An Overview on Swarm Robots and Its Applications

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Abstract:

Machine to Machine Economy (M2M) and industry 4.0 are going to see a rise in technologies like Machine Learning, Robotics and Machine and Machine Communication in the next 5-10 years. Swarm Robotics — A technology inspired by Swarm Intelligence is enhancing and helping these 2 trends and will see scalable applications with swarm robots. Swarm Robotics has multiple applications like manufacturing, agriculture and will give rise to more futuristic applications in the upcoming years. Here, we share developments and some applications of swarm robots and cover how a group of robots work together to accomplish a complex task. This chapter gives an overview of the literature was used to conduct the research, with books and papers on artificial intelligence and swarm robot applications.

Keywords: artificial intelligence, robotics, swarm robotics, swarm behavior, group of robots, machine learning, industry 4.0

I. Introduction:

Swarm robots centers on the synchronization and cooperation of sizable collections of relatively uncomplicated robots to accomplish intricate objectives. They are designed to mimic animal swarm behavior such as ants, birds, bees, and termites. Swarm robots involve synchronization of numerous individual entities, typically functioning without a central authority, and depending on basic localized actions to collaborate.

II. Literature Review:

1. **On Artificial Immune Systems and Swarm Intelligence Jon Timmis, Paul S Andrews and Emma Hart** mentions the similarities and classifications between Artificial Systems (AIS) and Swarm Intelligence (SI) and the various aspects of AIS that have direct parallels with SI and examine the role of AIS and SI in science and in engineering with focus on immune system and how they can solve complex problems.
2. **Swarm behavior control of mobile multi-robots with wireless sensor networks by Weiming Shen b and Wenfeng Li** explains about that complex adaptive system and talks about challenges in the applications that combines wireless sensor networks (WSN) and multi-mobile robots (MMR)
3. **Automated sequencing of swarm behaviors for supervisory control of robotic swarms** Sasanka Nagavalli, Nilanjan Chakraborty, Katia Sycara created an algorithm for swarm navigation application and dynamic area coverage application, it demonstrates the utility of their algorithm in situations where the behaviors in the library have not been designed for the task at hand.
4. **Local Communication Protocols for Learning Complex Swarm Behaviors with Deep Reinforcement Learning,** uses Reinforcement Learning to learn about decentralized control policies that can manage with limited local sensing and communication abilities in the swarm agents.
5. **Search and rescue with autonomous flying robots through behavior-based cooperative intelligence by Ross D Arnold,** Hiroyuki Yamaguchi & Toshiyuki Tanaka have conducted research on search and rescue operations through autonomous flying robots and about their behavior-based intelligence.
6. **The two-wheeled robotic swarm concept for Mars exploration by Alexander Petrovsky, Ivan Kalinov, Pavel Karpyshev, Dazmitry Tsetserukou, Anton Ivanov, Alessandro Golkar** conducted research and produced concept of a two-wheeled rover for Mars exploration.
7. **A Systematic Review of Swarm Robots by Olaronke, I. Rhoda, I. Gambo, I. Ojerinde, O. A. Janet, O.** where authors reviewed eighty literatures relating to swarm robots and its applications.
8. **Swarm Robots in Education: A Review of Challenges and Opportunities by Wafa Johal, Yu Peng, Haipeng Mi** conducted literature on swarm robots for education purpose by using appearance of swarm robots, curriculum of experiments and studying interactions between teachers and learners.
9. **Review of Techniques for Fault Diagnosis in Damaged Structure and Engineering System by** Dhirendra Nath Thatoi Harish Ch. Das, and Dayal R. Parhi conducted a literature review on the techniques for fault diagnosis for damages in damaged structure and engineering and how swarm robots help in the fault diagnosis.
10. **Characterizing Human Perception of Emergent Swarm Behaviors by Phillip Walker & Michael Lewis, Katia Sycara** conducted research on human swarm interaction, swarm states and how they can be used by swarm robots to make informed decisions through collective behaviors.

III. Methodology:

Operational Definitions:

1. Swarm Intelligence:
Swarm intelligence is artificial intelligence technique and its study is based on the collective behavior in independent and decentralized systems inspired from nature such as birds, animals, insects.

2. Multi-agent system:
Multi-agent systems are computerized systems consisting of multiple agents interacting with each other for solving complex problem

3.Robot Swarms:
Group of robots are known as robot swarms and they exhibit co-ordination between multiple robots and their collective behavior in an environment.

4. Internet of Things (IOT):
Internet of Things is a technology that enables communication between network of connected devices and cloud and also inter-device communications. Here swarm robots follow the IOT principles of communication.

5. Sensor network:
Sensor network is network of sensors in swarm robots which is essential for communication between robots in a swarm.

6. Decentralization:
Decentralization is a feature of swarm robots where robotic systems operate without centralized control system and are independent in nature in order to perform asynchronous tasks.

IV. OBJECTIVE OF THE STUDY:

The aim of the study is to give an overview on how swarm robots help solve complex problems and contribute to development of innovative applications.

V. METHODS OF STUDY:

Literature Overview

- We studied the research papers from the popular journals like IEEE explore, Google scholars, ACM Digital libraries and others to understand entire proposals of robotics applications and the need of it and existing work in progress and we choose specific applications into manufacturing

- We analyzed the technological and psychological implications and benefits of developing newer swarm robots
- We can create surveys – LinkedIn, FB, IG to understand the user perspective the actual needs of today's world.
- An empirical study based on thematic literature search was conducted using a number of books and articles, and digital libraries such as Google Scholar as well as research papers from Google search results and social media platforms like Facebook and Instagram. Also used to gather the material for the investigation were secondary reviews, white papers and books on artificial intelligence

VI. OVERVIEW

Swarm robotics is a fascinating area of research that draws from various fields, including biology, computer science, engineering, and mathematics, to create systems that leverage the power of collective intelligence to tackle complex challenges.

Swarm robotic systems give rise to innovative approaches to solve complex tasks where monitoring and fixing problems by humans become extremely difficult. They are used in applications where humans might have risk in losing their lives.

An important feature that makes swarm robots exceptional is swarm intelligence. Algorithms like Artificial Immune Systems (AIS), Clonal Selection Based Algorithms, Danger Theory and Dendritic Cell Algorithms, Negative Selection Algorithms etc. are influenced from immune systems in animals to tackle complicated swarm tasks. Particle Swarm theory is also a highly used technique here where group of particles navigate through possible solutions to find the most optimal solution from them. Swarm robots consist of characteristics that always get highlighted in various applications such as decentralization, scalability, robustness and adaptability, emergent behavior, redundancy and swarm intelligence.

Swarm robots operate without a centralized control system. Swarm robot applications are self-deployed and have different motion control protocols between them. The agents in swarm application use local information like co-ordinates, velocities etc. They communicate with each other using local interactions, allowing them to collectively make decisions and self-organize.

Swarm robotics systems can scale from just a few robots to hundreds or even thousands, depending on the application. The more robots in the swarm, the more efficient they can be in tasks such as exploring unknown environments, searching for targets, or covering a large area.

Individual robots in a swarm can fail or be removed from the system without significantly affecting the overall performance. The swarm as a whole can adapt to changes in the environment or the loss of individual members. The scalability feature in swarm robots also enables researchers to add a new robot into the group for additional support and performance enhancement.

Through local interactions and simple rules, complex and often unexpected behaviors can emerge at the swarm level. This emergent behavior is a result of the collective interactions among robots rather than pre-programmed instructions. Swarm robots also have redundancy in their tasks. If one robot fails to perform a task, another robot can take its place without disrupting the overall operation.

Most important applications of swarm robotics include:

1. **Exploration of Space and territories:** Swarm robots can explore unknown or hazardous environments, such as disaster-stricken areas or planets, where sending a single robot might be too risky or insufficiently efficient. The MARS exploration rovers launched in 2021 are used for target search and environmental exploration.
2. **Search and Rescue:** In scenarios like earthquake-stricken buildings, swarm robots can search for survivors more quickly and cover a wider area compared to individual robots. Another application prominently used is for firefighting purpose where UAVs and locomotive robots help fight fire and rescue people during wild fires.
3. **Agriculture:** Agricultural practices are revolutionized by swarm robots, assuming roles like crop monitoring, precise plant pollination, and targeted pesticide distribution, thereby optimizing yields. In the realm of construction, swarm robots demonstrate their prowess by working together harmoniously to erect structures and execute maintenance tasks in otherwise inaccessible or challenging environments, providing a solution for areas difficult for human workers to navigate.
4. **Construction:** Swarm robots can work collaboratively to construct structures or perform maintenance tasks in places that are challenging for human workers to access.
5. **Environmental Monitoring:** Swarm robots can be used to collect data from various environmental sensors in remote or inhospitable locations.
6. **Transportation:** Swarm robots can transport items collectively, simulating behaviors seen in ant colonies or bee hives.
7. **Logistics and Warehousing:** In warehouses and distribution centers, swarm robots can be employed for efficient inventory management, item sorting, and order fulfillment, optimizing logistics operations.
8. **Security and Surveillance:** Swarm robots can enhance security by patrolling designated areas, monitoring for intruders or suspicious activities, and providing real-time surveillance data.
9. **Entertainment and Education:** Swarm robots are used for educational purposes, teaching concepts like robotics, programming, and collective behavior. They also have potential applications in interactive entertainment and art installations.
10. **Medical Applications:** In healthcare, swarm robots might assist in tasks such as drug delivery, minimally invasive surgeries, and monitoring patients in hospital settings.
11. **Monitoring Infrastructure:** Swarm robots can inspect and monitor critical infrastructure like bridges, pipelines, and power lines for signs of damage or wear, helping prevent failures.
12. **Agroforestry:** Swarm robots can aid in tasks related to agroforestry, such as planting trees in deforested areas, monitoring forest health, and managing wildlife habitats.

13. **Ocean Exploration:** Underwater swarm robots can explore and map the ocean floor, study marine life, and collect data on oceanography and marine ecosystems.
14. **Collaborative Manufacturing:** In manufacturing, swarm robots can collaborate on tasks like assembly, quality control, and material handling, enhancing efficiency and flexibility.
15. **Communication Networks:** Swarm robots can establish ad-hoc communication networks in areas with limited connectivity, ensuring communication in disaster-stricken or remote locations.

VII. CONCLUSION

In conclusion, this chapter delves into the captivating realm of swarm robotics, underscoring its significance as a multidisciplinary field that draws inspiration from biology, computer science, engineering, and mathematics. The synthesis of these disciplines culminates in the creation of systems that effectively leverage collective intelligence to navigate intricate challenges with finesse and ingenuity.

Our exploration has revealed the diverse applications of swarm robotics. The potential impact of swarm robotics reverberates across various sectors and industries. Through the lens of exploration, we recognize how swarm robots reshape traditional frontiers, penetrating uncharted and hazardous terrains. From disaster-stricken regions to extraterrestrial landscapes, these robotic ensembles transcend the limitations of solitary missions. The efficacy of search and rescue operations also benefits from the orchestrated collaboration of swarm robotics, exemplified in scenarios like post-earthquake scenarios where swift area coverage enhances the likelihood of locating survivors.

Environmental monitoring receives a substantial boost from swarm robots equipped with specialized sensors, facilitating data collection from remote and challenging environments. This influx of data enriches research and analysis, contributing to a deeper understanding of complex ecosystems.

The paradigm of transportation assumes new dimensions as swarm robots emulate the cooperative behaviors witnessed in natural systems like ant colonies and bee hives. This emulation empowers the synchronized movement of objects, introducing innovative possibilities for collaborative logistics.

As we gaze into the future, the pervasive influence of swarm robots is poised to revolutionize diverse industries – spanning manufacturing, nano-engineering, agriculture, and space exploration. With the emergence of novel methodologies and techniques in swarm intelligence, collective swarm behavior, and the amalgamation of the Internet of Things (IoT) with swarm systems, these entities are primed to tackle increasingly intricate challenges. It is through these advancements that swarm robotics holds the potential to effect positive and transformative changes for the betterment of humanity. This chapter illuminates the trajectory of swarm robotics and its impending impact on the technological landscape.

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