USING MULTI-AGENT SYSTEMS IN THE MANAGEMENT OF COLLABORATIVE ROBOTS

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Abstract: Multi-agent systems are an effective tool for managing collaborative robots, providing adaptability, autonomy, and flexible task distribution. This paper analyzes the main control methods, including centralized, decentralized, and hybrid approaches, as well as multi-agent system models such as reactive, deliberative, hybrid, and swarm-based. Their advantages and disadvantages are identified based on operational conditions. The study demonstrates that the hybrid control method, combined with a swarm or hybrid model, provides the best balance between efficiency, scalability, and adaptation speed in dynamic environments.

Keywords: multi-agent systems, collaborative robots, centralized control, decentralized control, hybrid model, swarm model.

ВИКОРИСТАННЯ МУЛЬТІАГЕНТНИХ СИСТЕМИ В УПРАВЛІННІ КАЛОБОРАТИВНИМИ РОБОТАМИ

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***Анотація*:** Мультіагентні системи є ефективним інструментом для управління колаборативними роботами, забезпечуючи адаптивність, автономність і гнучке розподілення завдань. У роботі аналізуються основні методи управління, такі як централізоване, децентралізоване та гібридне, а також моделі мультіагентних систем, включаючи реактивну, деліберативну, гібридну та ройову. Визначено їхні переваги та недоліки залежно від умов експлуатації. Дослідження показує, що гібридний метод управління у поєднанні з ройовою або гібридною моделлю забезпечує найкращий баланс між ефективністю, масштабованістю та швидкістю адаптації у динамічних середовищах.

***Ключові слова*:** мультіагентні системи, колаборативні роботи, централізоване управління, децентралізоване управління, гібридна модель, ройова модель.

Multi-agent systems (MAS) are an effective approach to control collaborative robots (CRs) in production and research environments. They provide distributed control, adaptability and autonomy, which allows to improve the interaction of robots with each other and with humans. At present, there are the following methods of controlling collaborative robots using MAS:

- a method of centralized agent control, when a central server or control agent coordinates the actions of all other agents in the system. Each robot agent receives tasks and instructions from a central control module;
- a method of decentralized agent control, when each agent (robot) makes decisions autonomously, based on local information and communication with other agents;
- a hybrid method (centralized-decentralized approach), when it combines centralized control with autonomous agents. The central node sets general strategies, and agents make local decisions based on their situation.

Table 1 compares the advantages and disadvantages of each method of managing collaborative work using MAC.

Table 1. - Comparison of advantages and disadvantages of collaborative work management methods using MAC

Management Methods	Advantages	Disadvantages
Centralized Management	Global control over the system Optimal resource planning Easy implementation and setup Fast decision-making through centralized data processing	Low scalability – as the number of agents increases, the load on the central server increases Single point of failure – failure of the central node stops the entire system Slow adaptation to changes in the environment
Decentralized Management	High scalability – adding new agents does not lead to overload No single point of failure – the system remains operational even if individual agents fail Adaptability – robots can quickly respond to changes in the environment	Possible conflicts between agents – without centralized management it is difficult to avoid contradictory actions Limited local information – agents may make ineffective decisions due to lack of a complete picture Difficult coordination between agents
Hybrid Management	Trade-off between global control and agent autonomy Optimization of resources and communication High adaptability to changing conditions Failure tolerance – if the central node is lost, agents can operate autonomously	High implementation complexity – requires a balance between centralized and decentralized management Increased requirements for computing resources Need for an effective synchronization mechanism between the central node and agents

The hybrid method is the most flexible, but its implementation complexity makes it less accessible compared to other methods. The choice of approach depends on the specific requirements of the system and the level of autonomy that is required for the agents to work.

Models of multi-agent systems for controlling collaborative robots are based on the principles of interaction of autonomous agents working together to achieve a common goal. One of the most common is the reactive model, in which robots act based on local rules and sensor data without complex calculations, which provides a high speed of response, but limited flexibility in complex scenarios. The deliberative model involves planning actions by robots based on global information and long-term goals, which improves coordination, but requires significant computing resources. The hybrid model combines a reactive approach for quick response and a deliberative one for strategic planning, which makes it effective in changing environments. Swarm Intelligence mimics the behavior of natural communities, such as anthills or bee swarms, providing high scalability and adaptability, but requiring carefully tuned rules of interaction. The market model is based on the principles of economics, where agents "trade" tasks and resources for the optimal distribution of work, which increases efficiency, but can cause conflicts if the balance is not correct. Each of these models has its own advantages and is used depending on the level of autonomy, the required speed of

decision-making and the complexity of the working environment. Table 2 compares the advantages and disadvantages of multi-agent systems models for managing collaborative work.

Table 2. - Comparison of advantages and disadvantages of multi-agent systems models for managing collaborative work

Model	Advantages	Disadvantages
Reactive Model	High response speed Easy to implement Reliability in dynamic environments Low computing resource requirements	Lack of long-term planning Low adaptability to complex changes in the environment Possibility of uncoordinated behavior
Deliberative Model	Global action planning High efficiency for complex tasks Improved coordination between agents Ability to predict future states	High computational cost Slow response to real-time changes Complexity of implementation and need for large amounts of data
Hybrid Model	Combines the speed of reactive agents and the strategic planning of deliberative ones Balance between reaction speed and optimality of decisions Flexibility in different conditions Increased system reliability	High complexity of implementation Requires significant computing resources Possible conflicts between management levels
Swarm Intelligence Model	High scalability – works well with a large number of agents Self-organizing and adaptive High resilience to individual agent failures Does not require centralized management	It is difficult to predict the behavior of the entire system Does not always achieve optimal results Highly dependent on the interaction parameters between agents

The hybrid model is usually the best compromise between efficiency and speed, but the complexity of implementation can be an obstacle. The swarm model is ideal for dynamic and large-scale systems, while the reactive model is a fast and simple solution for less complex environments. The deliberative model is effective for strategic management, but is inferior in real-time due to significant computational costs.

Analysis of the tables shows that the choice of method and model of a multi-agent system for managing collaborative work depends on the requirements for coordination, scalability, and speed of adaptation to changes in the environment. Centralized management provides high efficiency of resource allocation and coordination accuracy, but suffers from low scalability and vulnerability to failures of the central server. The decentralized approach allows agents to work autonomously, which increases the flexibility and reliability of the system, but complicates coordination and can lead to conflicts between agents. The hybrid method is the most balanced solution, as it allows you to maintain a centralized strategy, while providing agents with autonomy to quickly respond to local changes, which makes it optimal for complex and dynamic environments. Regarding multi-agent system models, the reactive approach works well in rapidly changing conditions, but does not provide

strategic planning, which limits its application in complex tasks. The deliberative model allows agents to make informed decisions, but requires significant computing resources and is inefficient in rapidly changing conditions. The hybrid model combines the advantages of both approaches, allowing you to effectively balance the speed of response and the optimality of solutions. The swarm model demonstrates high scalability and adaptability, which is especially useful for large systems, but it is difficult to predict and control. The choice of the optimal configuration depends on the specific task: to control a group of robots in a changing environment, it is advisable to apply a hybrid control method using a hybrid or swarm model. This will allow achieving an effective balance between centralized control and local autonomy, which will ensure fault tolerance, adaptability, and efficient use of resources in collaborative robotic systems.

CONCLUSIONS. Analysis of methods and models of multi-agent systems for managing collaborative robots indicates the need to choose an approach depending on the operating conditions and system requirements. Centralized management provides effective resource allocation, but has limited scalability and sensitivity to failures of the central node. The decentralized method provides high flexibility and adaptability, although coordination between agents can be difficult. The hybrid approach is an optimal compromise, allowing to combine centralized management with fast response of autonomous agents, which is especially important for dynamic environments. The choice of a multi-agent system model is also determined by the specifics of the tasks: the reactive model is effective for rapid changes, but does not allow long-term planning, the deliberative one provides global optimization, but requires significant computational resources. The hybrid model combines the advantages of the two approaches, and the swarm model is characterized by high adaptability, although its behavior can be difficult to predict. As a result, to control collaborative robots in dynamic environments, it is advisable to use hybrid control methods together with a hybrid or swarm model, which provides an optimal balance between agent autonomy, resource efficiency, and resilience to changes in the environment.

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