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Improving Swarm Control Algorithms For Multiple Cleaning Robots Using Intelligent Based Technique

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Abstract: The lateness observed in the cleaning of a dirty place was subdued by improving swarm control algorithms for multiple cleaning robots using intelligent based technique. To perfectly achieve this, it was done in this manner, swarm control algorithms for multiple cleaning robots was characterized and the causes of poor swarm control algorithms for multiple cleaning robots was established and conventional SIMULINK model for swarm control algorithms for multiple cleaning robots was designed. Then, an intelligent technique rule base that will reduce the causes of poor swarm control algorithms for multiple cleaning robots was developed. Then an intelligent technique rule base that will reduce the causes of poor swarm control algorithms for multiple cleaning robots was developed and ANN was equally trained in it for effective reduction of the causes of poor swarm control algorithms for multiple cleaning robots. later, an algorithm that will implement the process was developed, a SIMULINK model for improving swarm control algorithms for multiple cleaning robots using intelligent based technique designed and the results obtained were validated and justified. The results obtained were the conventional Task completion time that causes poor swarm control algorithms for multiple cleaning robots was903s. On the other hand, when an intelligent based technique was incorporated into the system, it drastically reduced to814s and the conventional Area coverage efficiency that causes of poor swarm control algorithms for multiple cleaning robots was 88%. On the other hand, when an intelligent based technique was integrated into the system, it automatically increased to 99%. With these results obtained, it meant that the percentage improvement in swarm control algorithms for multiple cleaning robots when an intelligent based technique was integrated into the system was 11%.

Keyword: improving, swarm, control, algorithms, multiple, cleaning, robots, intelligent, based ,technique

1.0 INTRODUCTION

The increasing demand for autonomous systems in domestic, industrial, and public environments has accelerated research into multi-robot systems, particularly swarm robotics. Swarm robotics is inspired by the collective behavior of social insects such as ants, bees, and termites, where simple agents interact locally to produce complex, coordinated global behavior without centralized control (Sahin, 2005). This decentralized approach makes swarm robotics highly suitable for tasks such as environmental monitoring, search and rescue, surveillance, and cleaning operations in large or dynamic environments. In recent years, multi-robot cleaning systems have gained significant attention due to their potential to improve efficiency, reduce operational time, and enhance coverage in environments such as offices, hospitals, airports, and smart homes. Unlike single-robot cleaning systems, multiple cleaning robots working in coordination can divide tasks, reduce redundancy, and ensure faster area coverage. However, coordinating multiple robots introduces challenges such as collision avoidance, task allocation, path planning, and maintaining system robustness in dynamic or partially unknown environments. Traditional centralized control methods often struggle with scalability and fault tolerance when applied to multi-robot systems. As the number of robots increases, centralized systems become computationally expensive and vulnerable to single-point failures. This limitation has motivated researchers to adopt swarm control algorithms that rely on decentralized decision-making and local interactions among robots. Classical swarm intelligence techniques such as Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO) have been widely applied to coordination problems due to their adaptability and robustness (Dorigo & Gambardella, 1997; Kennedy & Eberhart, 1995). Despite their success, conventional swarm control algorithms still face limitations when applied to real-world multi-robot cleaning tasks. These limitations include slow convergence in complex environments, inefficient exploration-exploitation balance, and difficulty adapting to dynamic obstacles or changing environmental conditions. Additionally, most traditional approaches rely on fixed heuristic rules that may not generalize well across different operational scenarios. To address these challenges, researchers have increasingly turned to intelligent-based techniques, including machine learning, reinforcement learning, and hybrid bio-inspired algorithms. Intelligent swarm control approaches enable robots to learn from environmental feedback and improve their coordination strategies over time. For example, reinforcement learning allows robots to optimize cleaning paths based on reward signals such as coverage efficiency and energy consumption, while deep learning techniques can enhance perception and decision-making in uncertain environments (Sutton & Barto, 2018). Hybrid models that combine swarm intelligence with artificial intelligence techniques have shown promising results in improving performance metrics such as coverage rate, energy efficiency, and task completion time. These approaches integrate global optimization capabilities of swarm algorithms with adaptive learning mechanisms, enabling more flexible and scalable multi-robot coordination. Recent studies also emphasize the importance of communication strategies among robots, where limited but efficient information sharing can significantly enhance swarm performance without overloading the system (Brambilla et al., 2013). Furthermore, advancements in sensor technology and embedded systems have enabled the deployment of more sophisticated multi-robot cleaning platforms in real-world settings. However, issues such as limited battery life, communication constraints, and environmental uncertainty still pose significant challenges. Therefore, improving swarm control algorithms using intelligent-based techniques remains a critical area of research. In summary, the development of intelligent swarm control algorithms for multiple cleaning robots is driven by the need for scalable, adaptive, and efficient autonomous cleaning systems. By integrating swarm intelligence with machine learning and other AI-based methods, researchers aim to overcome the limitations of traditional approaches and enhance the performance of cooperative robotic cleaning systems in complex environments.

2.0 METHODOLOGY

To characterize and establish the causes of poor swarm control algorithms for multiple cleaning robots

Table1 was a sample characterized table that identifies common causes of poor swarm control algorithms for multiple cleaning robots. The metrics are presented with recommended threshold values using SI units where applicable. These values are representative engineering benchmarks commonly used in robotics research and may be adjusted depending on the application and operating environment.

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Table:1 characterized and established causes of poor swarm control algorithms for multiple cleaning robots

S/N	Performance Metric	SI Unit	Recommended Threshold Value	Poor Performance Indicator	Conventional causes of poor swarm control algorithms for multiple cleaning robots	Possible Cause(s)
1	Task completion time	s	≤ 900 s (for 100 m² cleaning area)	> 900 s	903 s	Poor task allocation, inefficient path planning, slow decision-making
2	Area coverage efficiency	%	≥ 95%	< 90%	88%	Inadequate swarm coordination, overlapping cleaning paths
3	Robot collision rate	collisions/s	≤ 0.001 collisions/s	> 0.005 collisions/s	0.007 collisions/s	Weak collision avoidance algorithm, poor communication
4	Communication latency	s	≤ 0.05 s	> 0.20 s	0.22 s	Network congestion, communication interference
5	Inter-robot	m	≥ 20 m	< 10 m	8 m	Weak wireless

	communication range					signal, environmental obstruction
6	Path planning efficiency	m	≤ 1.10 × optimal path length	> 1.30 × optimal path length	1.32 optimal path length	Poor optimization algorithm, inadequate obstacle avoidance
7	Energy consumption	J/m^2	≤ 450 J/m^2	> 600 J/m^2	602 J/m^2	Excessive robot movement, redundant cleaning operations
8	Battery utilization efficiency	%	≥ 85%	< 70%	68%	Inefficient scheduling, unnecessary idle time
9	Swarm convergence time	s	≤ 30 s	> 60 s	62s	Slow optimization algorithm, poor consensus mechanism
10	Localization error	m	≤ 0.10 m	> 0.30 m	.32 m	Sensor inaccuracies, GPS/SLAM errors
11	Obstacle detection accuracy	%	≥ 98%	< 90%	88%	Low-quality sensors, poor object recognition

						algorithm
12	Sensor response time	s	≤ 0.10 s	> 0.30 s	0.32s	Sensor processing delay, hardware limitations
13	Robot idle time	%	≤ 5%	> 15%	17%	Poor workload balancing, ineffective task scheduling
14	Packet loss during communication	%	≤ 1%	> 5%	7%	Wireless interference, unstable communication network
15	Fault recovery time	s	≤ 20 s	> 60 s	62 s	Lack of fault-tolerant swarm algorithm
16	Cleaning overlap ratio	%	≤ 5%	> 15%	17%	Poor coordination, inefficient coverage algorithm
17	Processing time per decision cycle	s	≤ 0.02 s	> 0.10 s	0.12 s	High computational complexity, inefficient intelligent algorithm

18	Swarm scalability	Number of robots	Stable operation up to ≥ 50 robots	Performance degrades beyond 20 robots	25	Centralized control, poor scalability
19	Navigation accuracy	m	≤ 0.05 m	> 0.20 m	0.23 m	Localization drift, poor sensor fusion
20	Mean Time Between Failures (MTBF)	h	≥ 500 h	< 200 h	198 h	Hardware reliability issues, inadequate maintenance

Tablle2 Summary of Major Causes of Poor Swarm Control

Category	Primary Causes	Impact on Performance
Algorithmic	Poor swarm optimization, slow convergence, inefficient task allocation	Increased cleaning time, reduced efficiency
Communication	High latency, packet loss, limited communication range	Poor coordination, collisions, delayed responses
Navigation	Weak localization, poor path planning, obstacle avoidance failures	Coverage gaps, redundant movements
Energy Management	High energy consumption, poor battery scheduling	Reduced operational time and productivity
Sensing	Sensor noise, inaccurate detection, delayed response	Navigation errors, missed obstacles
Scalability	Centralized control architecture, computational overload	Reduced performance as the number of robots increases
Fault Tolerance	Poor recovery mechanisms, lack of adaptive learning	System instability and reduced robustness
Intelligent Decision-Making	Absence of AI-based learning, static control rules	Inability to adapt to dynamic environments

Notes

- The threshold values provided are **benchmark engineering values** derived from typical performance expectations in swarm robotics research and autonomous mobile robot systems. Actual thresholds should be tailored to the cleaning environment, robot hardware, and operational objectives.

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- Metrics such as **time (s)**, **distance (m)**, **energy (J)**, **communication range (m)**, and **Mean Time Between Failures (h)** are expressed in **SI units**. Percentage-based metrics (e.g., coverage efficiency, packet loss) are dimensionless but are conventionally reported as percentages.

To design a conventional SIMULINK model for swarm control algorithms for multiple cleaning robots

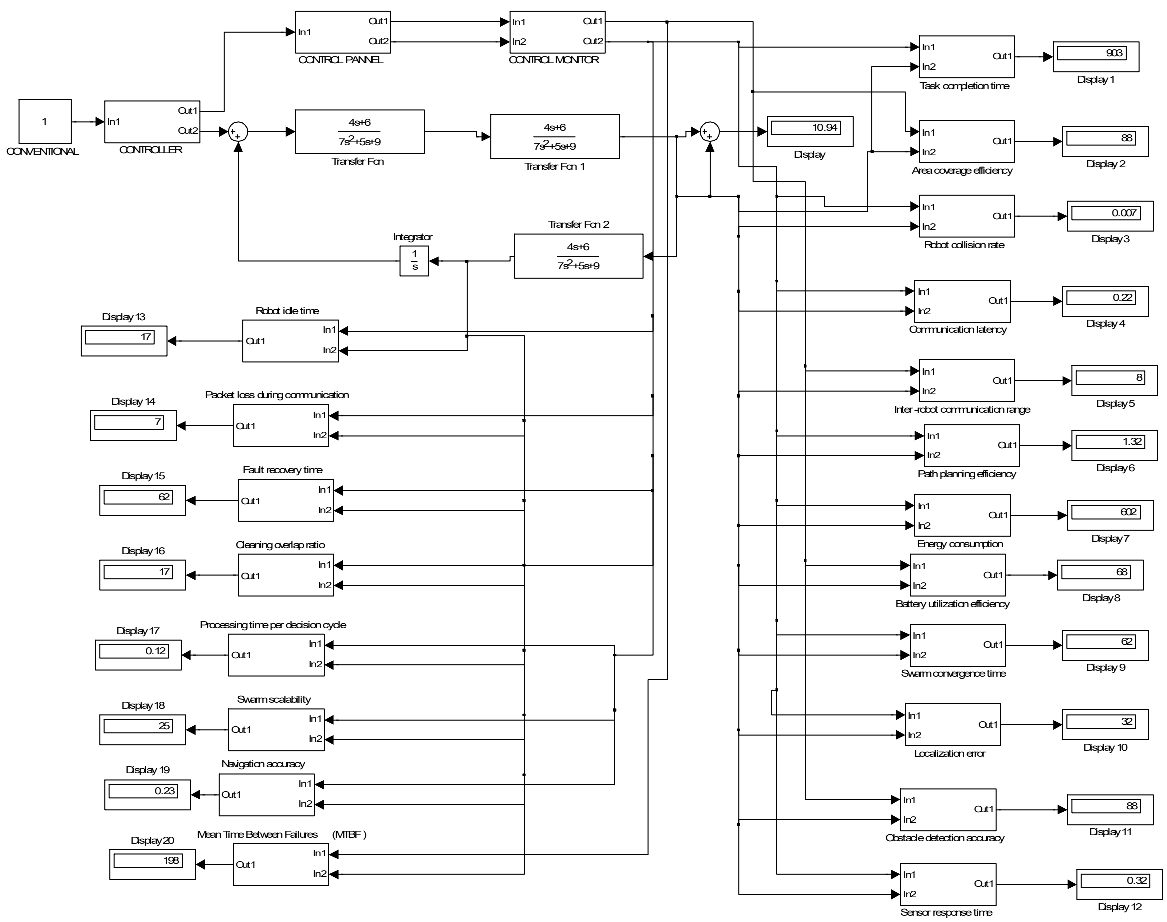

Fig 1 designed conventional SIMULINK model for swarm control algorithms for multiple cleaning robots

The results obtained were as shown in figures 8 and 9

To develop an intelligent technique rule base that will reduce the causes of poor swarm control algorithms for multiple cleaning robots

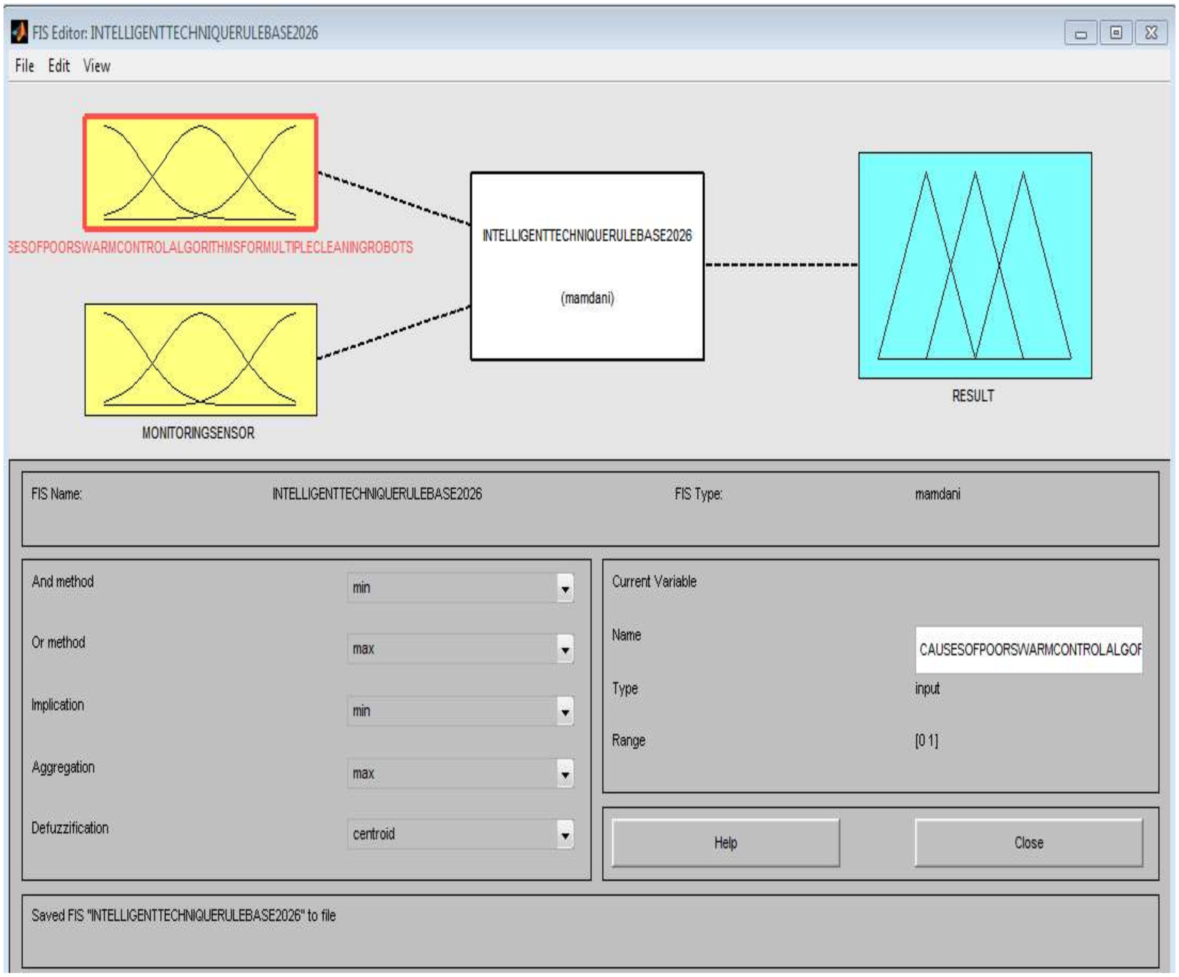

Fig 2 develop an intelligent technique fuzzy inference system that will reduce the causes of poor swarm control algorithms for multiple cleaning robots

Fig 2 had two inputs of causes of poor swarm control algorithms for multiple cleaning robots and monitoring sensor. It also had an output of result.

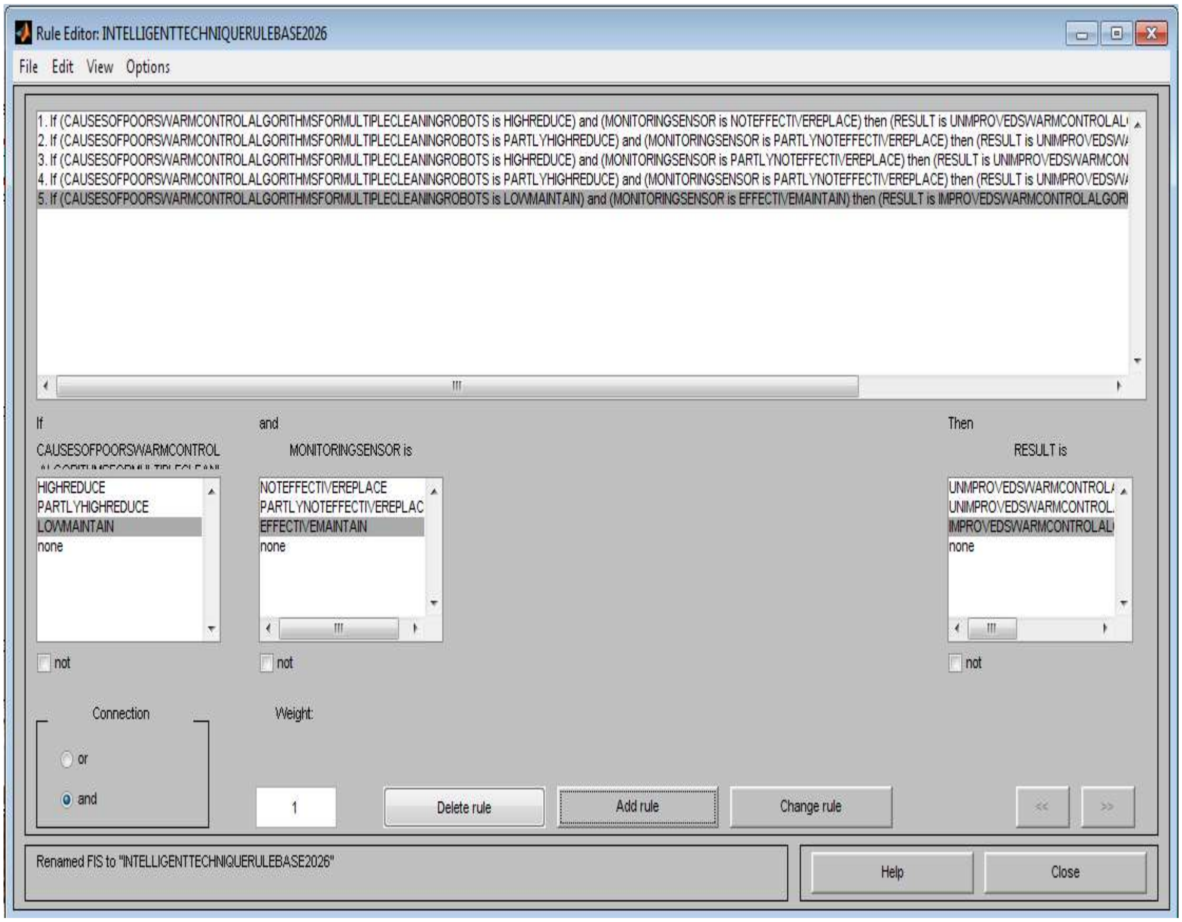

Fig 3 developed intelligent technique rule base that will reduce the causes of poor swarm control algorithms for multiple cleaning robots

Fig 3 was fully detailed in table 3

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Table 3 detailed developed intelligent technique rule base that will reduce the causes of poor swarm control algorithms for multiple cleaning robots

1	IF CAUSES OF POOR SWARM CONTROL ALGORITHMS FOR MULTIPLE CLEANING ROBOTS IS HIGH REDUCE	AND MONITORING SENSOR IS NOT EFFECTIVE REPLACE	THEN RESULT IS UNIMPROVED SWARM CONTROL ALGORITHMS FOR MULTIPLE CLEANING ROBOTS
2	IF CAUSES OF POOR SWARM CONTROL ALGORITHM IS PARTLY HIGH FOR MULTIPLE CLEANING ROBOTS IS HIGH REDUCE	AND MONITORING SENSOR IS NOT EFFECTIVE REPLACE	THEN RESULT IS UNIMPROVED SWARM CONTROL ALGORITHMS FOR MULTIPLE CLEANING ROBOTS
3	IF CAUSES OF POOR SWARM CONTROL ALGORITHMS FOR MULTIPLE CLEANING ROBOTS IS HIGH REDUCE	AND MONITORING SENSOR IS PARTLY NOT EFFECTIVE REPLACE	THEN RESULT IS UNIMPROVED SWARM CONTROL ALGORITHMS FOR MULTIPLE CLEANING ROBOTS
4	IF CAUSES OF POOR SWARM CONTROL ALGORITHMS FOR	AND MONITORING SENSOR IS PARTLY NOT EFFECTIVE REPLACE	THEN RESULT IS UNIMPROVED SWARM CONTROL

	MULTIPLE CLEANING ROBOTS IS PARTLY HIGH REDUCE		ALGORITHMS FOR MULTIPLE CLEANING ROBOTS
5	IF CAUSES OF POOR SWARM CONTROL ALGORITHMS FOR MULTIPLE CLEANING ROBOTS IS LOW MAINTAIN	AND MONITORING SENSOR IS EFFECTIVE MAINTAIN	THEN RESULT IS IMPROVED SWARM CONTROL ALGORITHMS FOR MULTIPLE CLEANING ROBOTS

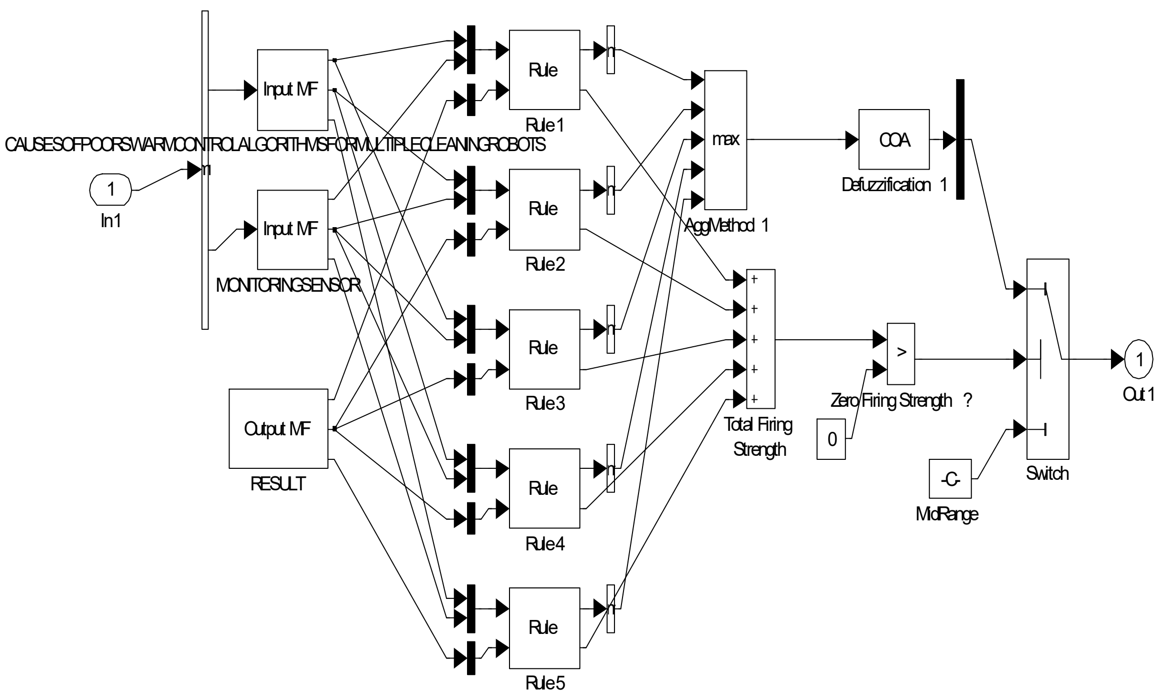

Fig 4 the operational mechanism of developed intelligent technique rule base that will reduce the causes of poor swarm control algorithms for multiple cleaning robots

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To train ANN in the developed intelligent technique rule base for an effective reduction of the causes of poor swarm control algorithms for multiple cleaning robots

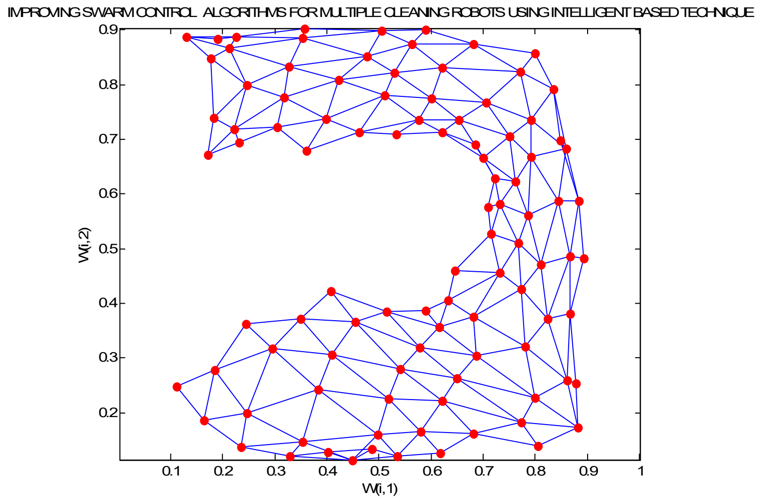

Fig 5 trained ANN in the developed intelligent technique rule base for an effective reduction of the causes of poor swarm control algorithms for multiple cleaning robots

In fig 5 ANN was trained twenty times in the five rules 20 x 5 = 100 to give hundred neurons that looked similar to a human brain and performed effectively in compliance with the stipulated rules.

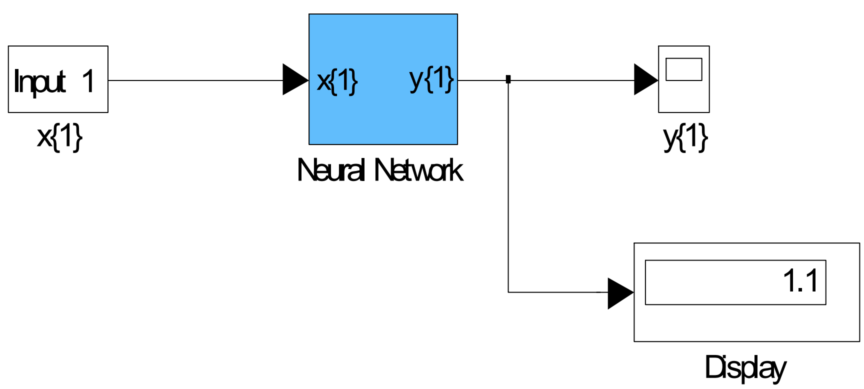

Fig 6 result obtained in developed intelligent technique rule base for an effective reduction of the causes of poor swarm control algorithms for multiple cleaning robots

To develop an algorithm that will implement the process

1.Characterize and establish the causes of poor swarm control algorithms for multiple cleaning robots

2. Identify Task completion time that did not attain threshold

3.Identify Area coverage efficiency that did not attain threshold

4.Identify Inter-robot communication range that did not attain threshold

5.Identify Obstacle detection accuracy that did not attain threshold

6.Identify Robot idle time that did not attain threshold

7.Identify Fault recovery time that did not attain threshold

8.Identify Mean Time Between Failures (MTBF) that did not attain threshold

9. Design a conventional SIMULINK model for swarm control algorithms for multiple cleaning robots and integrate 2 through 8

10. Develop an intelligent technique rule base that will reduce the causes of poor swarm control algorithms for multiple cleaning robots

11. Train ANN in the developed intelligent technique rule base for an effective reduction of the causes of poor swarm control algorithms for multiple cleaning robots

12 integrate 10 and 11

13 Integrate 12 into 9

14. Did causes of poor swarm control algorithms for multiple cleaning robots reduce and attain threshold?

15. IF NO go to 13

16.IF YES go to 17

17. Improved swarm control algorithms for multiple cleaning robots

18.Stop

19.End

The design a SIMULINK model for improving swarm control algorithms for multiple cleaning robots using intelligent based technique

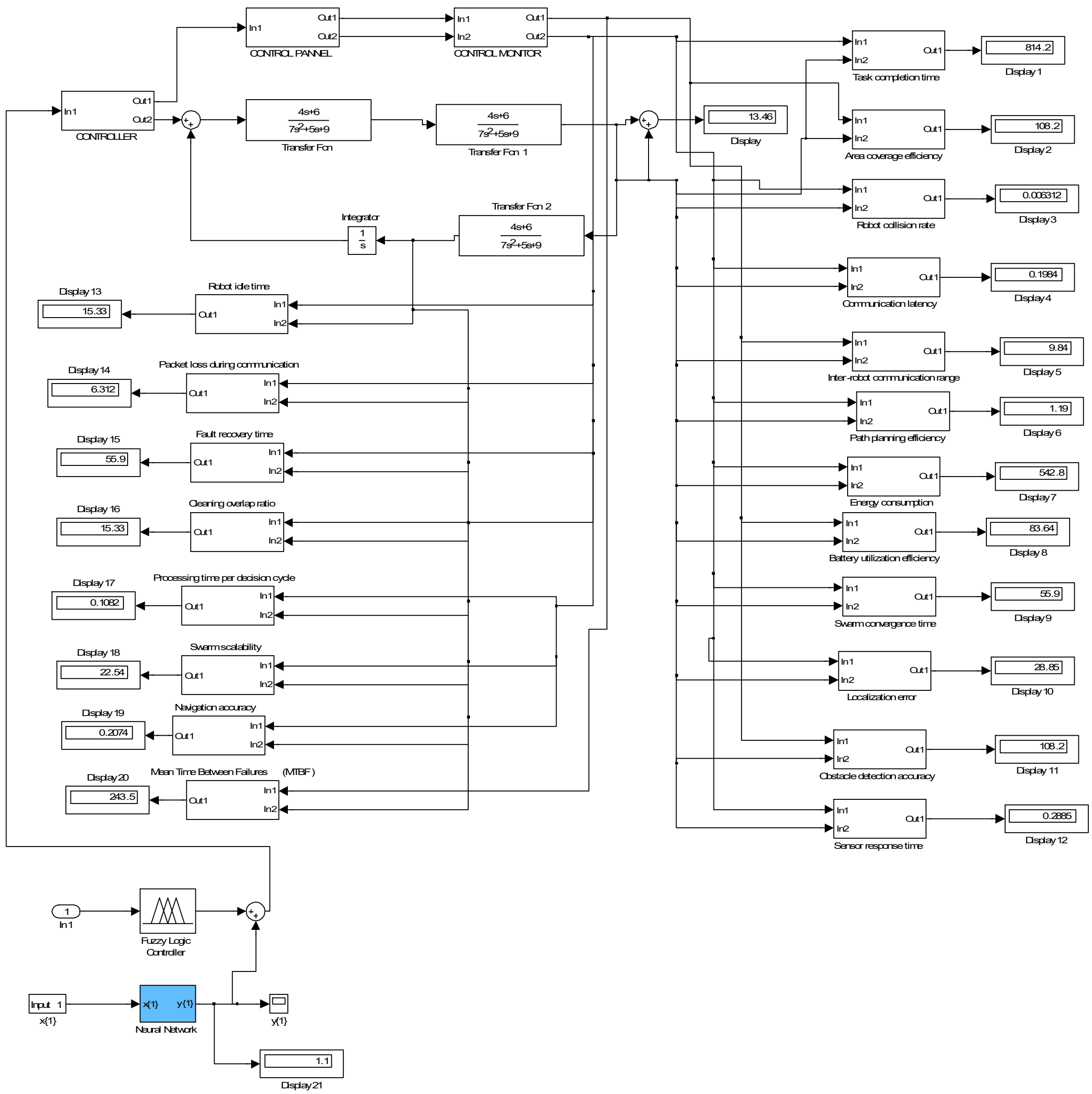

Fig 7 designed SIMULINK model for improving swarm control algorithms for multiple cleaning robots using intelligent based technique

The results obtained were as shown in figures 8 and 9

To validate and justify the percentage improvement in the reduction of causes of poor swarm control algorithms for multiple cleaning robots with and without an intelligent based technique

To find percentage improvement in the reduction of Task completion time causes of poor swarm control algorithms for multiple cleaning robots with an intelligent based technique

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Conventional Task completion time = 903 s

Intelligent based technique Task completion time= 814s

%improvement in the reduction of Task completion time causes of poor swarm control algorithms for multiple cleaning robots with an intelligent based technique=

$$\frac{\text{Conventional Task completion time - Intelligent based technique Task completion time}}{\text{Conventional Task completion time}} \times \frac{100\%}{1}$$

%improvement in the reduction of Task completion time causes of poor swarm control algorithms for multiple cleaning robots with an intelligent based technique=

$$\frac{903\text{ s} - 814\text{s}}{903\text{ s}} \times \frac{100\%}{1}$$

%improvement in the reduction of Task completion time causes of poor swarm control algorithms for multiple cleaning robots with an intelligent based technique= 9.9%

To find percentage improvement in the reduction of Area coverage efficiency causes of poor swarm control algorithms for multiple cleaning robots with an intelligent based technique

Conventional Area coverage efficiency = 88%

Intelligent based technique Area coverage efficiency = 99%

%improvement in the reduction of Area coverage efficiency causes of poor swarm control algorithms for multiple cleaning robots with an intelligent based technique=

Intelligent based technique Area coverage efficiency - Conventional Area coverage efficiency

%improvement in the reduction of Area coverage efficiency causes of poor swarm control algorithms for multiple cleaning robots with an intelligent based technique=

99% - 88%

%improvement in the reduction of Area coverage efficiency causes of poor swarm control algorithms for multiple cleaning robots with an intelligent based technique= 11%

3.0 Results and discussions

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Table 4 comparison of conventional and intelligent based technique Task completion time that causes of poor swarm control algorithms for multiple cleaning robots

Time (months)	Conventional Task completion time that causes of poor swarm control algorithms for multiple cleaning robots(s)	Intelligent based technique Task completion time that causes of poor swarm control algorithms for multiple cleaning robots(s)
1	903	814
2	903	814
3	903	814
4	903	814

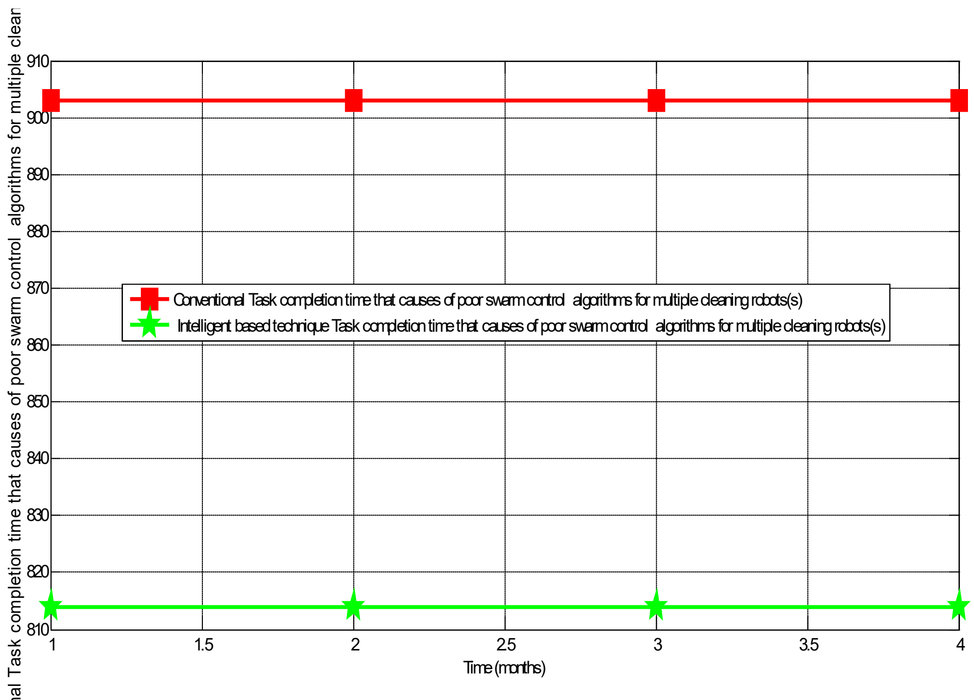

Fig 8. comparison of conventional and intelligent based technique Task completion time that causes of poor swarm control algorithms for multiple cleaning robots

The conventional Task completion time that causes poor swarm control algorithms for multiple cleaning robots was903s. On the other hand, when an intelligent based technique was incorporated into the system, it drastically reduced to814s.

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Table 5 comparison of conventional and intelligent based technique Area coverage efficiency that causes of poor swarm control algorithms for multiple cleaning robots

Time (months)	Conventional Area coverage efficiency that causes of poor swarm control algorithms for multiple cleaning robots(%)	Intelligent based technique Area coverage efficiency that causes of poor swarm control algorithms for multiple cleaning robots(%)
1	88	99
2	88	99
3	88	99
4	88	99

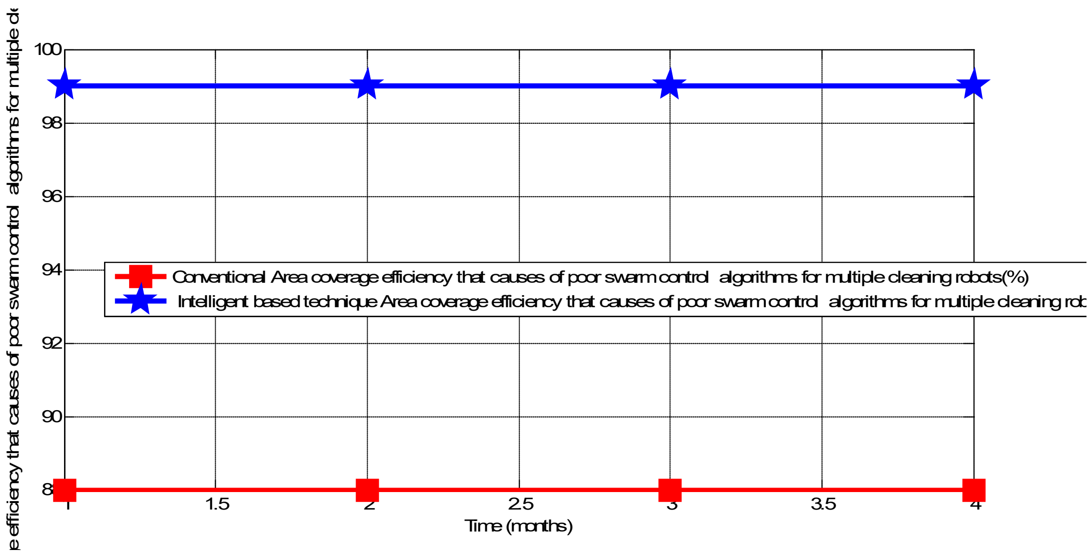

Fig 9 comparison of conventional and intelligent based technique Area coverage efficiency that causes of poor swarm control algorithms for multiple cleaning robots

The conventional Area coverage efficiency that causes of poor swarm control algorithms for multiple cleaning robots was 88%. On the other hand, when an intelligent based technique was integrated into the system, it automatically increased to 99%. With these results obtained, it meant that the percentage improvement in swarm control algorithms for multiple cleaning robots when an intelligent based technique was integrated into the system was 11%.

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4.0 Conclusion

The delay in the cleaning of dirty things was overcame by introducing improving swarm control algorithms for multiple cleaning robots using intelligent based technique. To perfectly achieve this, it was done in this manner, swarm control algorithms for multiple cleaning robots was characterized and the causes of poor swarm control algorithms for multiple cleaning robots was established and conventional SIMULINK model for swarm control algorithms for multiple cleaning robots was designed. Then, an intelligent technique rule base that will reduce the causes of poor swarm control algorithms for multiple cleaning robots was developed. Then an intelligent technique rule base that will reduce the causes of poor swarm control algorithms for multiple cleaning robots was developed and ANN was equally trained in it for effective reduction of the causes of poor swarm control algorithms for multiple cleaning robots. later, an algorithm that will implement the process was developed, a SIMULINK model for improving swarm control algorithms for multiple cleaning robots using intelligent based technique designed and the results obtained were validated and justified. The results obtained were the conventional Task completion time that causes poor swarm control algorithms for multiple cleaning robots was903s. On the other hand, when an intelligent based technique was incorporated into the system, it drastically reduced to814s and the conventional Area coverage efficiency that causes of poor swarm control algorithms for multiple cleaning robots was 88%. On the other hand, when an intelligent based technique was integrated into the system, it automatically increased to 99%. With these results obtained, it meant that the percentage improvement in swarm control algorithms for multiple cleaning robots when an intelligent based technique was integrated into the system was 11%.

To characterize and establish the causes of poor swarm control algorithms for multiple cleaning robots

2. To design a conventional SIMULINK model for swarm control algorithms for multiple cleaning robots

3. To develop an intelligent technique rule base that will reduce the causes of poor swarm control algorithms for multiple cleaning robots

4. To train ANN in the developed intelligent technique rule base for an effective reduction of the causes of poor swarm control algorithms for multiple cleaning robots

5. To develop an algorithm that will implement the process

6. The design a SIMULINK model for improving swarm control algorithms for multiple cleaning robots using intelligent based technique

7. To validate and justify the percentage improvement in the reduction of causes of poor swarm control algorithms for multiple cleaning robots with and without an intelligent based technique

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