International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 6 Issue 4, May-June 2022 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Distributed Robotics: A Primer

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ABSTRACT

Distributed robotics has been the focus of attention in recent years. The idea of using a group of robots instead of a single one to execute a task came from the necessity of accomplishing a task that is too complex for a single robot. The use of multiple processing units lead to a distributed system within a single robot. Modern robotics systems are increasingly distributed, heterogeneous, and collaborative and can involve challenging computational tasks. A distributed approach can offer desirable advantages such as improved performance. This paper presents an introduction to distributed robots.

KEYWORDS: *robots, robotics, distributed robotics, multi-robot systems, swarm robotics*

How to cite this paper: Matthew N. O. Sadiku | Uwakwe C. Chukwu | Abayomi Ajayi-Majebi | Sarhan M. Musa "Distributed Robotics: A Primer" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-6 | Issue-4, June 2022, pp.311-316, URL: www.ijtsrd.com/papers/ijtsrd50026.pdf

IJTSRD50026

INTRODUCTION

Robots, from the Czech word robota, means "forced labor." Today, robots are regarded as intelligent agents that can perform actions similar to what humans can do. Robots are often designed to fulfill the possibility to be extended for future tasks. Robotics systems are used in different areas such as medical, manufacturing, agriculture, consumer delivery, warehouse inventory management, aerospace, defense, and more. Some American jobs are at high risk of being replaced by technology. Due to robotic automation, the US has lost five million manufacturing jobs since the year 2000,

Past robots used one computer as the processing unit The main drawback of a single-processing unit systems if the only processing unit fails, the system itself will fail. The use of multiple processing units leads to a distributed system within one single robot. The distributed systems that do not rely on centralized robotic entities. Using a distributed system with many processing units in one robot can bring the system into a save state or even take over tasks of the failing processing unit [1].

Distributed teams of agents hold great promise for solving complex tasks efficiently, reliably, and automatically As distributed robotic systems are getting more capable due to technological advancements, such as high-throughput low-latency communication means and small-scale low-power sensing and actuation modalities, large-scale swarms of small-scale robots are getting more relevant for real-world deployments [2].

WHAT IS A ROBOT?

The word "robot" was coined by Czech writer Karel Čapek in his play in 1920. Isaac Asimov coined the term "robotics" in 1942 and came up with three rules to guide the behavior of robots [3]:

1. Robots must never harm human beings,
2. Robots must follow instructions from humans without violating rule 1,
3. Robots must protect themselves without violating the other rules.

Robotics has advanced and taken many forms including fixed robots, collaborative robots, mobile

robots, industrial robots, medical robots, police robots, military robots, officer robots, service robots, space robots, social robots, personal robots, and rehabilitation robots [4,5]. Robots are becoming increasingly prevalent in almost every industry, from healthcare to manufacturing.

Although there are many types of robots designed for different environments and for different purposes/applications, they all share four basic similarities [6]: (1) All robots have some form of mechanical construction designed to achieve a particular task; (2) They have electrical components which power and control the machinery; (3) All robots must be able to sense its surroundings; a robot may have light sensors (eyes), touch and pressure sensors (hands), chemical sensors (nose), hearing and sonar sensors (ears), etc. (4) All robots contain some level of computer programming code. An autonomous robot must have a basic body structure (the chassis), sensors, a central control system (microprocessor), actuators (motors), a power supply and an overall program for its behavior. Programs are the core essence of a robot since they provide intelligence. There are three different types of robotic programs: remote control, artificial intelligence, and hybrid. Some robots are programmed to faithfully carry out specific actions over and over again (repetitive actions) without variation and with a high degree of accuracy.

The advantages of robotics include heavy-duty jobs with precision and repeatability. Despite these advantages, there are certain skills to which humans will be better suited than machines for some time to come. Humans have the advantages of creativity, decision-making, flexibility, and adaptability.

BACKGROUND ON DISTRIBUTED ROBOTICS

Using a group of simple robots can be more efficient, easier, less expensive, more flexible and more fault-tolerant than having a single, highly specialized robot for each task. The idea of using a team of robots instead of a single one to execute a given task came from the necessity of accomplishing a task that is too complex for a single robot. This has led to distributed sensing, which can improve the robots and the object localization. The robots in the team do not have access to sensor data of other mates, but only receive processed commands based on sensor readings [7].

The word “distributed” means spread out across space. The concept of distributed robotics has its origins in the late-1980's, when researchers began to explore issues in multiple mobile robot systems. It is based on distributed computing, which refers to the use of distributed systems to solve computational problems. A distributed system is made up of different hardware and software architectures that are on several computers, but run as a single system. It consists of autonomous computing nodes which can communicate with each other and cooperate on a common task. The main purpose of distributed computing is to enable a group of users to perform work on a pool of shared resources [8]. Figure 1 shows some distributed robots [9].

Distributed robotics is a multi-robot system that consists of mobile robots that are linked mechanically to each other by a system of physical links and sensors. Each robot contains an onboard computer with a wireless radio for communication and a stereo camera. Sharing knowledge between the multiple robots can be as simple as sharing position and map knowledge to improve their path planning and location of targets. The desired collective behavior of the distributed robotic system comes from interactions between robotic units and the environment.

It is an interdisciplinary branch of robotics that combines research in computer science, communication systems, control theory, and electrical and mechanical engineering. With the assistance of technological advancements such as cloud computing, artificial intelligence, and manufacturing techniques, distributed robot systems are becoming indispensable in industrial activities including warehouse logistics or autonomous transportation.

At the moment, developing robot applications requires detailed knowledge of signal processing, control, path planning, network protocols, and various platform-specific details. It also requires using ROS (Robot Operating System), which is the de facto standard for developing robotic systems.. It is widely used for robotic system development. ROS can be implemented on various operating systems. It offers an open-source framework for building robotic systems. It allows for rapid development, testing, debugging of distributed robotics system.

Distributed or decentralized robotic system takes many forms. For example, it manifests itself in the following many ways:

- **Cooperative Robotics:** The field of cooperative autonomous robotics is new. Cooperative robotics enables multiple robots to cooperatively carry, push, or manipulate common objects. Cooperation implies non-interference between agents and that agents can help each other by collaborating on a task. The behavior-based paradigm has had a strong influence in much of the cooperative mobile robotics research.

Inherently cooperative tasks cannot be decomposed into independent subtasks to be solved by a distributed robot team. Instead, the success of the team is dictated by the combined actions of the robot team, rather than the individual robot actions [10]. Typical cooperative robotic systems are unmanned aerial vehicles (UAVs) and unmanned ground vehicles (UGVs).

- **Swarm Robotics:** Swarm robotics focuses on the study of distributed robotics systems composed of a large number of independent and autonomous robots. Nature provides us with abundant examples of how large numbers of individuals can make decisions without the coordination of a central authority. A collective decision is the result of a process distributed among a collective of agents that leads the collective to make a choice that, once made, can no longer be traced back to any of its individual agents. Collective decisions are widespread in group-living animals such as social insects, birds, fishes, and many other living collectives, rely on simple interaction mechanisms to do so. Figure 2 shows different branches of collective decision making [11]. Robots in the swarms need a mechanism to explore the environment. The ability to make decisions collectively is a fundamental pillar for the development of autonomous robot swarms. An example of swarm robotics is shown in Figure 3 [12].
- **Distributed Mobile Robotics (DMR):** This involves teams of networked robots navigating in a physical space to achieve tasks in a coordinated fashion. The field has grown dramatically in recent years. Applications of DMR systems are applied in diverse areas such as surveillance, law enforcement, agriculture, disaster management, warehouse and delivery systems [13].

APPLICATIONS OF DISTRIBUTED ROBOTS

Distributed robotic systems are starting to revolutionize many applications from targeted material delivery to precision farming. These systems are ideal for certain future applications such as robot autonomy, decentralized control, collective emergent behavior, collective learning, knowledge sharing, manufacturing, transportation, agriculture, delivery, etc. Typical applications of distributed robots include [14]:

- Enhancing safety in the workplace by reducing risks, guarding facility areas and keeping all essential personnel informed of their surroundings.
- Supporting the efforts of medical staff by monitoring hospital rooms and patients, detecting risks and unsafe situations, alerting personnel in the event of an accident, and monitoring assets.
- Improving the quality of work for Industry 4.0 by measuring and understanding stress level amongst the worker force, identifying group sizes in specific areas, gauging noise level, and collating data from machines and the environment.
- Construction is a major industry that has been slow in incorporating automation. Distributed robotics system can be used for timber construction, as shown in Figure 4 [15]. It involves creating a new architecture-specific robotic system for complex timber assemblies. The system consists of multiple collaborative single axis robots, designed to utilize timber beams as a building material and for its locomotion system, minimizing its complexity. A construction future is conceptualized where distributed robotics can build around the clock, higher, faster, stronger and quieter.

Other areas of applications include monitoring, navigation, exploration, and surveillance.

BENEFITS AND CHALLENGES

The main benefit of distributed robotic system is that the local part can be equipped with processing units which are low on energy. Robots are getting cheaper. Distributed robotic systems can solve complex problems while operating in highly unstructured real-world environments.

However, the computational complexity of distributed robotic system can be intractable. Other challenges include [16]:

- **Programmability:** Although distributed robotic systems are becoming increasingly prevalent in complex safety-critical applications, programmability is a major barrier to their large scale adaptation. Safe programming of such a system is difficult as the programmer has to correctly reason about failures, uncertain environments, and interfering robots in the workspace.
- **Limitation:** At present, robots are good only at highly repetitive tasks in structured environments. They are still far inferior to humans in simple tasks like picking items from a shelf.
- **Chinese Competition:** China has emerged as the largest growth market for robotics. Chinese companies bought more than twice as many industrial robots (68,000) in 2015 than American companies did (27,000). China has understood that its competitive advantage of cheap labor will not last forever. Just two provinces, Guangdong

and Zhejiang, in China intend to spend $270 billion over the next five years to equip factories with industrial robots. Chinese robots will soon be working in America.

These challenges should keep the robotics community busy for many years to come.

CONCLUSION

Distributed robotics is an interdisciplinary field that is rapidly growing. Distributed robotic systems can autonomously solve complex problems while operating in highly unstructured real-world environments. They are expected to play a major role in addressing future needs such as food supply, transportation, manufacturing, security, and emergency and rescue services [17]. As research progresses in distributed robotic systems, more and more aspects of multi-robot systems are being explored.

From educational viewpoint, it is important to teach distributed robotics to students. They should be taught to use tools that will enable them learn how to develop distributed robotics and create future applications for next-generation robotics. Robotics education is characterized by converging approaches of technology, computer science, and cognitive psychology [18]. More information about distributed robotics can be found in the books in [19-26] and the following journals devoted to robot-related issues:

- Robotica
- Robitics and Autonomous Systems
- Advanced Robotics
- Journal of Robotics
- Journal of Robotic Systems
- Journal of Robotic Surgery
- Journal of Robotics and Mechatronics
- Journal of Intelligent & Robotic Systems
- Journal of Mechanisms and Robotics-Transactions of the ASME
- Journal of Automation, Mobile Robotics and Intelligent Systems
- Intelligent Service Robotics
- IEEE Journal on Robotics and Automation
- IEEE Robotics & Automation Magazine
- IEEE Robotics and Automation Letters
- IEEE Transactions on Robotics
- International Journal of Medical Robotics and Computer Assisted Surgery
- International Journal of Robotics Research
- International Journal of Social Robotics
- International Journal of Humanoid Robotics
- International Journal of Advanced Robotic Systems.
- Recent Trends in Mobile Robots

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Figure 1 Some distributed robots [9].

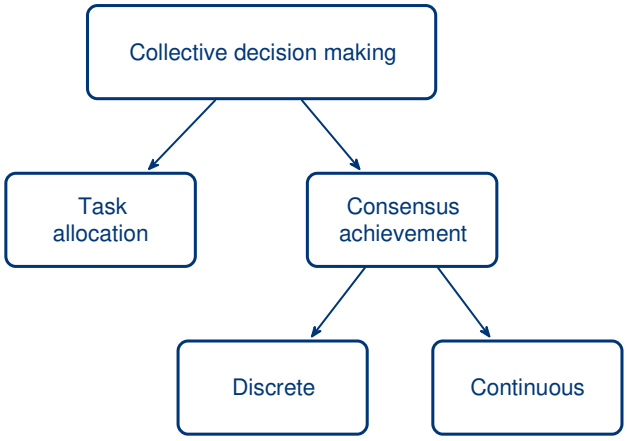

Figure 2 Different branches of collective decision making [11].

Figure 3 Swarm robotics [12]

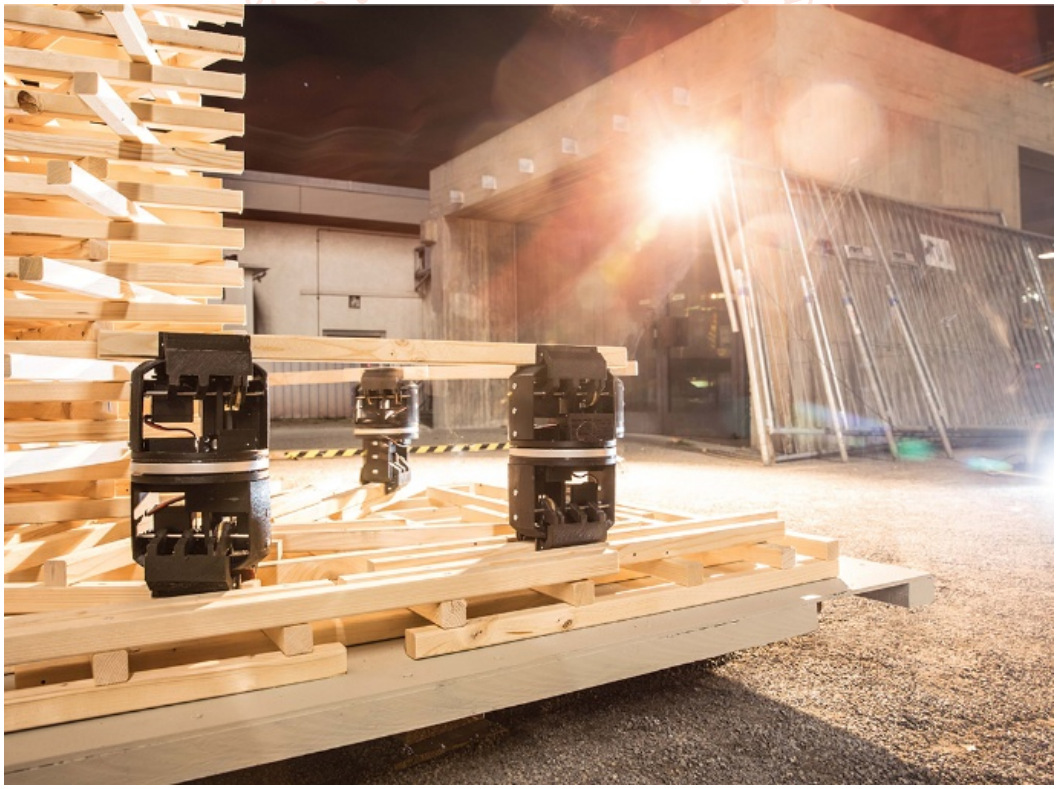

Figure 4 Distributed robotics system for timber construction [15]