Faculty of Automation and Computer Science

Eng. LUCIA VĂCARIU

PhD THESIS

Ontological Communication for Improved Command and Cooperation Of Heterogeneous Mobile Robots Systems

ABSTRACT

Thesis advisor:
Prof. PhD. Eng. GHEORGHE LAZEA
This PhD Thesis contains 7 major Chapters, a Chapter with References and a Chapter with additional materials referenced as Appendices.

Chapter 1 – Introduction, makes a brief presentation into the field of Cooperative Mobile Robots Systems. Some fundamental solutions raised in the thesis are described: the reasons for using cooperative robots systems, the means of using communication to solve high-level cooperation, and the reasons for using an ontological level of knowledge. Preconditions on the design of robots and the system of robots are stated.

Based on the results of this analysis, the author asserts the global and specific objectives of the research. Finally, the structure of the thesis is summed up.

Chapter 2 – The state-of-the art in the field of ontological communication, presents the latest research results published in the field of mobile robots systems. Main topics are: control architectures, cooperation, communication, heterogeneity and robot adaptation in a dynamic environment. The conclusion is that, even if no consensus exists among researchers on general control architectures to solve all these concerns, the research must provide transparent systems that rapidly can be adapted and integrated into various applications intended to act in dynamic environments.

The study of the evolution of multiagent systems theory shows that these systems are appropriate to be used to control multirobot systems.

Semantic knowledge (i.e. ontological level of information) is viewed like having a strong impact on the future research on mobile robots systems acting in cooperation. Within this trend, the ontological information exchanged both among interacting robots and among humans and robots can extend the cooperative skills of mobile robots systems. It is expected that communicating ontological information will make the systems more flexible, robust and reliable.

Chapter 3 – Controlling mobile robots systems contains the most important theoretical formalism and structures that are proposed to assure improved cooperation in cooperative heterogeneous mobile robots systems. The formalism is linked to appropriate control architectures and the ontological implication of the control and control architecture are presented.

Within the chain of control, there are identified some mechanisms: the base control, the dynamics of the control, adaptability and finally cooperation and re-planning.
The first part presents mathematical relations established in the mobile robots system for sensors, perception relations, symbolic perceptions, symbolic space, specific ontologies, actuators, actuator relations, actuator action effects, and robot plans. The formal description of control shows the logic that ties robot sensors to actuators, actions and planning. So, we have a complete control cycle.

During the execution of the system mission, each robot interprets its perception relations and obtains ontological concepts. The ontology is identified if all the properties of concepts are identified. It is stated that the specific ontologies are coherent and each robot has a commitment for his specific ontology (all his actions and goals are included in the specific ontology). The specific ontologies are distributed among the system of mobile robots and by communicating parts of these ontologies the robots can easily adapt to environment changes.

In real application the cooperative multirobot systems must deal with dynamic environments. If a robot cannot continue his task due to a challenging environment, it will communicate with the others robots in the system and will exchange the missing ontological information. The deadlocked robot will receive the ontological concept that will make it more intelligent and consequently more adaptable. The robot can finish its task and finally the entire mission.

To solve the problem of extended cooperation and of re-planning, four types of ontological operations have been introduced: simple ontological substitution, multiple ontological substitutions, simple ontological abstraction, and multiple ontological abstractions. Using these operations, all the robots are able to minimize the amount of information communicated in time and to augment their capabilities.

The proposed conceptual control architecture is based on the use of ontology at different levels: changing the plans of robots, execution of plans and monitoring the actions. The general ontology has all the concepts of the application domain. The specific ontologies are compliant with the robot’s capabilities.

The implementation of the conceptual architecture is made by a multiagent system. The multiagent system administrates the system of heterogeneous mobile robots by using agents specialized on different tasks of the cooperative mission. In this part it is explained how the design of the multiagent system can be accomplished using the ontology at all stages.

Chapter 4 – **Multirobot system optimization**, describes hybrid methods, both numerical and symbolical, that allow evaluation of improvements of ontological communication in heterogeneous mobile robots systems. The system has a global cost function. Probabilities and Markov chains are used to determine the cost of each chain of robot actions.
The distributed multiagent system uses for optimization a vector of resources. Discontinuous functions are optimized using a subgradient method; this method works even with continuous functions. The weights used in the algorithm that optimizes the multiagent system are calculated by ontological distances between ontological concepts. This is a new approach in the field of hybrid optimization, introduced in the thesis.

The results demonstrate that the system converges to an optimum.

Chapter 5 – **Cooperation in heterogeneous mobile robots systems** covers the improvements in cooperation. Cooperation is necessary because of growing complexity and diversity of applications with mobile robots systems.

In this thesis cooperation is treated like a coordination of robots to accomplish a common mission and is assured by direct communication between robots. The exchanged messages are made at the ontological level of information. Messages are ontological concepts or sub trees of the ontological taxonomy.

The developed general spatial ontology has the concepts that describe the physical environment, with objects and relationships between objects. During a cooperation mission, at the beginning, all robots have a specific ontology, which is a sub-part of the spatial ontology – one that is appropriate to their own characteristics. The robots of the system are heterogeneous in their physics characteristics and in their knowledge.

When the environment changes, the robots might not recognize the new real situation and they don’t know how to continue the cooperative mission. With the control system described in the thesis the robots will solve the problem and improve the cooperation by ontological communication. Using ontological operations, the robots will exchange enough ontological information about that particular situation so they will be able to re-plan their actions and to continue their tasks. They will augment the first specific ontology with the new information acquired and will create a local ontology. This is a growing process going on all the time spent in the system’s mission. This ontology will assure the improvement of adaptability of the robots. The robots become more intelligent, having more knowledge.

Chapter 6 – **Experimental results**. This chapter describes some applications designed, implemented, and tested to validate the theoretical formalism and mechanisms introduced in the thesis. The obtained simulations and practical demonstrations emphasize the degree to which the theoretical ideas and methods proposed for the control of heterogeneous mobile multirobot cooperative systems can be used for practical applications.
The results cover three types of missions: Supervisory and control of a supermarket; Search and Rescue mission; Adapting a mobile multirobot system into a SmartHouse environment.

The mission of Supervisory and control of a supermarket is the most extensively presented, with all the necessary details to show the entire mechanism of control, with all his steps. First, the multiagent system is described, starting from the system objectives, passing over to defining scenarios, sequences of events and interactions, models of roles, moments of communication and finishing with creating the agents’ classes. The system has defined three important roles: Supervisor, Transporter and Cleaner.

The ontology of the system is similar to the spatial ontology created before, with ontological concepts appropriate for this specific application. The ontology is more general than each of the specific ontologies of the particular robots.

Due to their task definition, the robots can be Supervisor, Transporter and Cleaner. The robots have the sensors, actuators and knowledge to accomplish just these assignments, consequently they are heterogeneous. The thesis presents the progress of the mission without and with ontological communication. It is shown that the robots’ cooperation skills are upgraded by using ontological communication.

Using this mission, an optimization of the system is made and the results show the convergence for convex continuous and discontinuous cost functions, where the weights are calculated with ontological distances.

The Search and Rescue mission presents same good results for the approach introduced in the thesis. Using real Pioneer mobile robots, there was another results obtained in robots path planning and mapping.

The mission that proposes the adaptation of a mobile system of robots in a SmartHouse deals with more challenges than the other applications. Besides the need for extended cooperation in the mobile multirobot system, it was necessary to interact with the SmartHouse, which had a personal control and monitoring system based on ontological representation and use of information. The multirobot system endowed with ontological communication could be integrated in the SmartHouse. The robots used where of type Supervisor, Transporter and Pet. They participated in different missions in the house, aiding and diverting the lodgers.

The applications demonstrate that the approach used in the thesis is appropriate for heterogeneous mobile multirobot systems to obtain the augmentation of cooperation and of adaptability to a dynamic context.
Chapter 7 – **Conclusions and future developments**, contains some short conclusions about the relevance of the thesis. The thesis engages in a new direction of research, following the nature of the multidisciplinary problem that needs to be solved. The use of ontological level of information exchange, to obtain an extended cooperation, is a new approach. Using a combination between numerical and symbolical methods to obtain the optimization of the system is a new trend in research.

The main original contributions of the thesis are:

1. Comparing control architectures, analyzing cooperation facilities and indicating the problems unsolved.
2. Emphasizing the need to communicate abstract information in cooperation tasks among robots.
3. Showing the lack of adaptability of heterogeneous multirobot systems in dynamic environments.
4. Identifying the benefits of multiagent systems in mobile robots systems.
5. Formally defining the basic control, dynamics of the control and solving the cooperation and re-planning.
6. Establishing different types of architectures and making a comparison among them based on a utility criterion.
7. Establishing the conceptual architecture for the multirobot system with ontological communication.
8. Establishing the mechanism of cooperation, choosing a mechanism of communication in the multiagent system that correlates with the system’s ontology, to obtain the adaptability to dynamic environment and to solve the heterogeneity among robots in a unified way.
9. Calculating the utility function using Markov chains, for actions of cooperative robots using ontological communication.
10. Optimizing the distributed multiagent system using a subgradient method and solving the weights by calculating ontological distances.
11. Demonstrating that the ontological communication augments the cooperation.
12. Description of a spatial ontology and realizing the transfer of ontological knowledge mechanism and the ontology modification.
13. Adapting the cooperative functionalities of the robots in dynamic environments.
14. Illustrating the proposed approach by three different cooperative missions: Supermarket supervision task, Search and Rescue and Adapting a multirobot system to a SmartHouse.
15. Simulations have been made to show the mechanisms of extended cooperation.
16. Experiments with mobile robots Pioneer demonstrated the possibility to use different types of robots to successful accomplish cooperative missions.

Future developments can be made in: human – robots interaction; integrating multirobot systems with Web semantic; extending the dynamic of multirobot system by introducing and extracting robots from the system.

The References contains 121 books and papers used for documentation during the PhD research time. A number of 11 papers were published in the field by the author.