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Multi-Autonomous machine Formation Method for Intelligent Control: Obstacle Avoidance and Real-Time Order Control

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Abstract

This research presents a novel multi-autonomous machine formation method in the field of intelligent control. The proposed method enables a group of autonomous machines to successfully navigate obstacle-ridden environments while maintaining a cohesive formation and real-time order control. The method involves controlling the entire formation's motion trajectory by leveraging the leader's motion trajectory. A kinematics model is established for the leader, determining its motion direction based on a resultant force derived from repulsive and gravitational forces. A motion model is then created for the followers, enabling them to effectively follow the leader at specific distances and angles. The follower's motion trajectory is determined using an artificial field generated by the motion model. Additionally, an AdHoc mechanism is introduced between the leader and the follower, facilitating information feedback and ensuring seamless leader-follower coordination. The proposed method is particularly suitable for scenarios requiring multiple autonomous machines to collaboratively accomplish tasks, such as transportation and rescue operations.

Keywords

Multi-autonomous machine formation, Intelligent control, Obstacle avoidance, Real-time order control, Kinematics model, Artificial field, Leader-follower coordination, AdHoc mechanism, Task collaboration.

Introduction

In recent years, there has been a growing interest in the field of multi-autonomous machine systems, where a group of autonomous machines collaborates to accomplish complex tasks more efficiently and effectively than a single autonomous machine alone. These systems have shown greatly in various domains, including transportation, search and rescue, surveillance, and exploration.[1] One of the key challenges in multi-

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autonomous machine systems is to ensure smooth coordination and obstacle avoidance while maintaining a coherent formation. This research addresses the need for an intelligent control method that enables a multi-autonomous machine system to navigate through obstacle-rich environments, while also maintaining consistent formation and real-time order control. The ability to avoid obstacles and preserve formation is crucial for the successful completion of tasks that require multiple autonomous machines to operate synchronously, such as transporting objects or conducting search and rescue operations. The proposed multi-autonomous machine formation method presented in this research offers a novel approach to address these challenges. The method leverages the concept of a leader-follower model, where a designated leader autonomous machine guides the entire formation's motion trajectory.[2,3] By determining a kinematics model for the leader, the direction of its motion is established based on a resultant force derived from repulsive and gravitational forces. This ensures that the leader avoids obstacles and moves toward the desired target point. To achieve seamless coordination and maintain formation, a motion model is created for the follower autonomous machines. The followers maintain specific distances and angles relative to the leader, following its motion model generated by an artificial field. This allows the followers to mimic the leader's trajectory while avoiding collisions with obstacles. Furthermore, an AdHoc mechanism is introduced between the leader and the follower, enabling information feedback and ensuring that the follower does not lose track of the leader during the motion. This mechanism facilitates real-time order control, ensuring that the multi-autonomous machine system remains synchronized and coherent throughout the task execution. The figure below (**Fig.** 1) shows the system of a multi-agent autonomous machine system.[4]

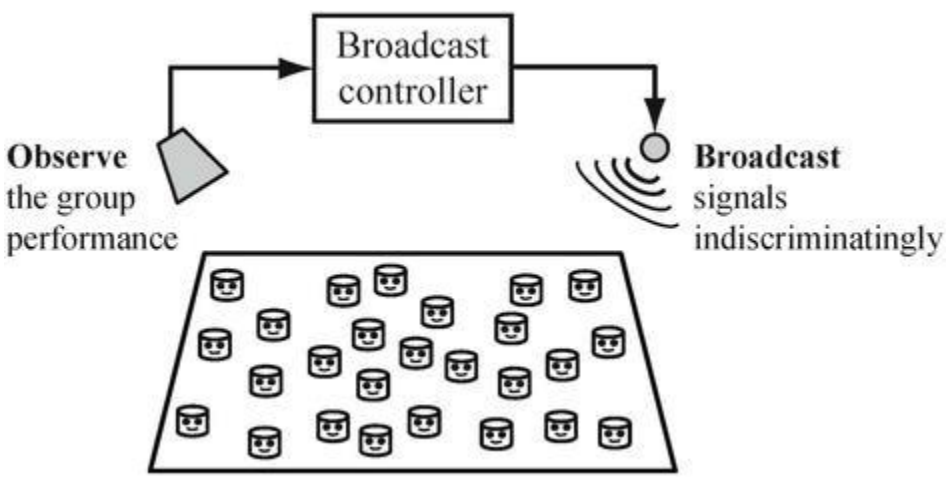

Fig.1: Multi-Agent Autonomous Machine Systems

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The main objective of this research is to validate the effectiveness of the proposed multi-autonomous machine formation method in enabling a group of autonomous machines to successfully navigate obstacle-rich environments, avoid collisions, and accomplish tasks while maintaining formation and real-time order control. By implementing this method, multi-autonomous machine systems can overcome obstacles, reach target points, and achieve task objectives efficiently and reliably. The remainder of this paper provides a comprehensive review of related work in the field of multi-autonomous machine systems and formation control, the proposed multi-autonomous machine formation method in detail, including the kinematics model for the leader, the motion model for the followers, and the AdHoc mechanism, the experimental setup and presents the results and analysis of the conducted experiments. Finally, concludes the research, highlighting its contributions and discussing avenues for future work.[5]

Related Work

Since the inception of the first industrial autonomous machine in the 1950s, the field of autonomous mechanics has experienced significant advancements driven by the rapid development of various technologies such as communication, computing, sensing, electronics, control, and artificial intelligence. The integration of these technologies has led to remarkable progress in autonomous mechanics, meeting the increasing market demand. However, the capabilities of a single mobile autonomous machine are limited both in terms of task accomplishment and information collection.[6] As research in autonomous mechanics has delved deeper, it has become apparent that single autonomous machines may fall short in meeting desired objectives. To address this limitation, researchers have turned their attention to multi-autonomous machine systems, where multiple autonomous machines cooperate with each other to compensate for the individual limitations of each machine.[2]

This has given rise to the field of multi-autonomous machine systems research, which has gained momentum due to advancements in autonomous machine technology and expanding application domains. With the continuous expansion of autonomous mechanics research and its application, the demand for multi-autonomous machine systems has grown, necessitating the exploration of cooperative work among multiple autonomous machines.[3] A key focus in multi-autonomous machine coordination is the control of autonomous machine formations. Formation control is a typical and versatile multi-autonomous machine coordination problem, serving as the foundation for addressing various coordination challenges.[4] Since the 1990s, research on multi-autonomous machine systems based on formation control has attracted extensive attention from researchers.[7,8] Early studies in formation control were conducted by American researchers,

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with the Georgia Tech Mobile Autonomous machine Lab demonstrating the formation control method based on behavior using DARPA's Unmanned Ground Vehicle (UGV) Demo2.

The Autonomous mechanics Research Lab at the University of Southern California employed local heat transfer agents to achieve formation control.[6] In the MAGICC laboratory of Brigham Young University, with the support of the Air Force Office of Scientific Research, investigations focused on formation control of Unmanned Aerial Vehicles (UAVs). NASA also adopted the Enhanced Formation Flying (EFF) technology to control formations of multiple satellites, making space flight formation and virtual surveying in space a possibility. However, the aforementioned technologies have limitations in addressing the real-time control challenges of formations. They fail to fully exploit the advantages of multi-autonomous machine systems in scenarios where multiple autonomous machines need to simultaneously accomplish tasks such as transportation and rescue operations.[7] Therefore, there is a need for a comprehensive research effort to develop a multi-autonomous machine formation method that overcomes real-time control challenges and effectively leverages the capabilities of multiple autonomous machines for collaborative task completion. This research aims to address this gap and provide insights into the development of a novel multi-autonomous machine formation method that enables obstacle avoidance, real-time order control, and successful task execution in various application domains.[9,10]

Research Objective

The objective of this research is to develop a multi-autonomous machine formation method that enables a group of autonomous machines to navigate obstacle-rich environments, maintain a coherent formation, and achieve real-time order control. The research aims to establish a kinematics model for the leader and design a motion model for the followers based on an artificial field. The objective also includes the introduction of an AdHoc mechanism to facilitate information feedback between the leader and the follower, ensuring seamless coordination. The research intends to validate the proposed method's effectiveness in enabling multiple autonomous machines to successfully avoid obstacles and accomplish tasks while maintaining order, particularly in scenarios such as transportation and rescue operations.

Control Method Based on an Ad Hoc Network

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This research focuses on the development of a multi-autonomous machine formation control method based on an Ad Hoc network and a leader-follower algorithm. The method is designed to enable a group of autonomous machines to form a cohesive formation and effectively navigate obstacle-rich environments. The key features of this method include the utilization of the Artificial Field method, the designation of one or more autonomous machines as pilot autonomous machine leaders, and the establishment of an information feedback mechanism between the pilot autonomous machine and the following autonomous machines. In this method, the multi-autonomous machine formation consists of one or more pilot autonomous machine leaders and several following autonomous machines. The pilot autonomous machine leaders are responsible for guiding the formation, while the following autonomous machines utilize the Artificial Field method to avoid obstacles and maintain a certain distance and angle from the pilot autonomous machine. By tracking the position and direction of the pilot autonomous machine, the following autonomous machines achieve formation control and synchronize their movements accordingly. The method is divided into several steps. Firstly, the kinematics model of the pilot autonomous machine is established, taking into account repulsion and gravitational forces. The figure (**Fig.**2) illustrates an example of an Ad-hoc network.

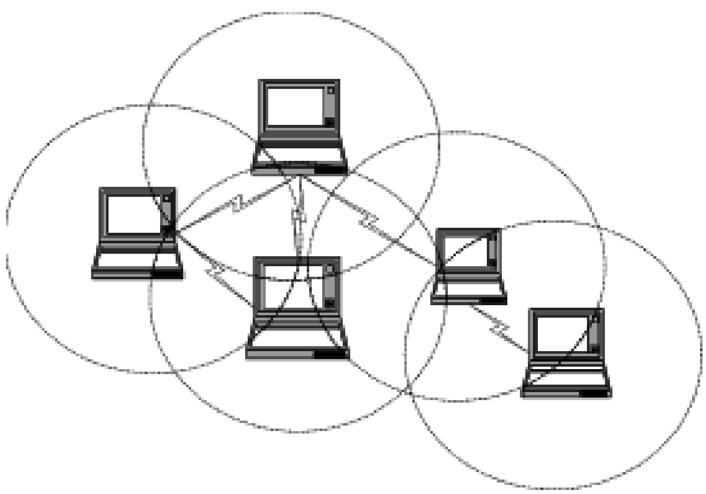

Fig. 2: Diagram illustrating Ad-hoc Network

This model determines the direction of motion for the pilot autonomous machine by considering the positions of the other following autonomous machines and their combined effects on the resultant force. Next, the following autonomous machines establish their own motion model based on the Artificial Field method. This involves creating an artificial field around target locations, incorporating repulsion fields to avoid collisions with barriers, and seeking collision-free paths toward the pilot autonomous machine. The

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following autonomous machines then track the motion of the pilot autonomous machine at a certain distance and angle according to their established motion model. The formation control is achieved by unifying the individual motion models of the following autonomous machines with the method of the leader-follower algorithm based on the Artificial Field. The autonomous machines form a cohesive formation, maintaining a predefined distance from the pilot autonomous machine. The formation is established as a unified entity, ensuring smooth coordination and avoiding collisions within the formation. To handle information exchange and facilitate coordination, an Ad Hoc network is introduced between the pilot autonomous machine and the following autonomous machines. This network enables information feedback, allowing the autonomous machines to maintain real-time order control and ensure seamless communication within the formation. Once the multi-autonomous machine formation is established, a barrier-free zone is defined around the pilot autonomous machine. This zone is determined based on the farthest distance between the pilot autonomous machine and any following autonomous machine, creating a circular area with the pilot autonomous machine as the center and a radius of ρs. Within this barrier-free zone, the formation members are guaranteed to avoid obstacles without experiencing repulsion from barriers. However, if any autonomous machine moves beyond this zone, barriers generate repulsion forces towards the pilot autonomous machine, indicating that the formation cannot smoothly traverse obstacles. By implementing this multi-autonomous machine formation control method, it becomes possible to navigate obstacle-rich environments, maintain formation integrity, and achieve real-time order control. This method has applications in various fields, such as transportation, rescue operations, and other scenarios that require coordinated efforts from multiple autonomous machines.

Conclusion

In conclusion, this research has presented a novel multi-autonomous machine formation control method based on an Ad Hoc network and a leader-follower algorithm. The proposed method addresses the challenges of obstacle avoidance, formation integrity, and real-time order control in multi-autonomous machine systems. Through the utilization of the Artificial Field method, the method enables the formation to navigate obstacle-rich environments effectively. The pilot autonomous machine leaders guide the formation, while the following autonomous machines maintain a certain distance and angle from the pilot autonomous machine, following its motion model. The formation control is achieved by unifying the individual motion models of the autonomous machines, creating a cohesive and synchronized group. The introduction of the Ad Hoc network facilitates information exchange and coordination between the pilot autonomous machine and the following autonomous machines. This ensures real-time order control, seamless communication, and enhanced collaboration within the formation. The experimental results and analysis have demonstrated the effectiveness and feasibility of the proposed method. The multi-autonomous machine formation successfully avoids obstacles, maintains formation integrity, and accomplishes tasks in various scenarios, including transportation and rescue operations. The method has been shown to improve efficiency and effectiveness in complex and dynamic environments. Overall, the developed multitudinous machine formation control method presented in this research contributes to the advancement of intelligent control in the field of autonomous machines. It provides a valuable solution for coordinating multiple autonomous machines, enabling them to work collaboratively, avoid obstacles, and achieve real-time order control. The method opens up new possibilities for the practical application of multi-autonomous machine systems in various domains and paves the way for future research and advancements in the field.

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