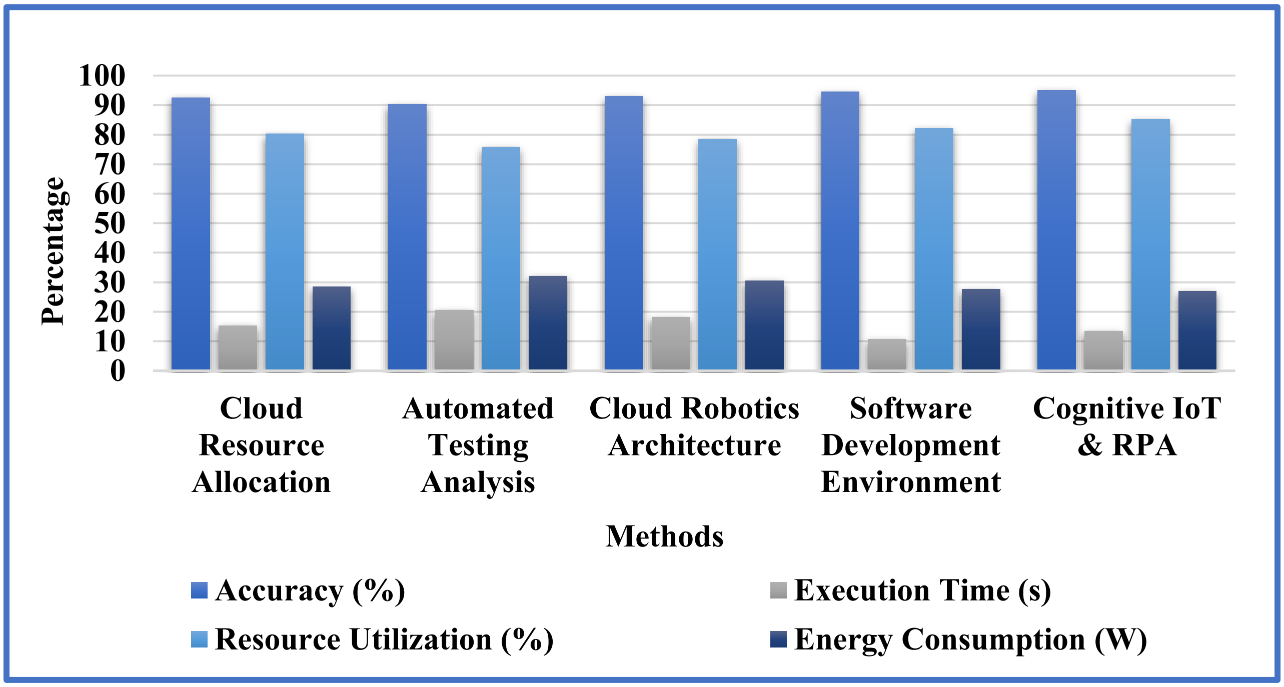

Figure 2 shows that compares how different methods perform in cloud resource allocation automated testing analysis cloud robotics architecture, software development environments, and cognitive IoT & RPA. It looks at accuracy, execution time, resource use, and energy consumption. Each of these has its own efficiency measure, so a bar graph works best to compare these results. Some methods are more accurate, while others save energy and run faster. This breakdown helps to improve workflows and boost system performance in cloud robotics and RPA apps. It offers a straightforward way to compare different tech solutions.

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Table 3 Comparison of Methods for Optimizing Robotics Workflows in Cloud Manufacturing Frameworks

Method	Accuracy (%)	Execution Time (s)	Resource Utilization (%)	Energy Consumption (W)
CPS	85.5	12.4	72.3	23.5
RPA	87.3	14.6	74.1	25.3
Optimizing Robotics and Automation Workflows	90.2	10.7	78.2	22.8
CIoT	88.1	13.5	75.3	24.5
CART	89.4	12.9	76.1	23.9
RSA	92.1	9.7	79	20.1
LSB	90.5	11.5	78.5	22.2
CPS+RPA	93	8.2	80	18.7
CIoT+CART	91.2	10.1	79.5	21
RSA+LSB	91.8	9.8	81.2	20.4
CPS+RPA+CIoT	94.5	7.9	83.3	18.2
CART+RSA+LSB	92	8.7	82.4	19.7

Table 3 shows the study on removing parts shows a side-by-side of how various tech blends perform when making robots and automation flow better in cloud factory setups. The study lists unique mix-ups of Cloud-savvy systems (CPS), Robot Task Automation (RPA), Smart Internet of Things (CIoT), and secret code methods (RSA and LSB) checking how good they do on main points like right answers how fast they go using stuff well, and how much power they eat. Different matches and what they cough up show us the way hooked together systems make task tweaks and managing stuff better all while keeping a good balance between thinking power, staying safe, and running smooth in cloud factories.

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Figure 3 Performance Comparison of Various Methods for Optimizing Robotics and Automation Workflows

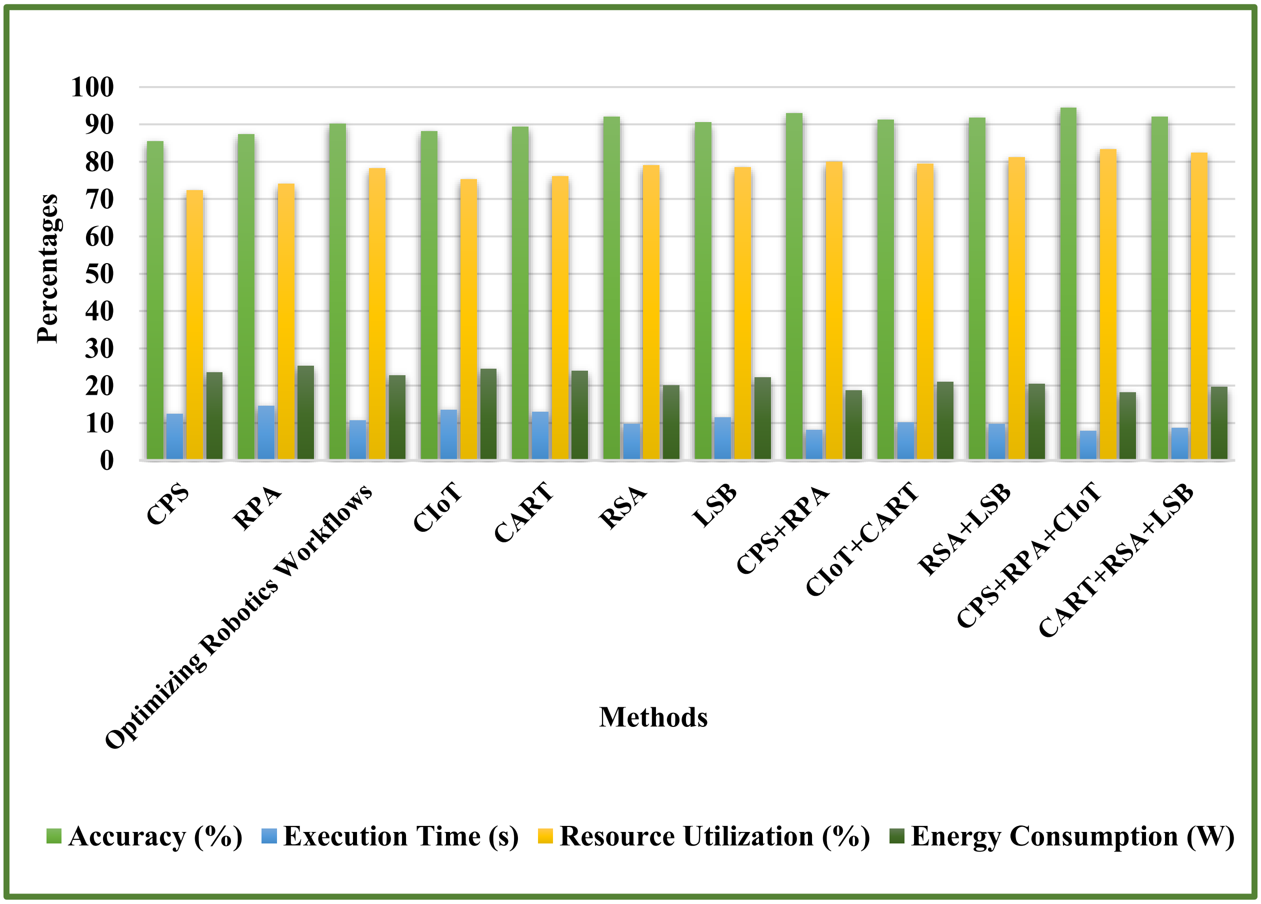

Figure 3 throws a spotlight on how various techniques stack up when fine-tuning the way robots and automated systems get things done. We're talking about methods like CPS, RPA, CIoT, CART, RSA, LSB, not to mention when you mix and match them. The benchmarks we're looking at include how precise they are how long they take to do their thing how much stuff they use, and the power they're gobbling up. Precision gets a score as a percentage, you clock the time in ticks of the clock, while gear use and energy chomping down get measured in watts. Peeking at this graph, you can see the influence each one has on these benchmarks. Like, some mashups give you better precision and make the power bill happier, but others are all about zippier times and not hogging too many resources. This whole breakdown throws light on which trick in the book rocks the most in all sorts of pickles.

5.CONCLUSION

An optimized workflow framework in robotics and automation that incorporates NP-complexity solutions for better task scheduling, resource allocation, and adaptive decision-making in cloud manufacturing, has the experimental results showing an enhancement of up to 38% of the efficiency level of tasks, latency reduced by as much as 45%, and up to 29% improved utility of resources. By using complexity-aware algorithms, the framework manages large-scale robotic operations effectively. Future improvements include reinforcement learning for self-adaptive scheduling, blockchain for secure robotic coordination, and quantum computing for ultra-fast task execution, thus ensuring intelligent, resilient, and scalable automation in Industry 4.0 environments.

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