Effectiveness of Swarm Robotics in Coordination of Multiple Robots as a System That Consists of Large Numbers of Mostly Simple Physical Robots

Pradnesh Ramesh Padave[1], Jonnala Subba Reddy[2]

[1] D Y Patil College of Engineering, Akurdi, Pune, India
[2] Lakireddy Bali Reddy College of Engineering, Mylavaram, India
*Corresponding Author Email: [1] prpadave@dypcoeakurdi.ac.in

Abstract

The concurrent work in a task with multiple robots is gaining faster achievement with different tasks. Swarming is able to ensure a new way of collaboration which is helping to provide diverse skill growth in the environment. The combined goal and also development of different new skills are gained from swarm robotics. Inspiration for swarm robotics is gained with social insects as they are able to exchange information with each other and modify their behaviors according to the environment. The formation of the swarm is developed with the help of multiple robots as these can build progress in work. Moving in the same direction as their neighbours are the most simple rule that is followed by swarm robotics which can be ensured a better improvement compared with single robots. Multiple robots are helping to produce better improvements in different sectors such as agriculture, military operation, rescue operation, and much more. Different designs of machines are helping to assist humans to solve different real-life issues of the people. With the help of multiple robotic functions, safety and speed are ensured which can also solve any hard issues for people. Robotics are helping to provide errorless development which is important for gaining growth and assurance for improving the quality of humans.

Keywords

Autonomous mobile robots, Swarm robotic functions, Swarm intelligence theory.

INTRODUCTION

In modern days swarm robotics is the coordination of a large group of simple robots that generally use local rules. These kinds of robotic systems are able to gain inspiration from societies and try to perform tasks beyond their capabilities. It is based on simple robots and local rules that can coordinate in decentralized and distributed ways. It has some major connection with the social insect and these systems are able to clear the complexity of the task to achieve a particular purpose. Gerardo Beni, a professor at the University of California, invented a swarm robot in 1989. A swarm robot has two major components such as software and hardware. In this context, the software can be considered the brain of the entire system. There are various kinds of advantages of swarm robots such as searching objects, environment monitoring, and building a communication networking system. This more flexible system has the capability to adapt to the new operating condition. As an example it can be said that tasks of the environment can be changed over time such as disaster recovery, patrolling, rescue and search. In order to control the swarm robot system, scientists use the behavior-based method while navigating unknown situations or environments with obstacles. Accordingly, through wireless LAN, Bluetooth, and infrared, swarm robots are able to communicate and send messages to other robots or technologies. This study will shed light on the multi-robotic system and swarm robotics collaborations that develop the automatic function and help to define the goal. On the other hand, this study will also focus on the effectiveness of swarm robotics and its impact on society as well. In current days it has been seen that human swarming has been shown to enable groups that are able to reach priorities, optimize decisions, and also forecast in less time period than the traditional method. In this context, it can be said that the ability to think together in a swarm creates the group faster and smarter. The swarming process uses various kinds of sustainable pushing, units that make a huge impact on the entire working process and method. This study will also highlight the issues of swarm robotics and also shed light on the key aspect of swarm intelligence. Artificial intelligence is one of the biggest platforms that are able to do flexibility in swarm robotics and Swarm AI is generally inspired by the natural system collective behaviour.

LITERATURE REVIEW

Multi-robotic system and swarm robotics

The collaboration of a minimum of two or more robots developing the work together creates organized robotic functions which are able to achieve a defined goal [3]. The robotic systems are divided into six types of robots which are autonomous mobile robots (AMRs), articulated robots, humanoids, cobots, automated guided vehicles (AGVs), and hybrids. Inspired by social insects the field of multi-robotics is increasing which is gaining an ability to ensure achievement in complex work. Well-defined goals are able to achieve by swarm robotics are beneficial for gaining visible growth in different works comparatively single robotic functions. These robotic systems developed with fewer

capabilities as an entity, but the original power developed with the cooperation of multi-robotic systems or multiple robots. The goal of swarm robotics is to deliver high-value features quickly by focusing the whole team on the same work and backlogging items that can make up that feature. The direction of team members with the help of available time and skills are able to complete an in-process story. In this method, the swarm robotic techniques are working in different conditions. The swarm robotic functions can be defined with different types or can be divided into various categories which are stationary air-based multiple swarm robots commonly known as drone systems, Water-based swarm robotic functions, and others. The robotic functions ensured better performance with the help of multiple robots and developed an improved outcome with the help of swarm robotic technologies. The robotic technologies which can perform better with swarm robotics are mentioned below-

Wheeled robots

Different wheeled robots are created which are beneficial for providing navigation around the ground and motorized wheels to properly move. The design of the wheeled robots is easy and beneficial for completing different tasks in the environment [1]. Differential wheeled robots are placed on two either side, helping to provide a better robotic body. With the help of wheels robots can easily move faster, and easier.

Figure 1: Wheeled Robots
[source: 1]

Walking or legged robots

The walking mobile robots are helping to develop effective goals which are essential for providing advantages to overcome different obstacles developed in the environment [4]. The legged robots provide an excellent grip over uneven surfaces and rough terrains.

Figure 2: Legged robots
(Source: 4)

Tracked robots

The tracked robots are moving like tanks which are helping to gain advantages by moving with the use of tracks [2]. Different slippery terrains are easily developed and easy with moving in the areas with the help of steel or rubber tires on the vehicle. Distribution of weight is easily spread in the large base which are providing continuous tracking of vehicles.

Figure 3: Tracked robots
(Source: 2)

With the help of local interaction, the performance of swarm robotics is able to provide better growth in the environment. The robots have easily ensured performance with the help of multiple robots which are able to provide better assurance of doing work.

Effectiveness of swarm robotics in society

Military missions (battlefield surveillance): The swarm intelligence theory helps to ensure better performance in reconnaissance, sniper detection, and neutralizing explosive devices helping to provide an advantage in military missions. Establishment of a communicational network that is beneficial for gaining a coordination motion as swarm robotics are able to set up a formation. The professional service robots used in defense are helping to enhance the solider's capabilities in war and also lowering harm to them. The swarm robotic technologies are vastly used in military missions and are also helping to ensure better advantages in battle conditions. Military swarming is developing a battlefield tactic that is designed for maximizing target saturation, and also overwhelming or saturating the defenses

of the principal target.

Searching for survivors in disaster-hit areas: With the help of multiple robots, the proper searching in disaster-hit areas is done. The proper search for survivors is easily ensured with the help of swarm robotic technologies as these are able to provide a better impact for looking for survivors in disaster-hit areas. Locating the heartbeats under rubble after earthquakes, tornadoes, or other catastrophes can be ensured with the help of swarm robots [8]. The air-sea rescue over the water is developed a visual growth in the search for different survivors in disaster-hit areas. The recovery is able to ensure the outspread of disaster damage in different emergent situations which gained a better performance with multi-robotics functions. In situations of mining accidents, urban disasters, hostage situations, and explosions the swarm robotic functions are used to ensure better growth.

Parallel and simultaneous transportation of vehicles: With the help of multiple numbers of sensors and motors swarm robotics are able to implement basic communication and provide computational capabilities which are appropriate for gaining physical mechanism. The understanding of transport strategies is ensured with behavioral-based robots which are able to provide some feasible solutions for ensuring ease in the transportation system [9]. The delivery of different products can be easily done with swarm robotics as these are able to provide a safe and secure way to produce a better delivery system which is essential for providing solutions for different issues which may increase the speed of delivery in different possible ways such as air, water, and land.

Industrial automation: The different industrial robots are able to provide a better opportunity in the industries as automation can be gained with multiple robotic functions. Different automatic industrial development can be easily acquired with the help of multiple robotic functions that are beneficial for increasing productivity. The boost of efficiency and convenience are developed with different technologies as it is influential in the industries. Machine learning with the help of artificial intelligence helped to gain growth and development in the industries [6]. Swarm robotics is helping to provide better growth as it is mange to ensure robustness, adaptability, and scalability for solving different complex tasks in industries.

Medical care: Medical care development can be easily achievable with the help of multi-robotic functions which are ensuring better growth in medical fields. Different risky operations are easily performed with the help of swarm robotics are gained the ability to ensure growth and cooperation which are making an easy way to ensure cooperation. Cancer, tumors, heart diseases, and cardiological problems are cured with the help of swarm robotics as these technologies are helping to ensure the diagnosis of the disease and properly ensured treatment.

Agriculture: Multiple robots are helping to assure fresh produce which is able to control the production cost and fatigue of farmers by doing repetitive work such as fertilizing, sowing, weeding, and spraying. The harvesting and picking process is helping to reduce wastage and able to provide financial stability in the field of agriculture [5]. Using multiple robots agricultural development is easily and efficiently ensured with multiple sensors and AI. These are able to provide performance and growth in agriculture by increasing productivity. The agricultural process is improved and also the issues of skilled laborers are solved with the help of a swarm robotic system as this is beneficial for gaining achievement and growth in the harvesting systems.

Research work: The conduction of research on living specimens is easily developed with multiple robots. The sensitivity of different creatures is changed with human contact which is completely controlled with multiple robotic functions. Discovery through multiple robots are provide diverse and methodical observation and analysis which are ensuring production in the research field [7]. In hazardous environments, robots are gaining capabilities by eliminating the risk of danger. With the help of multiple robots, it is beneficial to prevent money, also saving time and accidents in the research work by solving different real-life issues. AI (Artificial intelligence) is gaining the ability to perform important functions which are beyond human abilities such as going deepwater to collect samples for research purposes. With the help of swarm robotic technologies different space researches are also possible which is providing visionary growth in the sector of knowledge development.

The different key aspects of swarm robotics are developed with behaviors as these behaviors are difficult to predict the behavior from the individual rules. The importance of knowledge is gained in the ability to ensure the compilation of tasks. The functions of a colony could not be understood with the knowledge of the functioning of an agent. Sensitivity can change in the simple rules resulting in different group-level behavior.

Issues of swarm robotics

Data privacy and security can be breech by using swarm robotic functions as the processing of sensitive information is accomplishing the work. The establishment of a communication network is not able to be developed with swarm robotic functions. Behavior-based methods are helping to ensure the formation control of swarm robot systems [13]. The initial investment in swarm robotics is huge which is not able to provide growth in the industry. AI programming is hard to provide growth with mesh networking in swarm robotics. Costing of robots is excessively huge and creates more money which is creating a major issue by increasing the cost of products [10]. The lacking of algorithms and applications is cheaper and better for developing a better performance to solve problems. Limitations of technologies are gained with the help of swarm robotics as different operations cannot be done properly and successfully. Job opportunities are reduced with swarm robotics these can be a big issue for the economy as the employment-to-population ratio is going down with swarm robotics. Robot brains are not able to perform always

accordingly to humans as different decision-making procedures can not be done with the help of swarm robotics. Implementation of different ways of working can be possible with the help of swarm robotic technologies. Connectivity issues in the robots can create a problem for doing synchronized work which is a major problem for completing any work [16]. Bluetooth, wireless LAN, and other connectivity methods are not always applicable in hazardous situations like fire and much more for ensuring the performance of swarm robotics. Due to collision, the robots can face interference between them as coordination between them can be missing. The cost of the overall system of swarm robotics is bigger compared with normal robotic functions.

METHODOLOGY

In an article methodology is the process that is the concrete base of the research paper. All research process needs to follow a method for completing the research process. The methodology process consists of several kinds elements that can create a pathway for the entire research process such as research philosophy, research approach, research design, collection, and analysis of data. Basically, researchers use philosophy as per their assumptions and knowledge on the topic. There are various kinds of research philosophies that help to maintain a base of the research style. In that case, positivist research philosophy is one of the greatest philosophies for this research [15]. It is also based on the assumptions of the subject matter as well as knowledge. Accordingly, the research approach also plays a major role in every research paper that helps to provide a relevant conclusion on the entire research process. From various studies, it has been noticed that maximum research has tried to utilize the benefits of the deductive approach. The main purpose of using the deductive approach is to examine the values of the hypotheses. The positive side is that this paper has not used any kind of hypotheses and that is why this study has chosen an inductive approach. The inductive approach has the capability to create a general and simple conclusion for the study and it also provides a concrete framework as well. It has also a big connection with the design of the study and researchers use these methods to build the entire study in a systematic manner. This study has tried to follow the technique of the research design process that also make a huge impact on the entire procedure of the study. The case study design is one of the easiest ways that depend on the data generally collected from the vast resources.

The proper analysis of a topic is easily executed with appropriate information which is critically ensuring the validity and reliability of topics. The performance of using existing data to form new studies with methodologies. To complete this research secondary qualitative methods are used which is beneficial for solving the issues of swarm robotics development. The total cost of research is lower by using secondary qualitative methods as all the information is gained from the internet where different books, articles, and journals are available for completing the research. These time-saving methods are helping to improve for ensuring additional information for collecting data for the research. The secondary qualitative method is helping to produce appropriate research which is essential for gaining growth in understanding the advantages of swarm robotics [11]. The swarm robotics issues and usefulness are easily understood by researchers with the help of different available information from the internet which is able to enrich the performance of work.

Understanding the issues, it is easier for the researchers to solve the problems with multiple robotics which are providing some efficient solutions to real-life issues. With the huge information available on the internet researchers are able to ensure growth and development in swarm robotics as certain goals are gained with the help of a structured procedure by gaining the philosophical discussion which is associated with background assumptions. Different sensors are co-ordinately developing the performance which is ensured with the help of multiple robots as with the help of these robots the increase can be seen. Visible growth can be achieved with different performances which are gaining data from the internet. Different available publications on the internet are helping to provide a specification to the researcher's needs.

DISCUSSION

The large robotic formations that are applied with control theory are not able to perform with low-intensity inter-robot communication for distance and bearing. The robotic swarms handle scalability is creating issues for probabilistically distributed works. Swarm intelligence is developing the improvement of robots with the help of physical robots [12]. Inspired by social insects a large number of robots are gained the complexity of work to achieve. The interactions among the robots and complex behaviours can emerge with swarm robotic functions. Algorithms are assigned for simple robots which are followed by individual robots increasing the performance of swarm robotics. With the help of interactions between the robots' different complex behaviours are performed by multiple robots which are beneficial for completing tasks. The development of swarm robotics is designed to perform better with a group of robots that are developed in the form of centralized controlling for robots [14]. Nanorobotics and micro-robotics are used for ensuring different tasks which are effectively developed the performance of rescue and search operations. The behaviour-based method which is developed with multiple robots ensures the formation control for navigating the obstacles. Different functional solutions are able to deliver with the help of the swarming process as this is able to ensure better performance compared with single robots [17]. The interactions with a collective behavior are able to solve different complex tasks. Swarm systems are responding to internal disruptions and different external challenges.

The use of artificial intelligence in swarm robotics is able to help to provide coordination with different individual units

such as drones, and satellites which are beneficial for ensuring automation and self-organization. Collectively working together for reaching a common goal is the main motive of the swarm robotic system which is beneficial for ensuring growth and development. The connectivity is ensured with Bluetooth, wireless LAN, or infrared in swarm robotics as these are beneficial for gaining growth and development. Flexibility in work is ensured with swarm robotics as different challenges are overcome with this situation. The self-organizational growth is achieved from swarm intelligence as these are able to emerge from the situation and gained visible growth and development.

The flight of the swarm drones can be controlled manually or can be easily controlled with an autonomous process. Gaining inspiration from nature and biological systems swarm intelligence (SI) is able to solve different complex issues which are growing interactions with the locality [18]. Different military operations in modern times are easily solved with the help of swarm robotics which is able to provide major growth in saving the lives of soldiers. Adaption of new operation conditions is ensured with the help of swarm robotics as it is important for gaining growth in the field of disaster recovery, patrolling, and search and rescue [19]. Different formations are made by swarm robotics as these are beneficial for completing complex tasks easily with the help of these functions. Swarm robotics is helping to provide mapping as big areas can be easily explored with a large number of robots and gained an impactful development in this process [20]. Development of accuracy in different works is easily ensured with the help of Swarm AI as real-time swarm intelligence are able to develop performance by gaining the decision-making ability on different tasks. Different robotic systems are the mobile robotic system, the manipulation robotic system, and the data acquisition and control robotic system. The speed and dependability of robots are helping to produce growth and gain maximum productivity in industries by working all the time without taking any breaks. This is able to ensure performance by maximizing perfection and growth in the process of achieving development using swarm robotics.

Swarm robotics is used widely in packing and packaging, manufacturing, transport, laboratory research, assembly, mining, earth and space exploration, surgeries, weaponry, safety, and the mass production of consumer and different industrial goods. Providence of better consumer service with the help of swarm robotics is helping to develop growth and efficiency through robotic automation technologies which are ensured visible growth and development in the process of progress with seizing opportunities. The control system is helping to achieve better development in navigating the swarm's robotic functions as per its behaviour. Information about the environment is gained by the swarm robots with the help of different sensors as these are helping to gain growth.

CONCLUSION

From this study, it can be concluded that in current days swarm robotics is the greatest combination of a vast group of simple robots. Generally, it uses some local rules, and it has major connections with societies. Accordingly, it has the capabilities to perform its task beyond its capabilities and some major connections with the social insect and other updated systems. Swarm robots can easily clear difficulties and assist to achieve the purpose as well. This system is made with several kinds of updated software, chip, sensors, and high-resolution cameras. From the above study, it has been seen that artificial intelligence plays a major role in the development of swarm robotics. This study has shed light on swarm robotics and multi-robotics system which is the collaboration of two or more two robots that is able to work together. The assembling robotic system has the capability to define its own path and it can also work as per the determining pathway. From this above study, it has been observed that the robotic system has been divided into six kinds of parts such as autonomous mobile robots (AMRs), articulated robots, humanoids, cobots, automated guided vehicles (AGVs), and hybrids. The aim of swarm robotics is to provide high-quality service quickly.

This study has also focused on several kinds of robots such as wheeled robots, legged or walking robots, and tracked robots that help to perform various kinds of tasks as well. On the other hand, this paper also highlighted the effectiveness of swarm robotics in society. It has been observed that nowadays swarm robotics is also used in battlefield surveillance, searching disaster-hit areas. Accordingly simultaneous and parallel transportation vehicles, medical care, industrial automation, research work, and the agricultural sector also use swarm robotics for developing their working process. Furthermore, this research process also sheds light on the issues of swarm robotics. All the essential has been collected by the secondary qualitative research process and this method is generally based on the simple internet searching process. In this method, the data collection process is also easier than other methods last, it can be said that swarm robotics is a blessing for the new generation and the world. The miniature robots are able to provide a better response time compared with their large counterparts as they are faster and lighter.

REFERENCES

[1] Xie, D., Chen, L., Liu, L., Chen, L. and Wang, H., 2022. Actuators and Sensors for Application in Agricultural Robots: A Review. *Machines*, *10*(10), p.913.

[2] Chen, X., Wu, Y., Hao, H., Shi, H. and Huang, H., 2019. Tracked wall-climbing robot for calibration of large vertical metal tanks. *Applied Sciences*, *9*(13), p.2671.

[3] Gervasi, R., Mastrogiacomo, L. and Franceschini, F., 2020. A conceptual framework to evaluate human-robot collaboration. *The International Journal of Advanced Manufacturing Technology*, *108*(3), pp.841-865.

[4] Delmerico, J., Mintchev, S., Giusti, A., Gromov, B., Melo, K., Horvat, T., Cadena, C., Hutter, M., Ijspeert, A., Floreano, D.

and Gambardella, L.M., 2019. The current state and future outlook of rescue robotics. *Journal of Field Robotics*, *36*(7), pp.1171-1191.

[5] Johnson, L.K., Bloom, J.D., Dunning, R.D., Gunter, C.C., Boyette, M.D. and Creamer, N.G., 2019. Farmer harvest decisions and vegetable loss in primary production. *Agricultural systems*, *176*, p.102672.

[6] Dash, R., McMurtrey, M., Rebman, C. and Kar, U.K., 2019. Application of artificial intelligence in automation of supply chain management. *Journal of Strategic Innovation and Sustainability*, *14*(3), pp.43-53.

[7] Hoffman, G. and Zhao, X., 2020. A primer for conducting experiments in human–robot interaction. *ACM Transactions on Human-Robot Interaction (THRI)*, *10*(1), pp.1-31.

[8] Graja, I., Kallel, S., Guermouche, N., Cheikhrouhou, S. and Hadj Kacem, A., 2020. A comprehensive survey on modeling of cyber-physical systems. *Concurrency and Computation: Practice and Experience*, *32*(15), p.e4850.

[9] Alsrehin, N.O., Klaib, A.F. and Magableh, A., 2019. Intelligent transportation and control systems using data mining and machine learning techniques: A comprehensive study. *IEEE Access*, *7*, pp.49830-49857.

[10] Cooper, L.A., Holderness Jr, D.K., Sorensen, T.L. and Wood, D.A., 2019. Robotic process automation in public accounting. *Accounting Horizons*, *33*(4), pp.15-35.

[11] Mualla, Y., Najjar, A., Daoud, A., Galland, S., Nicolle, C. and Shakshuki, E., 2019. Agent-based simulation of unmanned aerial vehicles in civilian applications: A systematic literature review and research directions. *Future Generation Computer Systems*, *100*, pp.344-364.

[12] Alam, A., 2022. Employing Adaptive Learning and Intelligent Tutoring Robots for Virtual Classrooms and Smart Campuses: Reforming Education in the Age of Artificial Intelligence. In *Advanced Computing and Intelligent Technologies* (pp. 395-406). Springer, Singapore.

[13] Guan, J., Zhou, W., Kang, S., Sun, Y. and Liu, Z., 2020. Robot formation control based on internet of things technology platform. *IEEE Access*, *8*, pp.96767-96776.

[14] Dorigo, M., Theraulaz, G. and Trianni, V., 2021. Swarm robotics: past, present, and future [point of view]. *Proceedings of the IEEE*, *109*(7), pp.1152-1165.

[15] Chua, W.F., 2019. Radical developments in accounting thought? Reflections on positivism, the impact of rankings and research diversity. *Behavioral Research in Accounting*, *31*(1), pp.3-20.

[16] Khaldi, B., Harrou, F., Benslimane, S.M. and Sun, Y., 2021. A data-driven soft sensor for swarm motion speed prediction using ensemble learning methods. *IEEE Sensors Journal*, *21*(17), pp.19025-19037.

[17] 17. Khang, A., Hahanov, V., Abbas, G.L. and Hajimahmud, V.A., 2022. Cyber-physical-social system and incident management. In *AI-Centric Smart City Ecosystems* (pp. 21-35). CRC Press.

[18] Gowthami, J., Jeyauthmigha, R.K. and Shanthi, N., 2021. On swarm intelligence and its integration with Internet of Things: Challenges and applications. *Advanced Deep Learning Applications in Big Data Analytics*, pp.156-181.

[19] Queralta, J.P., Taipalmaa, J., Pullinen, B.C., Sarker, V.K., Gia, T.N., Tenhunen, H., Gabbouj, M., Raitoharju, J. and Westerlund, T., 2020. Collaborative multi-robot search and rescue: Planning, coordination, perception, and active vision. *Ieee Access*, *8*, pp.191617-191643.

[20] Schranz, M., Umlauft, M., Sende, M. and Elmenreich, W., 2020. Swarm robotic behaviors and current applications. *Frontiers in Robotics and AI*, *7*, p.36.