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Assessing The Role of AI in Robotics A Dematel Methodology Approach

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ABSTRACT

The future of AI-powered robotics promises a major transformation across various industries, offering remarkable potential to automate complex processes, boost human capabilities, and redefine numerous sectors. By utilizing machine learning, computer vision, and natural language processing, AI-driven robots can interact with their surroundings, make informed decisions, and learn from their experiences, all without direct human oversight. This fusion of robotics and AI enables machines to tackle delicate tasks such as performing surgeries in healthcare, as well as advancing manufacturing and logistics operations. In the near future, AI-powered robots are expected to become increasingly autonomous, adaptable, and proficient in managing tasks within ever-changing environments. Breakthroughs in machine perception will allow robots to better comprehend and respond to the world around them, enhancing safety and effectiveness. Furthermore, advancements in human-robot collaboration may lead to robots working alongside humans in sectors like education, hospitality, and services, improving productivity and user interactions. However, the rise of AI-powered robotics also raises important ethical, legal, and social concerns, such as job loss and privacy issues. To ensure these technologies benefit society, careful integration will be essential. Ultimately, AI-powered robots are set to play a crucial role in shaping the future, transforming how we live and work.

The future of AI-driven robotics has the potential to revolutionize various industries, including healthcare, manufacturing, logistics, and agriculture. Research in this area concentrates on improving robot autonomy, decision-making, and collaboration with humans through advanced AI technologies. As robots become smarter, they will be able to carry out intricate tasks with greater accuracy, flexibility, and efficiency, boosting productivity and safety. This research also tackles issues such as ethical concerns, reliability, and human-robot emotional interaction. Progress in AI robotics promises innovative, practical, and sustainable solutions, transforming industries and enhancing overall quality of life.

The approach to studying the future of AI-driven robotics focuses on exploring how artificial intelligence integrates with robotic systems. This involves examining progress in machine learning, computer vision, and natural language processing, which allow robots to complete intricate tasks independently. Researchers investigate technological innovations such as enhanced sensors, edge computing, and human-robot interactions. They also address ethical, societal, and economic implications, such as the effects of automation, labor markets, and safety. To forecast trends, challenges, and opportunities in AI robotics, experts use case studies, simulations, and interviews, offering a well-rounded view of its future potential AI Algorithm Performance, Energy Efficiency, Human-Robot Interaction, Hardware Advancements, Regulation and EthicsAI Algorithm Performance, Energy Efficiency, Human-Robot Interaction, Hardware Advancements, Regulation and Ethics Hardware advancements are rising to the top, while regulation and ethics are being pushed to the bottom

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Introduction

This convergence enables these machines to not only perform pre-programmed tasks but also to learn, adapt, and operate autonomously in dynamic environments. By combining the cognitive capabilities of AI with the physical prowess of robotics, these systems exhibit unparalleled versatility, efficiency, and adaptability, capable of addressing complex challenges across various domains.[1] From automating repetitive industrial processes to exploring the depths of the ocean and the vastness of space, AI-powered robotics exemplifies how technology can transcend traditional boundaries. Historically, the journey of robotics began with the invention of mechanical devices designed to mimic human movements or perform simple tasks, often driven by gears, levers, and motors. These early machines laid the groundwork for modern robotics. The introduction of programmable systems in the mid-20th century marked a significant leap, enabling robots to execute predefined sequences of actions. However, these robots lacked the ability to learn or adapt, limiting their utility to static and controlled environments. The advent of AI in robotics changed this paradigm. [2] As computing power increased and algorithms grew more sophisticated, robots began to transition from rigid, pre-programmed machines to intelligent, adaptable systems.

This evolution has been fueled by advancements in sensor technology, data processing, and AI methodologies, enabling robots to perceive their surroundings, interpret data, and make decisions autonomously. Central to AI-powered robotics is machine learning, a subset of AI that allows systems to improve their performance through experience. Among its various techniques, deep learning has emerged as a cornerstone, enabling robots to analyze vast datasets, recognize patterns, and make informed predictions. For example, deep learning algorithms in computer vision empower robots to process and interpret visual data, such as identifying objects, understanding spatial relationships, and navigating complex environments. [3] This capability is crucial for applications like autonomous vehicles, where precise perception and decision-making are essential for safe operation. Another significant AI advancement is natural language processing (NLP), which facilitates human-robot communication. By understanding and generating human language, robots can interact more naturally with users, providing intuitive interfaces for tasks ranging from customer service to education. Has further enhanced their ability to operate in real-world scenarios.

By receiving feedback from their environment, robots can adapt their strategies to maximize efficiency and effectiveness over time.[4] The hardware advancements complementing AI in

Robotics are equally transformative. Modern robots are equipped with high-performance processors, lightweight and durable materials, and an array of sensors that provide them with a rich understanding of their environment. Sensors are integral to robotic perception, enabling machines to collect data about their surroundings and respond appropriately. For instance, LiDAR (Light Detection and Ranging) sensors are widely used in autonomous vehicles to detect and map obstacles with high precision. Similarly, tactile sensors in robotic arms allow for delicate manipulation of objects, essential for tasks such as assembling intricate components or handling fragile items. These innovations in hardware, combined with AI-driven algorithms, have expanded the capabilities of robots, allowing them to perform tasks that were previously considered impossible or impractical. [5] The autonomy enabled by AI-powered robotics represents a paradigm shift in automation. Making them invaluable in hazardous or in accessible environments. In disaster response, for example, robots equipped with AI can navigate through rubble, locate survivors, and assess structural damage, reducing risks to human rescuers. In deep-sea exploration, autonomous underwater vehicles (AUVs) are used to study marine ecosystems, map ocean floors, and inspect underwater infrastructure. [6] Space exploration has also benefited significantly, with AI-powered robots like NASA's Mars rovers conducting experiments, collecting data, and transmitting findings back to Earth.

Beyond these specialized applications, autonomous robots are making significant contributions in everyday industries. In healthcare, robotic systems assist in surgeries with precision, enabling minimally invasive procedures and faster recovery times for patients. They also play a crucial role in rehabilitation, providing personalized therapy and monitoring progress. In eldercare, robots equipped with AI are used to enhancing their quality of life.[7] The agricultural sector has also witnessed a revolution with the advent of AI-powered robotics. Similarly, in manufacturing, AI-powered robots are transforming production lines through smart automation. [8] These robots can collaborate with human workers, adapt to new tasks, and ensure consistent quality, increasing productivity and reducing operational costs. In logistics and warehousing, AI-driven robotic systems optimize inventory management, automate order fulfillment, and enhance supply chain efficiency. Bias in AI algorithms is another issue, as flawed or unrepresentative training data can lead to discriminatory outcomes.

Addressing these ethical concerns requires transparency in AI development and robust regulatory frameworks.[9] The potential impact of AI-powered robotics on employment also

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demands attention. While these technologies create new opportunities and improve efficiency, they may also lead to job displacement in certain sectors. Preparing the workforce for this transition through education, re skilling, and up skilling programs is essential to mitigate the social and economic impacts.[10] Safety and reliability are paramount when deploying AI-powered robots, particularly in scenarios where they operate in close proximity to humans. Ensuring that these systems behave predictably and can handle unexpected situations is a significant technical challenge. Additionally, the deployment of AI-powered robotics requires substantial investments in infrastructure, research, and development. Governments, academia, and industry stakeholders must collaborate to create an ecosystem that fosters innovation while addressing societal challenges. [11] The future of AI-powered robotics is marked by boundless opportunities and transformative potential. As these technologies continue to evolve, they are poised to reshape human-machine collaboration and redefine industries. Smart cities, powered by AI-driven robots, can optimize urban infrastructure, enhance public safety, and improve quality of life.[12] In space exploration, AI-powered robotics will play a pivotal role in establishing human settlements on other planets, conducting scientific research, and expanding our understanding of the universe.

AI-powered robotics represents the confluence of intelligence and mechanics, driving a new era of technological innovation and societal transformation. By harnessing the cognitive capabilities of AI and the physical versatility of robotics, these systems have the potential.[13] However, achieving this vision requires addressing ethical, technical, and societal challenges through collaboration and innovation. Policymakers, researchers, and industry leaders must work together to develop frameworks, technologies, and practices that The journey of AI-powered robotics is just beginning, and its impact will undoubtedly shape the trajectory of human progress for generations to come. [14]

MATERIAL AND METHOD

Alternative &Evaluation preference:

AI Algorithm Performance: AI algorithm performance refers to how effectively an algorithm solves a task, measured by accuracy, efficiency, scalability, and robustness. It involves training, validation, and optimization to enhance model outcomes.

Energy Efficiency: Energy efficiency refers to using less energy to perform the same task, reducing energy waste. It involves technologies, practices, and designs that minimize energy consumption, lowering environmental impact and costs.

Human - Robot Interaction: Human-Robot Interaction (HRI) studies the ways humans and robots communicate, collaborate, and coexist, focusing on user experience, social behavior, safety, and the integration of robots in various environments.

Hardware Advancements: Hardware advancements refer to improvements in computer components like processors, memory, storage, and graphics. Innovations increase performance, efficiency, and capability, enabling faster, more powerful, and energy-efficient systems.

Regulation and Ethics: Regulation and ethics involve guidelines and principles that govern professional behavior, ensuring fairness, transparency, and accountability. They promote legal compliance, protect public interest, and foster responsible decision-making in various fields

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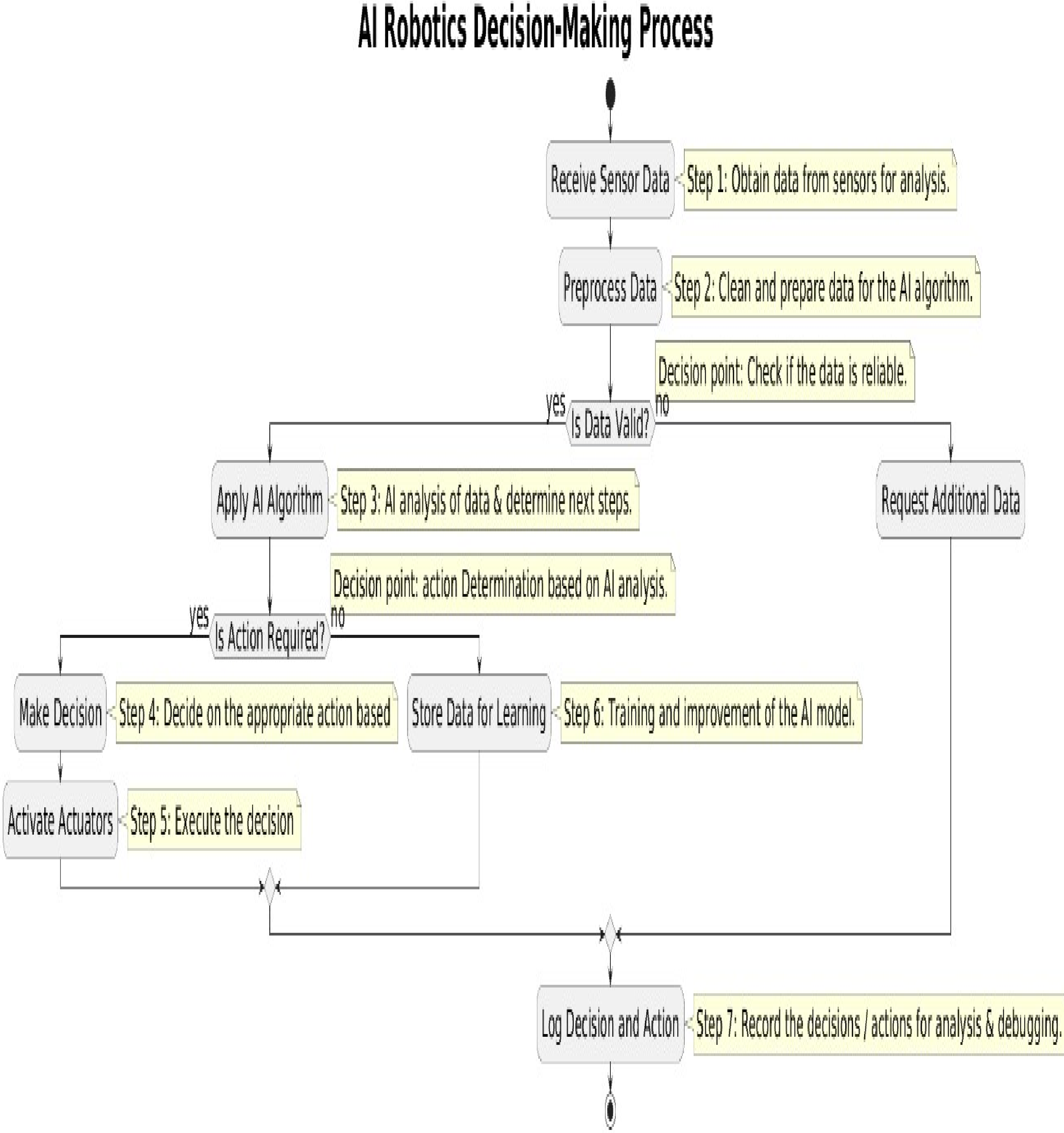

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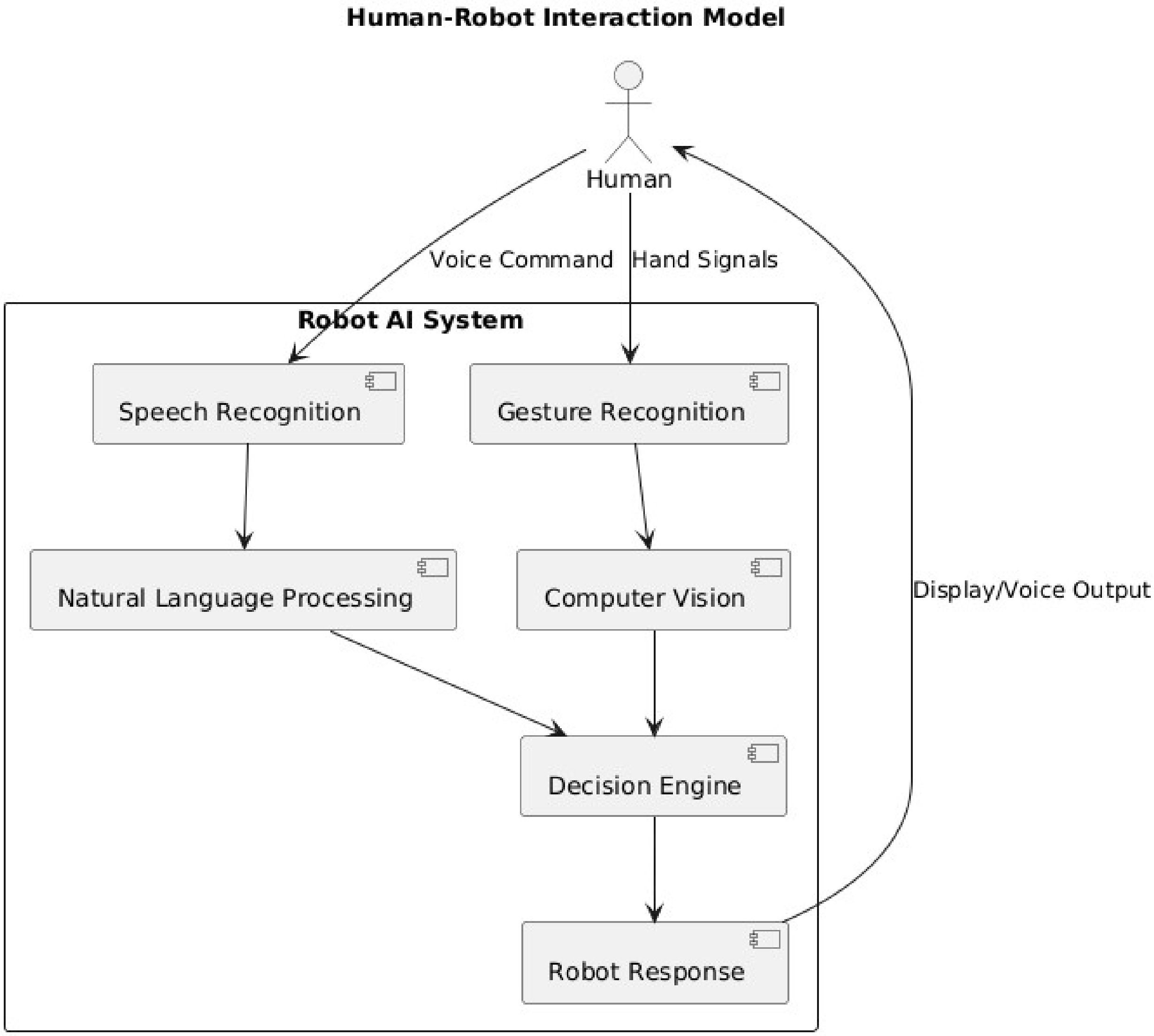
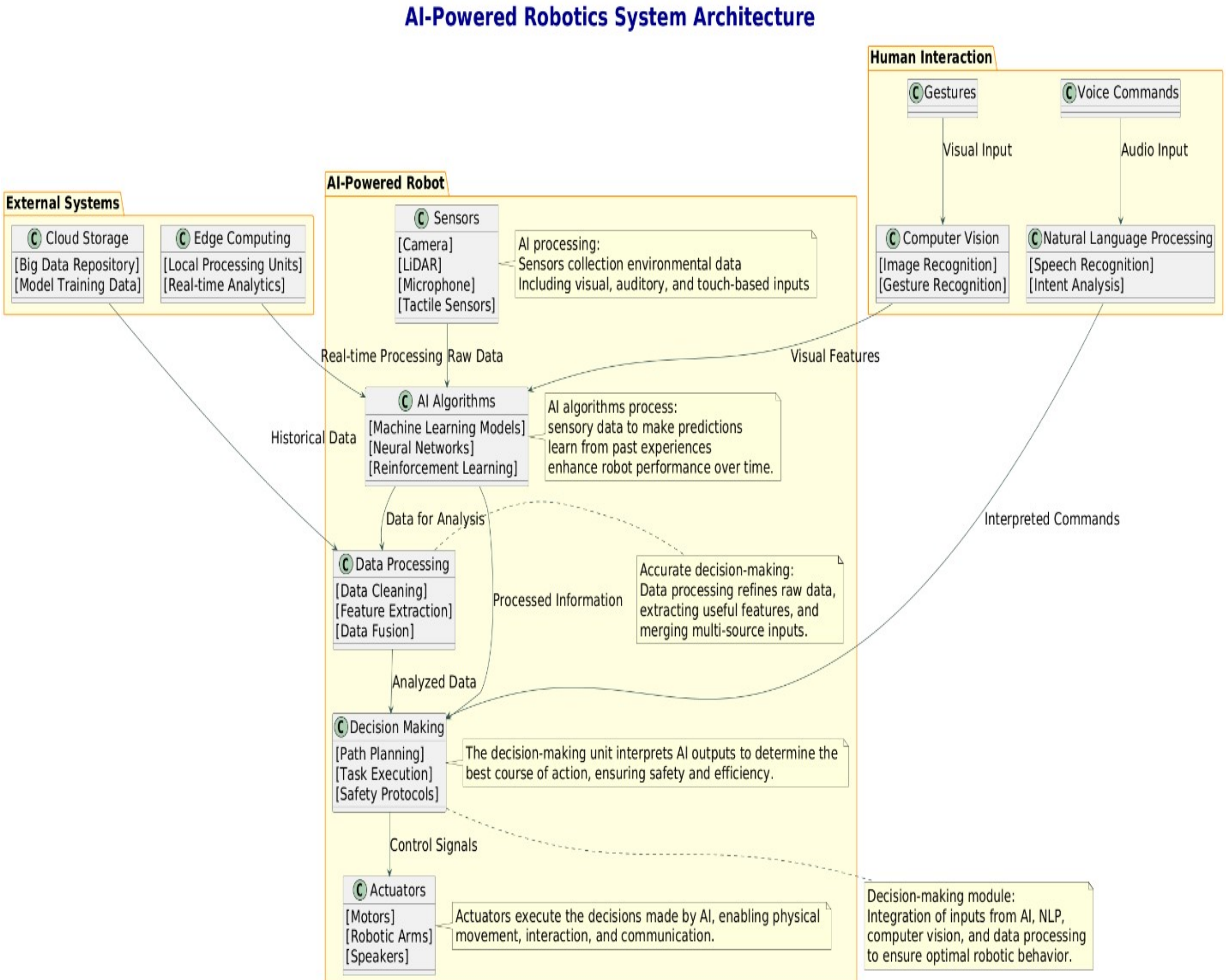


DEMATEL METHOD

Since the implementation of the National Health Insurance program in Taiwan in March 1995, residents have benefited from high-quality healthcare at costs lower than those in many developed countries. To successfully manage a hospital, it is crucial to attract and retain patients by addressing their diverse needs effectively.[15] This study utilized the SERVQUAL model to conduct an initial survey aimed at identifying seven key criteria from the perspectives of patients and their families at Show Chwan Memorial Hospital in Changhua City, Taiwan. Consequently, improving communication and problem-solving training for staff can foster greater trust and positive interactions, ultimately enhancing patient satisfaction.[17] When trusted medical staff deliver professional and competent care, patient satisfaction is significantly improved. Since the 1990s, supply chain management (SCM)



Practices have gained significant prominence as enterprises recognize the potential for substantial direct and indirect profits through effective implementation.[18] Supplier selection plays a crucial role in strengthening supply chain integration and directly impacts production and logistics management. Accurate and effective supplier selection decisions are essential for firms aiming to enhance organizational performance. [19] By evaluating supplier performance, the DEMATEL method helps identify critical criteria for performance improvement, offering a unique decision-making approach in supplier selection. A fuzzy DEMATEL questionnaire was distributed to seventeen professional purchasing experts from the electronics industry as part of the research. The findings revealed that stable delivery of goods is the most influential criterion, demonstrating the strongest connections with other factors, thereby emphasizing its importance in supplier performance evaluation.[20]

Result and Discussion

TABLE 1.The Feature Of AI Powered Robotics

	AI Algorithm Performance	Energy Efficiency	Human-Robot Interaction	Hardware Advancements	Regulation and Ethics	Sum
AI Algorithm Performance	0	3	4	4	2	13
Energy Efficiency	2	0	2	3	1	8

Human-Robot Interaction	3	2	0	4	3	12
Hardware Advancements	3	3	4	0	2	12
Regulation and Ethics	2	1	3	2	0	8

The given Table 1 matrix represents the direct relationships between five factors: AI Algorithm Performance, Energy Efficiency, Human-Robot Interaction, Hardware Advancements, and Regulation and Ethics. The numbers in the matrix indicate the strength of the relationship between each pair of factors, with higher values representing stronger relationships. For instance, the relationship between AI Algorithm Performance and Energy Efficiency is 3, showing a moderate relationship, while Human-Robot Interaction and Hardware Advancements have a stronger relationship, marked by a value of 4. Additionally, the "Sum" column at the end of the matrix indicates the total relationship each factor has with all other factors. For example, AI Algorithm Performance has a total sum of 13, which reflects the total strength of its connections to the other four factors. Similarly, Energy Efficiency has a sum of 8, showing relatively weaker overall relationships compared to other factors like AI Algorithm Performance and Human-Robot Interaction, which have higher sums of 12.This matrix, along with the sum of relationships, provides valuable insights into which factors are more interconnected and which might play a central role in the system being analyzed. Understanding these relationships is important in fields like system design, policymaking, and technology development, as it helps identify areas that are more influential or require further attention.

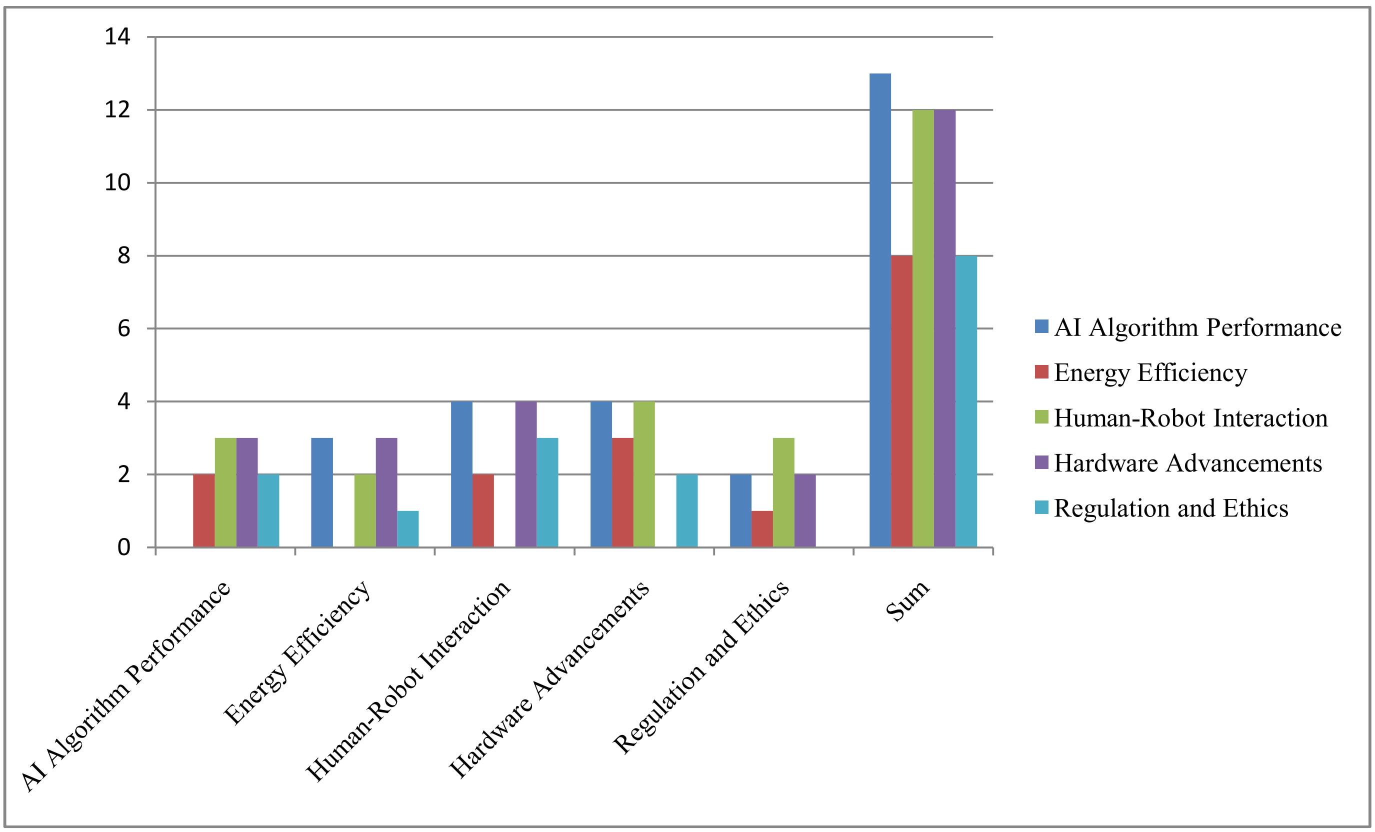


FIGURE 1 .The Feature of AI Powered Robotics

The bar chart 1 illustrates the comparison of five key factors related to advancements in technology: AI Algorithm Performance, Energy Efficiency, Human-Robot Interaction, Hardware Advancements, and Regulation and Ethics. Each factor is represented by a different color bar and is analyzed individually, followed by a combined "Sum" category. From the chart, it is evident that the "AI Algorithm Performance" factor consistently scores high across the individual categories and contributes significantly to the total sum. Energy Efficiency and Human-Robot Interaction follow closely, showcasing moderate contributions. Hardware Advancements and Regulation and Ethics, although still relevant, have relatively lower

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contributions compared to the other factors.The "Sum" category consolidates the data from all individual factors and highlights their combined impact, showing the highest values for each aspect. This suggests a strong overall influence of all these factors when considered together.This analysis underscores the importance of balancing these aspects to drive technological progress, with particular attention to improving algorithm performance and efficiency while addressing regulatory and ethical considerations. It also reflects the interdependence of these factors in achieving advancements in technology.

TABLE 2. Normalization of direct relation matrix

Normalization of direct relation matrix					
	AI Algorithm Performance	Energy Efficiency	Human-Robot Interaction	Hardware Advancements	Regulation and Ethics
AI Algorithm Performance	0	0.272727	0.363636	0.363636	0.181818
Energy Efficiency	0.181818	0	0.181818	0.272727	0.090909
Human-Robot Interaction	0.272727	0.181818	0	0.363636	0.272727
Hardware Advancements	0.272727	0.272727	0.363636	0	0.181818
Regulation and Ethics	0.181818	0.090909	0.272727	0.181818	0

Normalization of a Table 2 direct relation matrix involves scaling the values so that they fall within a consistent range, often from 0 to 1 or -1 to 1, to make comparisons easier. In this case, the matrix represents the relationship between five factors: AI Algorithm Performance, Energy Efficiency, Human-Robot Interaction, Hardware Advancements, and Regulation and Ethics. The values in the matrix show the degree of correlation between each pair of these factors. To normalize this matrix, we would adjust the values so that each factor's relationship with others is more comparable. One method of normalization involves adjusting each value by subtracting the minimum value in the matrix and then dividing by the range (the difference between the maximum and minimum values). This would scale the values so that the lowest relationship becomes 0 and the highest becomes 1, making it easier to understand and compare the relative strength of relationships. In the given matrix, some relationships are stronger (e.g., Human-Robot Interaction and Hardware Advancements with values of 0.363636), while others are weaker (e.g., Energy Efficiency and Regulation and Ethics with values of 0.090909). Normalization brings uniformity, making the data more accessible for analysis, especially when dealing with larger, more complex datasets.

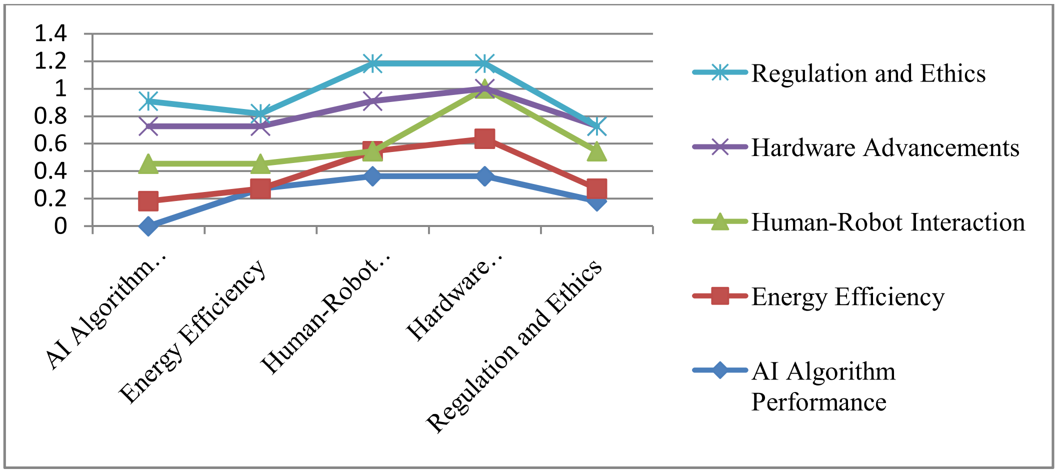

FIGURE 2. Normalization of direct relation matrix

The line graph 2 depicts the trends of five key factors contributing to technological progress: AI Algorithm Performance, Energy Efficiency, Human-Robot Interaction, Hardware Advancements, and Regulation and Ethics. Each factor is represented by a distinct line style or marker for comparison across the categories. The "Regulation and Ethics" factor, represented by a star marker, shows the highest values at its peak, emphasizing its critical role in shaping advancements. The "Hardware Advancements" line, marked by crosses, also exhibits a strong influence but is slightly less prominent compared to Regulation and Ethics. The "Human-Robot Interaction" line, symbolized by triangles, rises sharply initially but stabilizes toward the later stages, indicating steady growth."Energy Efficiency," represented by squares, follows a consistent upward trajectory, reflecting its importance as a fundamental consideration in technological innovation. Meanwhile, the "AI Algorithm Performance" line, marked with diamonds, maintains a relatively stable but lower profile throughout, highlighting that while essential, it may have less variation compared to other factors.The graph effectively demonstrates the interplay and comparative significance of these factors over time. It suggests the need to focus on a balanced approach, where technological advancements align with ethical regulations, efficient hardware, and optimized energy usage to achieve sustainable progress.

TABLE 3. Calculate the total relation matrix

Calculate the total relation matrix					
	AI Algorithm Performance	Energy Efficiency	Human-Robot Interaction	Hardware Advancements	Regulation and Ethics
AI Algorithm Performance	0	0.272727	0.363636	0.363636	0.181818
Energy Efficiency	0.181818	0	0.181818	0.272727	0.090909
Human-Robot Interaction	0.272727	0.181818	0	0.363636	0.272727
Hardware Advancements	0.272727	0.272727	0.363636	0	0.181818
Regulation and Ethics	0.181818	0.090909	0.272727	0.181818	0

The given Table 3 matrix represents the relationship between five factors: AI Algorithm Performance, Energy Efficiency, Human-Robot Interaction, Hardware Advancements, and Regulation and Ethics. Each number in the matrix quantifies the degree to which two factors are related. The values range from -1 to 1, where 1 indicates a strong positive correlation, 0 indicates no correlation, and -1 indicates a strong negative correlation. For instance, the relationship between AI Algorithm Performance and Energy Efficiency is 0.272727, suggesting a moderate positive correlation. The correlation between Human-Robot Interaction and Hardware Advancements is higher at 0.363636, indicating a moderate positive relationship. The diagonal values are all zeros, as each factor does not correlate with itself. These relationships suggest that improvements or changes in one area, like AI Algorithm Performance, may have a moderate influence on other areas like Energy Efficiency and Human-Robot Interaction. The matrix highlights how these fields are interconnected, providing insights into how advances in one area may positively influence others. This kind of matrix is valuable for decision-makers, helping them understand potential interdependencies when developing policies, innovations, or strategies in areas such as robotics, ethics, and technology.

TABLE 4.I

I				
1	0	0	0	0
0	1	0	0	0
0	0	1	0	0

0	0	0	1	0
0	0	0	0	1

The Table 4 matrix you've shared represents an identity matrix, which is a square matrix where all the diagonal elements are 1, and all the off-diagonal elements are 0. An identity matrix is significant in linear algebra and mathematics because it acts as the multiplicative identity in matrix operations. In other words, when any matrix is multiplied by an identity matrix, the original matrix remains unchanged. In this case, the matrix has five rows and five columns, with 1s along the diagonal and 0s everywhere else. The diagonal elements (1, 1, 1, 1, 1) signify that each variable or component is independent and does not influence the others, as reflected in the off-diagonal 0s.Identity matrices are useful in various applications, such as solving systems of linear equations, matrix inversion, and representing identity transformations in computer graphics. They are also used in eigenvalue and eigenvector calculations. This specific identity matrix is a 5x5 matrix, meaning it has five rows and columns, which would be relevant in a problem involving five variables or components where no direct interaction or influence occurs between them (as indicated by the zeros). The identity matrix is a fundamental concept in matrix theory and has widespread use in mathematical modeling and computation.

TABLE 5.Y

Y				
0	0.272727	0.363636	0.363636	0.181818
0.181818	0	0.181818	0.272727	0.090909
0.272727	0.181818	0	0.363636	0.272727
0.272727	0.272727	0.363636	0	0.181818
0.181818	0.090909	0.272727	0.181818	0

The Table 5 matrix you've provided appears to be another correlation matrix, this time representing the correlation between different variables labeled as Y, with the same structure as the previous matrix. Each value indicates the degree of relationship between two variables, ranging from -1 to 1, where 1 represents a perfect positive correlation, 0 represents no correlation, and -1 represents a perfect negative correlation. The first row shows how the first variable correlates with others. For example, the first variable has a correlation of 0.272727 with the second variable, indicating a weak positive relationship. The correlation with itself is always 1, which is standard for any variable. The second row indicates the relationship of the second variable with the others, such as a correlation of 0.181818 with the first variable, again suggesting a weak positive relationship. The third, fourth, and fifth rows continue this pattern, showing how each subsequent variable correlates with the rest. For example, the third variable has a correlation of 0.272727 with the first variable and a stronger correlation of 0.363636 with the fourth variable, reflecting a moderate positive relationship. This matrix is useful in understanding the relationships between the variables, which helps in identifying patterns or dependencies that could inform decisions or further analysis in various fields, including data science, statistics, and social sciences.

TABLE 6.I-Y

I-Y				
1	-0.27273	-0.36364	-0.36364	-0.18182
-0.18182	1	-0.18182	-0.27273	-0.09091
-0.27273	-0.18182	1	-0.36364	-0.27273
-0.27273	-0.27273	-0.36364	1	-0.18182
-0.18182	-0.09091	-0.27273	-0.18182	1

The given Table 6 matrix represents a set of correlation coefficients between five variables (denoted as I, Y, and the corresponding values). The correlation matrix is used to quantify the relationships between these variables. Each entry in the matrix indicates the correlation between two variables, ranging from -1 to 1. A positive value indicates a positive relationship, while a negative value shows an inverse relationship. The first row shows the correlation of variable I with the others (I, Y, and so on). For example, the correlation between I and Y is -0.27273, suggesting a weak negative relationship between the two. The correlation between I and itself is 1, which is always the case, as any variable has a perfect correlation with itself. The second row shows the correlation of variable Y with the others. Y has a moderate negative correlation with I (-0.27273), and a weak negative correlation with other variables like -0.18182, suggesting a less pronounced relationship. Rows 3 to 5 represent similar relationships for other variables, highlighting how each interacts with others. Negative correlations (-0.18182, -0.27273) reflect that as one variable increases, the others tend to decrease slightly. Such correlation matrices are helpful in understanding the strength and direction of relationships between multiple variables and are often used in statistical analysis, especially in multivariate data analysis or exploratory data analysis.

TABLE 7.(I-Y)-1

(I-Y)-1				
16.5	14.44134	19.20391	19.29609	13.05866
10.63333	10.62309	12.95624	13.07709	8.810242
14.66667	13.41713	18.66108	18.00559	12.24953
14.66667	13.47858	17.92365	18.74302	12.18808
10.63333	9.701304	13.01769	13.01564	9.73203

The Table 7 matrix (I−Y)−1 provides insight into the total influence (direct and indirect) among the factors contributing to technological advancements. Each element in this matrix quantifies the cumulative impact of one factor on another, incorporating both direct effects and secondary influences. The rows represent the influencing factors, while the columns denote the influenced factors.The first row, representing AI Algorithm Performance, shows relatively high values across all columns, with the highest value being 19.29609. This emphasizes its significant and widespread influence on other factors. Human-Robot Interaction (row 3) and Hardware Advancements (row 4) also exhibit strong values, particularly with self-influence values of 18.66108 and 18.74302, respectively, highlighting their central role in the ecosystem. Energy Efficiency (row 2) and Regulation and Ethics (row 5) show comparatively lower values across most columns, with their highest values at 13.07709 and 13.01564, respectively. This suggests that while these factors are critical, their impact is more localized or indirect in nature. The diagonal elements represent self-influence, with Hardware Advancements and Human-Robot Interaction standing out. Overall, the matrix underscores the interplay of direct and indirect relationships, emphasizing AI Algorithm Performance, Human-Robot Interaction, and Hardware Advancements as key drivers of influence in the system.

TABLE 8. Total Relation matrix (T)

Total Relation matrix (T)						Ri
	15.5	14.44134	19.20391	19.29609	13.05866	81.5
	10.63333	9.623091	12.95624	13.07709	8.810242	55.1
	14.66667	13.41713	17.66108	18.00559	12.24953	76
	14.66667	13.47858	17.92365	17.74302	12.18808	76
	10.63333	9.701304	13.01769	13.01564	8.73203	55.1
Ci	66.1	60.66145	80.76257	81.13743	55.03855	

The Table 8 Total Relation Matrix (T) provides a comprehensive view of the interactions among five key factors: AI Algorithm Performance, Energy Efficiency, Human-Robot Interaction, Hardware Advancements, and Regulation and Ethics. The matrix contains numerical values representing the influence of one factor on another. Additionally, the Ri (row sum) and Ci (column sum) summarize the overall influence exerted by and received by each factor. The Ri values represent the total influence each factor has on others. AI Algorithm Performance has the highest Ri (81.5), indicating it is the most influential factor. Human-Robot Interaction and Hardware Advancements follow closely, each with an Ri of 76, reflecting their critical role in shaping technological advancements. In contrast, Energy Efficiency and Regulation and Ethics have lower Ri values (55.1), signifying their relatively smaller influence on other factors. The Ci values represent how much influence a factor receives from others. Human-Robot Interaction and Hardware Advancements have the highest Ci values (80.76257 and 81.13743, respectively), showing they are significantly impacted by other factors. AI Algorithm Performance has a Ci of 66.1, demonstrating its moderate dependency, while Regulation and Ethics has the lowest Ci (55.03855), reflecting limited external influence. This matrix highlights the dynamic interplay between influence and dependency among these factors, with AI Algorithm Performance as a strong driver and Human-Robot Interaction and Hardware Advancements as key participants in a balanced exchange.

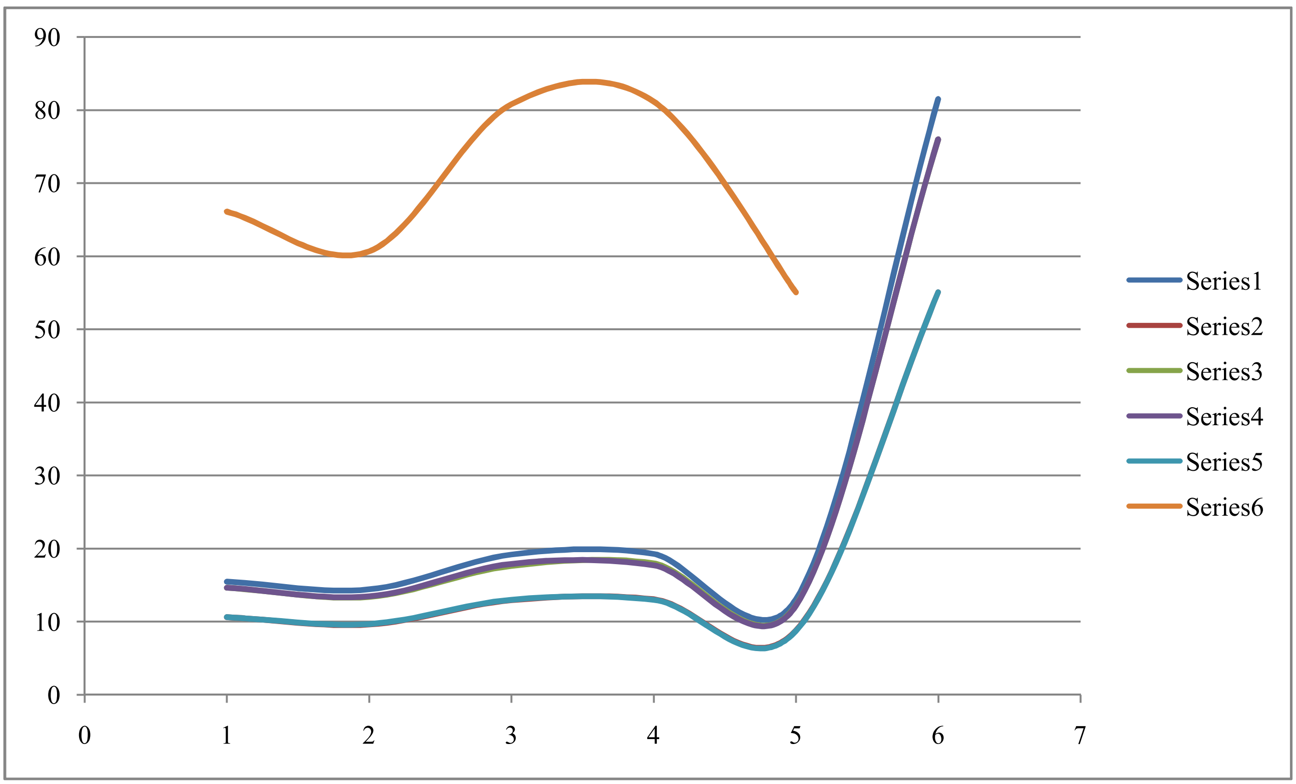

FIGURE 3.Total Relation matrix (T)

The line graph 3 compares six data series (Series1 to Series6) across a common x-axis range (0 to 7) and illustrates their varying trends in the y-axis values (0 to 90).Series6, represented by an orange line, exhibits a distinctive trend compared to the other series. It starts at a moderate value, peaks significantly around the midpoint, and then declines sharply, indicating a temporary surge before tapering off. This behavior sets it apart as the most dynamic series. The other series (Series1 to Series5) display a more consistent pattern with relatively low values in the initial stages, followed by a slight dip around the middle of the x-axis range (around x=4). Afterward, they rise sharply toward the end of the range. This suggests a steady progression followed by a rapid escalation. Among these, Series1, Series2, Series4, and Series5 exhibit closely aligned trends, indicating minimal variation among them. This alignment suggests a common factor or influence driving their behavior. Series3, while part of this group, appears to deviate slightly with a lower starting point and less pronounced rise. Overall, the graph highlights contrasting behaviors, with Series6 showing unique variability and the rest

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demonstrating steady, similar growth trends, particularly toward the end.

TABLE 9. Ri&Ci

	Ri	Ci
AI Algorithm Performance	81.5	66.1
Energy Efficiency	55.1	60.66145
Human-Robot Interaction	76	80.76257
Hardware Advancements	76	81.13743
Regulation and Ethics	55.1	55.03855

The table 9 presents two key metrics, Ri and Ci, for five factors influencing technological advancements: AI Algorithm Performance, Energy Efficiency, Human-Robot Interaction, Hardware Advancements, and Regulation and Ethics. These metrics likely represent the "row influence" (Ri) and "column influence" (Ci), reflecting the extent to which each factor influences or is influenced by others.AI Algorithm Performance has a high Ri of 81.5 and a Ci of 66.1, indicating its strong influence on other factors while being moderately affected by them. This reinforces its role as a significant driver of technological progress. Energy Efficiency shows a lower Ri (55.1) compared to its Ci (60.66145), suggesting it is more influenced by other factors than it directly influences them, highlighting its dependency on external advancements. Human-Robot Interaction and Hardware Advancements exhibit similar values, with Ri and Ci both around 76 to 81. This balance suggests they are both major contributors to technological systems while simultaneously being influenced by other factors, reflecting their dynamic interplay within the ecosystem. Regulation and Ethics, with the lowest Ri (55.1) and Ci(55.03855), demonstrates a relatively limited influence and dependency, emphasizing its foundational yet indirect role in ensuring responsible technological development. This analysis highlights the interplay of influence and dependency among these factors.

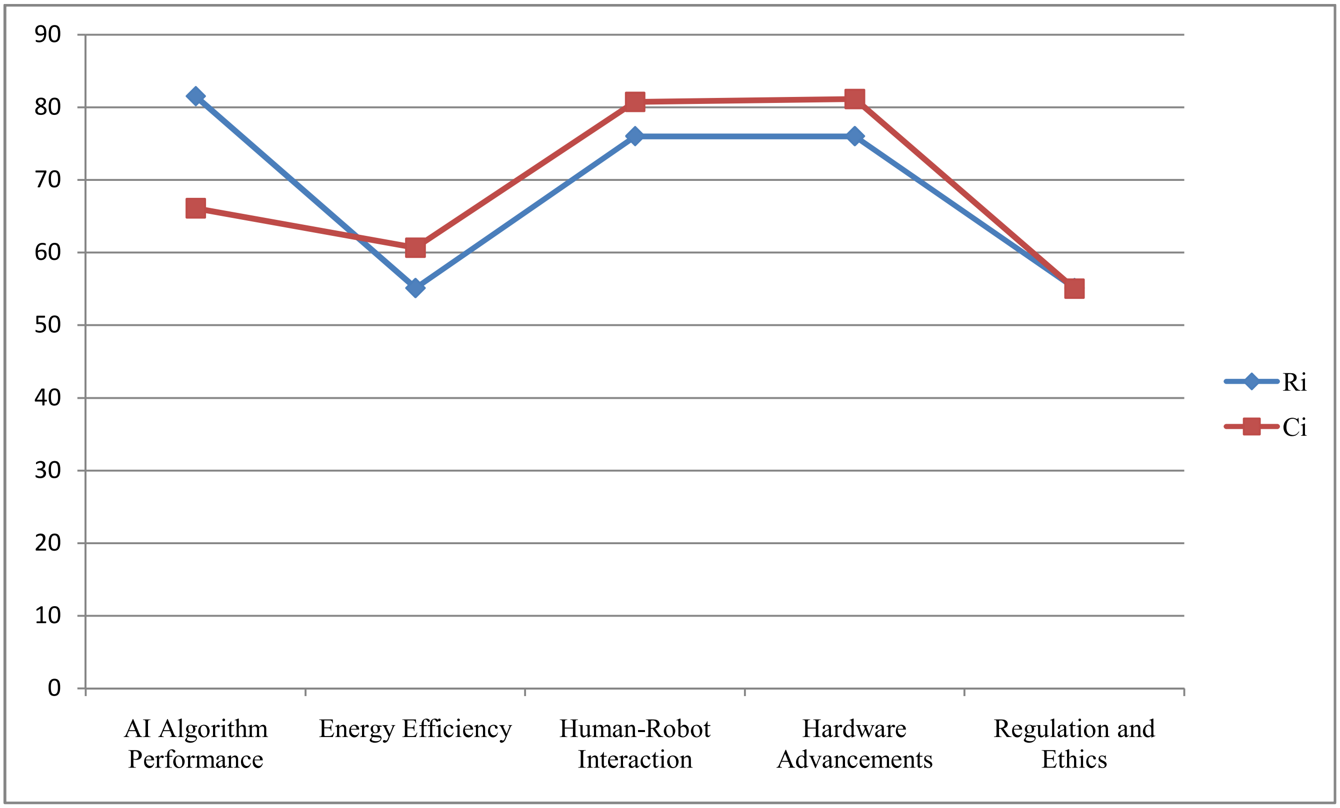

FIGURE 4.Ri&Ci

The graph 4 illustrates the relationship between the influencing (Ri) and influenced (Ci) criteria across five key factors relevant to a specific domain, potentially AI-powered robotics or another technological evaluation. The factors analyzed include AI Algorithm Performance, Energy Efficiency, Human-Robot Interaction, Hardware Advancements, and Regulation and Ethics. Each factor's Ri (influence exerted) and Ci (influence received) values are plotted, indicating their importance and interdependence. AI Algorithm Performance shows a high Ri value, suggesting it is a strong influencer, while its Ci value is relatively lower, implying it is less influenced by other factors. Energy Efficiency has the lowest Ri and Ci values, showing it plays a less central role compared to other criteria. Human-Robot Interaction and Hardware Advancements demonstrate balanced and higher Ri and Ci values, indicating they are both highly influential and influenced within the system. Regulation and Ethics exhibits a declining trend, with lower Ri compared to Ci, suggesting it is more affected by other factors than exerting influence. This analysis helps prioritize factors for improvement or strategic focus. For instance, enhancing AI Algorithm Performance could cascade positive impacts across the system due to its strong influence. Meanwhile, attention to Energy Efficiency might need direct intervention to elevate its role.

TABLE 10.T matrix

T matrix				
15.5	14.44134	19.20391	19.29609	13.05866
10.63333	9.623091	12.95624	13.07709	8.810242
14.66667	13.41713	17.66108	18.00559	12.24953
14.66667	13.47858	17.92365	17.74302	12.18808

10.63333	9.701304	13.01769	13.01564	8.73203

The given T matrix Table 10 provides numerical data associated with five factors represented in rows and columns. Each row corresponds to a specific factor, and each column likely represents an associated metric, measurement, or index. The factors are as follows: AI Algorithm Performance, Energy Efficiency, Human-Robot Interaction, Hardware Advancements, and Regulation and Ethics. The first row highlights values for AI Algorithm Performance, with the highest value being 19.29609 and the lowest at 13.05866, indicating a wide range of performance metrics. Human-Robot Interaction, in the third row, showcases significant values as well, with its highest value reaching 18.00559. Similarly, Hardware Advancements (row 4) presents strong metrics, with values ranging from 12.18808 to 17.92365, reflecting its importance in the technological framework. Energy Efficiency (row 2) and Regulation and Ethics (row 5) show comparatively lower values, with their highest metrics being 13.07709 and 13.01564, respectively. This suggests that while these factors are critical, their direct contributions might be less dominant compared to others. Overall, the T matrix illustrates the varying levels of influence and performance of these factors, highlighting Hardware Advancements and Human-Robot Interaction as having consistently higher values, which align with their importance in driving technological progress.

TABLE 11. Ri+Ci,Ri-Ci,Identity,Rank

	Ri+Ci	Ri-Ci	Rank	Identity
AI Algorithm Performance	147.6	15.4	3	cause
Energy Efficiency	115.7615	-5.56145	4	effect
Human-Robot Interaction	156.7626	-4.76257	2	effect
Hardware Advancements	157.1374	-5.13743	1	effect
Regulation and Ethics	110.1385	0.061453	5	cause

The table11 presents a comparative analysis of five factors influencing technological advancements: AI Algorithm Performance, Energy Efficiency, Human-Robot Interaction, Hardware Advancements, and Regulation and Ethics. The data includes the sum (Ri+Ci), the difference (Ri-Ci), the rank, and their classification as either a "cause" or an "effect."Hardware Advancements hold the top rank with the highest Ri+Ci value (157.1374) and a relatively low Ri-Ci value (-5.13743), signifying its importance as a driving effect in technological progress. Human-Robot Interaction follows closely in second place, with a slightly lower Ri+Ci value (156.7626) and an Ri-Ci value of -4.76257, also classified as an effect. This underscores its critical role in advancing human-centered technologies.AI Algorithm Performance ranks third, with a moderate Ri+Ci value (147.6) and a positive Ri-Ci value (15.4). Interestingly, it is identified as a cause, indicating its role in driving advancements in other areas. Energy Efficiency, ranked fourth, also classified as an effect, has an Ri+Ci value of 115.7615 but a slightly negative Ri-Ci (-5.56145), indicating its dependence on external drivers. Lastly, Regulation and Ethics rank fifth with the lowest Ri+Ci (110.1385) but a marginally positive Ri-Ci (0.061453), making it another cause, emphasizing its foundational role in guiding responsible technological development.

TABLE 12. Rank

	Rank
AI Algorithm Performance	3
Energy Efficiency	4
Human-Robot Interaction	2
Hardware Advancements	1
Regulation and Ethics	5

The table 12 ranks five critical factors contributing to technological advancements: Hardware Advancements, Human-Robot Interaction, AI Algorithm Performance, Energy Efficiency, and Regulation and Ethics. The ranking reflects the relative importance or impact of each factor, with "1" being the highest rank and "5" the lowest. Hardware Advancements, ranked first, highlight their pivotal role as the most significant factor driving progress. This position emphasizes the importance of cutting-edge physical technologies and infrastructures in supporting innovations across various domains.Human-Robot Interaction is ranked second, underlining its growing importance in creating seamless and efficient collaborations between humans and machines. Its high rank reflects the increasing focus on integrating robotics into industries and daily life while enhancing usability and functionality.AI Algorithm Performance holds the third rank, indicating its critical but relatively balanced influence. While AI algorithms serve as a backbone for many technological innovations, their impact depends on the synergy with other factors such as hardware and human interaction. Energy Efficiency is ranked fourth, showcasing its vital role in ensuring sustainable technological growth. Though slightly lower in priority, it remains essential for reducing environmental impact and promoting long-term viability. Regulation and Ethics rank fifth, reflecting their foundational but indirect role. They ensure that advancements occur responsibly, safeguarding societal values and ethical standards.

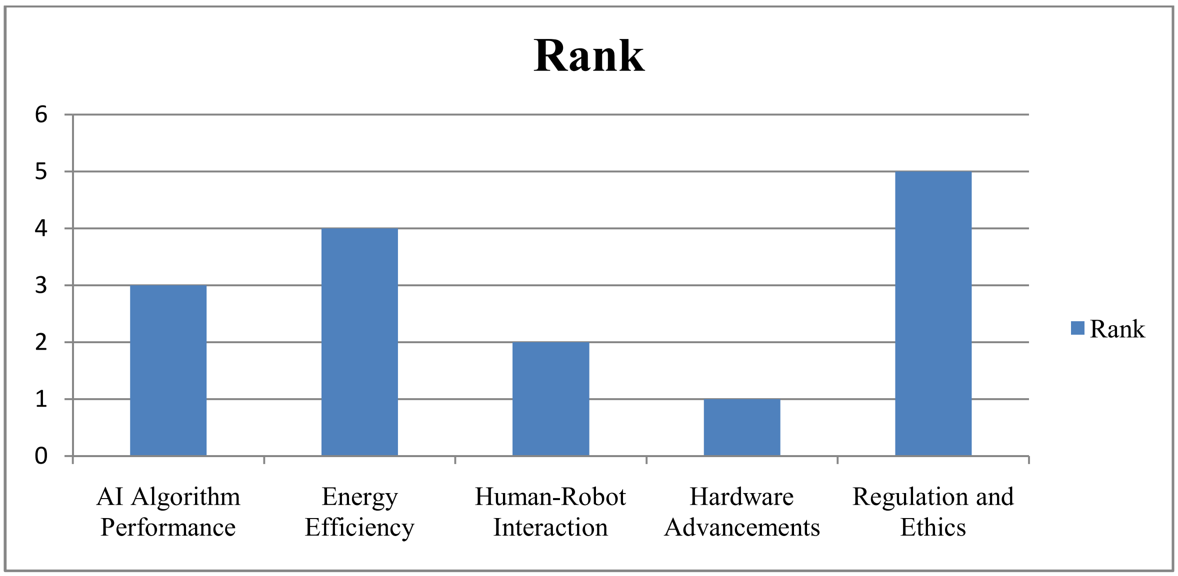

FIGURE 5. Rank

The bar chart 5 illustrates the rankings of five essential factors AI Algorithm Performance, Energy Efficiency, Human-Robot Interaction, Hardware Advancements, and Regulation and Ethics based on their significance in contexts like AI-powered robotics or technological advancements. According to the chart, Regulation and Ethics holds the top rank (5), underscoring its critical role in promoting responsible and ethical technology implementation. Human-Robot Interaction follows closely with a rank of 4, highlighting the importance of fostering effective collaboration and communication between humans and robots to improve usability and trust. AI Algorithm Performance ranks third (3), emphasizing its centrality in enabling functionality and intelligent decision-making in these systems. Energy Efficiency comes in fourth place (2), signifying its moderate importance, particularly in optimizing energy usage and supporting sustainability efforts. Finally, Hardware Advancements ranks lowest (1), suggesting that while hardware is necessary, its immediate influence may be less critical compared to the other factors.This ranking highlights areas of priority, such as strengthening ethical frameworks and improving human-robot interaction, which can address broader societal challenges while ensuring the technology remains functional, efficient, and user-focused.

CONCLUSION

As AI continues to advance, robotic systems will become even more adept at assisting surgeons by analyzing medical data, recommending personalized treatment options, and even performing autonomous procedures. In addition to surgery, robots powered by AI will increasingly support elderly care and people with disabilities, providing companionship, assistance with daily activities, and monitoring for medical conditions.

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These robots can help address the challenges of an aging global population by providing personalized care and enabling independent living.In addition to its industrial and service applications, AI-powered robotics is also transforming the way humans interact with machines. Social robots, such as humanoid robots and virtual assistants, are being developed to engage with people in natural, human-like ways. These robots can be employed in various roles, such as customer service, education, and therapy, offering personalized interactions that cater to individual needs. AI enables these robots to process natural language, recognize emotions, and respond appropriately, fostering more intuitive and seamless human-robot interactions.

As AI continues to evolve, these robots will become more adept at understanding complex social cues and engaging in more meaningful conversations, making them increasingly effective in fields such as mental health care, where empathy and personalized communication are critical. Additionally, the ethical implications of autonomous robots particularly those used in healthcare, defense, and law enforcement need careful consideration. There are concerns about accountability when robots make decisions that affect human lives, especially in situations where errors or malfunctions can have serious consequences. Security is another critical concern. As AI-powered robots become more integrated into critical infrastructure, there is the risk that malicious actors could exploit vulnerabilities in the systems, leading to disruptions in services, data breaches, or even physical harm. Ensuring that these robots are equipped with robust security measures and are resistant to hacking is essential for maintaining public trust in the technology. Striking a balance between the benefits of AI-powered robotics and safeguarding privacy and security will be key to the widespread adoption of these technologies.The development of AI-powered robotics also necessitates a shift in societal and regulatory frameworks. As robots become more autonomous, questions surrounding legal liability, intellectual property, and ethical responsibility must be addressed.

For example, if a robot causes harm to a person, who should be held responsible? Should robots be granted certain rights, such as the ability to make decisions, or should they remain tools that serve human interests? Policymakers will need to work closely with technologists. Looking further into the future, AI-powered robotics will likely continue to evolve, with advancements in cognitive capabilities, learning algorithms, and physical design. The potential for robots to collaborate with humans in complex environments, such as in outer space exploration or disaster response, will likely increase. These robots could work alongside human teams, complementing human abilities and providing support in situations that are dangerous or difficult for humans to navigate.These advancements could lead to breakthroughs in fields such as prosthetics, where AI-powered robots could enable more natural and functional replacements for lost limbs.

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