MIP: A New Hybrid Multi-Agent Architecture for the Coordination of a Robot Colony Activities

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Abstract. In this paper the development and the implementation of one new robotic architecture for the coordination and the planning of a robot colonies in dangerous and unknown environments are outlined. The name of this new architecture is Metaphor of Italian Politics (MIP Architecture).

The structure of this architecture is dynamics. It takes inspiration from the political organizations of the democratic governments, where the leader isn't only one robot but it is constituted by a government of robots. In the MIP architecture the robots team is coordinated by a Prime Minister, a Minister of the Defence and a Minister of Communication while a second group of robots, the Robot Citizens, are the executors of each mission.

The model of the agents is hybrid (reactive and deliberative), so every robot can assume every political position inside this dynamic structure. An election procedure for the government regeneration has been developed in order to avoid the collapse of a mission and improve the robot colony performances.

To validate the effectiveness of the our approach we have developed a framework based on the Mission Lab software developed at the Mobile Robot Lab of the Georgia Institute of Technology.

1 INTRODUCTION

A Robots Colony can be efficiently used for many difficult tasks. A robot team can complete an assigned task more rapidly than a single agent can by separating the task into sub-tasks and executing them instantaneously. A team can also make effective use of specialists studied for a single objective, rather than requiring that a single robot be a generalist, capable of performing all tasks but hasn't acquired special skill at no tasks.

Two main methods have been proposed in the literature: the first one in the **centralized approach** while the second one is the **distributed approach**.

The idea of a central computer coordinating the group, referring to the best condition to complete the specified task, is to give seriously thought to the robot team to be a single robot "system" with many degrees of freedom. The problem is that optimal coordination is computationally difficult: the best known algorithms are exponential in complexity. Moreover, the approach considers that all news about the robots and their environment can be consigned to a single location for elaborating and that this information does not modify during the time that an optimal plan is built. Jensen and Veloso [11], Svestka and Overmars [16], and Brumitt and Stentz [6] are examples of the centralized approach to manage a multi-robot system structured hierarchically.

The above considerations are ivory towers for problems in which the environment is unknown and/or changing, communication is limited, and robots behave in incalculable ways. Another forceless with this essay is that it generates a highly vulnerable system: if the master robot (the central planning unit) misbehaves, a new leader must be accessible or the entire team is damaged.

Local and distributed approaches point the problems that come out with centralized, overally coordinated approaches. The idea is that each robot functions largely independently, working on information that is locally available through its sensors. A robot may collaborate with other robots of its area, splitting a main problem into very large number of sub-problems or to work together on a sub task that cannot be achieved by a single robot.

This approach usually requires little computation, since each robot desire only plan and govern its own activities. On the other hand, little communication is required since robots establish communication and exchange messages. The robots are better able to give answer to unknown or changing environments, since they feel and return answers to the environment. Moreover, the system is more robust since the entire team's performance no longer is conditioned by the direction of a single leader. The approach works best for problems that can be disjointed into largely not connected sub-problems, or problems for which a wished group behaviour results from the agglomeration of individual behaviors and interactions, as with some biological species such as bees and ants.

A number of researchers have developed biologically inspired, locally reactive, behavior-based systems to carry out simple tasks [3], [2], [1], [5], [13], [12]. These distributed systems have found applications in many different domains. Some behavior-based systems have been extended to more complex task domain. Mataric [13], [12] shows how more complex behaviors can be built from a basic set of behaviors for a multi-robot team. Arkin et al. [3] present a flexible, behavior-based, software architecture for developing mission-specific robot behaviors for urban warfare application. Other novel attempts have been adopted to control multi-robot teams. Tambe [17] exposes a procedure of enabling elastic group work by supplying the agents with common paradigms of teamwork. Pagello et al. [10] examine multi-agent cooperation in the soccer domain through implicit communication. Schneider-Fontan and Mataric [15] present an approach of territorial division of tasks for a multi-robot team. Taking a similar approach, Parker [14] introduces a temporal division of tasks to allow fault-tolerant multi-robot cooperation. Dautenhahn et al. [21] introduced a research direction which stressed the particular role of the social interaction dynamics in bootstrapping the development of

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cognitively richer behaviours. Steels [22] shows that intelligence is related to whether behaviour of a system contributes to its self maintenance and is capable to create and use representation.
In the paper a new hybrid and dynamic architecture to coordinate a robots team for complex tasks in dynamic, dangerous, structured and not predictable environments is proposed. The architecture takes inspiration from the political organizations of the democratic governments, where the leader isn't only one robot but it is constituted by a government of multi-robots: the Prime Minister (PCM), the Minister of the Defence (MD) and the Minister of the Communication (MC). A second group of robots represents the "robot citizens". The basic idea is to reach a compromise among the centralized and the distributed approach adopting a centralized, but in the same time distributed among the government members, high-level deliberative planner and several agents with reactive and deliberative capabilities.
The architecture goal is to have a decentralization of the planning actions, where each robot saves a deliberative independence status without losing its own reactivity. The agents receive high level goals by the government members and exploits their own reactive capabilities to explore the environment (navigation, obstacle avoidance, bomb searching) and exploits their own deliberative capabilities to choose the faster exploration strategy, to overcome a deadlock exploration phase etc. The structure of each agent is hybrid, i.e. reactive and deliberative at the same time. The agent approach to the missions will be both high level reasoned and low level impulsive, defining two different strategies: the conservative ones and the progressive ones. So in the first case, robots are coded in order to have a lesser attitude towards risks but a bigger calculus capacity. In the second case robots are coded in order to have a bigger attitude towards risks and they will be more fast, safe and less strategic in order to give an prompt reply. Each robot can assume every political position inside the architecture. An election procedure for the government regeneration has been developed in order to avoid the collapse of a mission and improve the robot colony performances.

2 PRELIMINARY STUDIES

The MIP Architecture is an hybrid architecture that takes inspiration from the political organization of the democratic governments. The architecture implements the organization of a society of multi-robot teams interacting with a domain. The team is able to autonomously modify its own organizational structure, with the purpose of complete one or more tasks.
The MIP architecture is composed by behavior-based robots [4]. In this approach the behavioral answers are represented using only one format: vectors generated from potential fields. The coordination is reached through cooperative methods; it doesn't exist a predefined hierarchy for the coordination of robots; the behaviors are configured runtime and are based on the robot's intentions, on the capabilities and on environment ties; every single behavior contributes to the achievement of the overall answer.
In the architecture definition and design phase, some formal models, proposed in the literature, was used since they can facilitate the discovery of organizational theories. Carley et al. [18], [19], [20] made a comparison between the various artificial organizational models and the human model, showing that different agent models with different organizational structures produce different levels of performance.
The cooperation in a robots team is a fundamental condition for the achievement of many task goals. Many tasks require more resources than how a single robot can supply. It is possible to solve more complex problem authorizing more simple robots to cooperate together. In order to coordinate more robots it is desirable the presence of dynamic hierarchies. However Master/Slave relations, even if often they allow to carry out good solution for the mission, introduce brittleness inside the system, because we have the presence of a single robot from whose all robots are subordinate. Therefore it is better to don't use the structure master/slave, but to use equal team of robots. The project choices applied for the MIP architecture realization were:

- The agent model is hybrid. A reactive/deliberative model is chosen; but also a robot can assume every role (citizen or government members) after the elections;
- The organizational structure is a dynamic hierarchy (the dynamic is obtained from the election mechanism).
- The resources access is organized using blocks (the citizen only has knowledge of its state, the PCM has knowledge of the map and the MD has knowledge of the robots positions inside the map).
- The operative conditions are with feedback for the government, that it must hold a trace of the mission history to carry out the opportune choices (deliberative part), and without feedback for the citizens (reactive part).

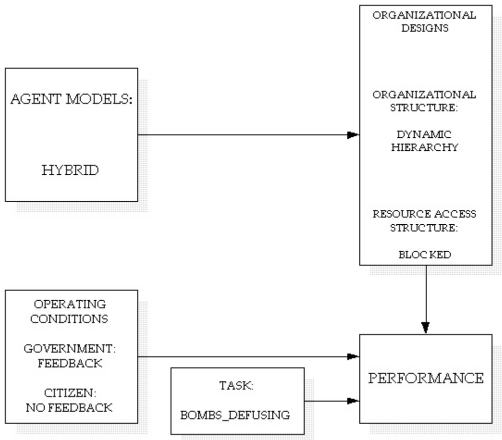

Figure 1. The MIP Architecture Organization: the Perfomance are affected by a dynamic organization of a colony of hybrid agents.

Figure 1 is a synthesis of the described choices.
The robots of MIP architecture must work in unknown and time-variable environments, because there are other robots moving inside the same map that can modify the world state and it is difficult to find out an accurate model of the map. The MIP Architecture robots need special behaviors for their navigation in time variable environments [9], [8].

3 THE STRUCTURE OF THE MIP ARCHITECTURE

The organizational structure of the MIP Architecture is based on four political parties as result of democratic elections. The *conservative political party* and the *progressive political party* are dominant since they can both lead the team of robots as a result of new elections. The *moderate political party* and the *mixed political party* are only used to realize the coalition of the government and to allow the main political parties (conservative and progressive) to reach the 50 % of the votes and to rise the power.
The described structure, concurs to avoid the collapse of the entire

mission because of the malfunctioning of a government element: in the MIP Architecture, in fact, it has been introduced a system of government regeneration based on new elections that allow to restore the conditions of normal activity.
As previously pointed out, the robots can be members of one of the four political parties, labeled as follows:

- PRO-AREA (progressive political party).
- CONS-AREA (conservative political party).
- MOD-AREA (moderate political party).
- MIX-AREA (mixed political party).

The PRO-AREA robots are coded in order to have a bigger attitude towards risks. The robots are fast, safe and less strategic in order to give an prompt reply. The CONS-AREA robots are coded in order to have a lesser attitude towards risks but a bigger calculus capacity. The robots are also less fast but more strategic. The MOD-AREA robots behaviour is a compromise between the PRO-AREA and the CONS-AREA robot being the reactivity parameter equal to strategy parameter. The MIX-AREA robots don't have particular aptitudes but they only serve to create the coalitions. Inside a coalition, every member make it one's duty hold a political position. The robots member of political area CONS and PRO, the only that can rise the power, must consider, beyond to the presence of the citizens, the presence of the three figures of government, everyone having its typical functions.

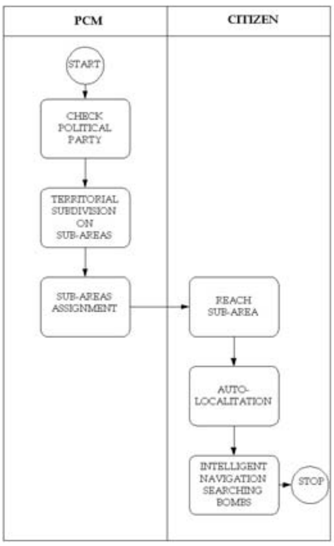

Figure 2. The Activity Diagram: management of the citizen activities during the exploration phase of a time-variable environment.

The head of government (PCM) has the following functions: he manages the reconstruction of the maps of the explored environments. Figure 2 shows that he takes care of the subdivision of the area in sub-areas and to assign each sub-area to the citizen robots. He is able also to plan the optimal path between two points during the phase of support to bomb disposal. The Minister of Defense (MD) is able to support the the disengagement, to monitor the mission evolution and to manage the government members elections. The Minister of Communication (MC) is able to manage the communications among agents and to filter the report of each citizen. The citizens are able to explore the environment and disengage bombs (two citizen are needed in this phase). The communications are considered ordinary if they are referred to the mission development, while they are considered extraordinary if they are referred to the role allocation phase, to the area assignment phase and to the bomb disposal phase.

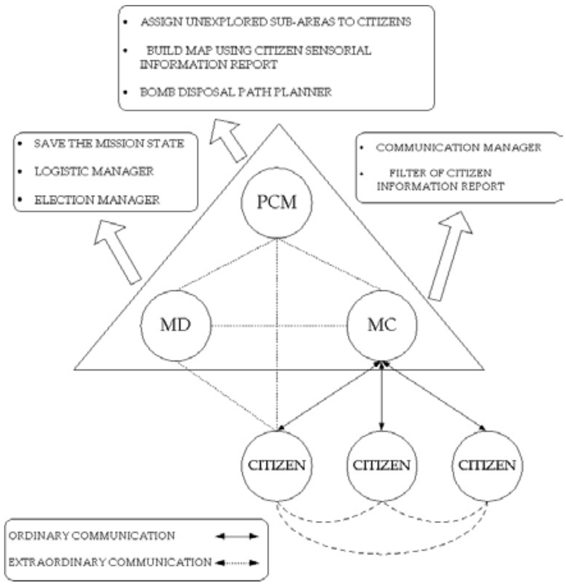

Figure 3. The MIP Architecture: A hybrid architecture with a dynamic and intelligent turnover of a government of three robots for the coordination of citizen, bomb-disposal executor robots.

The described architecture is shown in Figure 3. The model of each agents is hybrid, so every robot can assume every political position inside this dynamic hierarchical structure. Citizens do not have conscience of the state of the mission and can only access the information concerning their position in the map and the features of perceived objects. The robots of the government have a complete access to the information of whole state of the mission, even if the information is subdivided between the three members of the government.
The government operating conditions are based on a feedback: they have knowledge of the failure or the success a mission, of the states of the several robots through their behaviors in action and of the *merit factor* that represents one synthesis of the robot behavior during its mission. For the citizens the operating conditions don't take into consideration any kind of feedback.

4 FIRST IMPLEMENTATIONS AND RESULTS

We have built a framework for testing the new architecture based on the Metaphor of Italian Politic. The main target of every mission is to find and disengage each bomb placed in the environment. Every robot has a personal objective, and individual satisfaction function and a global target. Once the goal is reached, each robot, member of government party, is able to scale the social hierarchy. A merit factor is associated with each robot, and it is used during the election. The merit factor is a function depending on the reached sub-target and on the weight associated with the personal satisfaction, that is a function of the robot position inside the executive high level hierarchy. In order to avoid a mission collapse and to garanties efficient behaviour of robot colonies, an election procedure is activated for the government turnover. The election procedure is based on the above merit factor that is used to choose the new government.

Each robot is able to acquire images. Once a digital image has been acquired, the agent elaborates the information that can be useful to the robot. The main functionalities of this agent are the following:

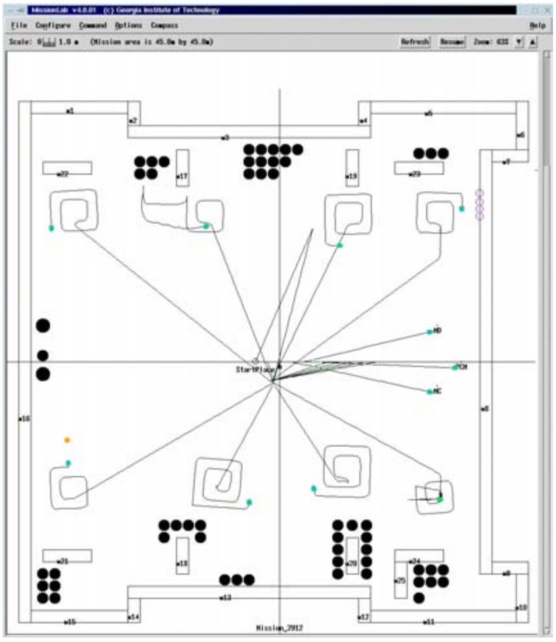

Figure 4. The implemented framework: the election phase and the first exploration phase.

- static obstacle detection (dimensions and colour recognition).
- dynamic obstacle detection (speed and direction).
- memorization of the obstacle information by a suitable tag.

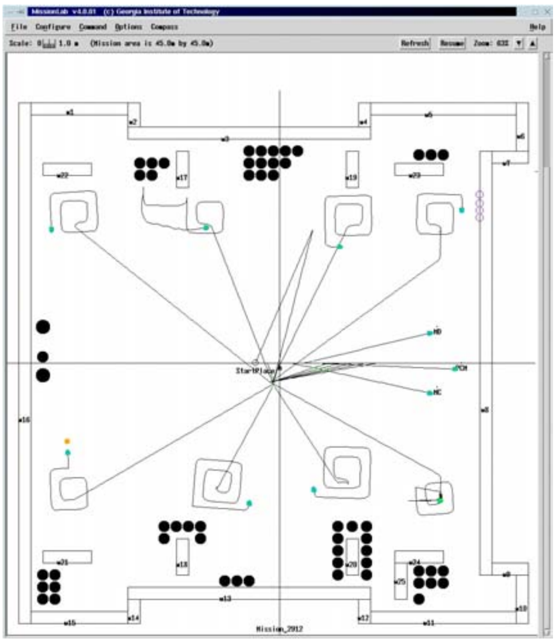

Figure 5. The implemented framework: the bomb detection phase.

During the testing phase, we have used a scenario with 11 robots. The robots team has to get organized and defuse the bombs that they will find inside the environment in a smaller time and smaller number of robots lost and destroyed. This kind of risky mission allow us to test the two possible behavioral approaches: the Conservative strategy and the Progressive strategy in order to verify the flexibility of robots reorganization every time that we have a change of the number of alive robots. The framework is characterized by a tidy evolution and by something that takes care of the unexpected features of the reality: in this specific case we are talking about the fact that it is impossible to foresee which is the minimum time for a robot in order to defuse a bomb. We have a random time before to have a bomb explosion and this feature allow us to demonstrate the possibility to coordinate a robots team using a sequence of stable states that they follow each other during the mission execution.
Figures 4, 5 and 6 show the three main scenes of an unknown environment exploration phase using the Mission Lab software, developed at the Mobile Robot Lab of the Georgia Institute of Technology.

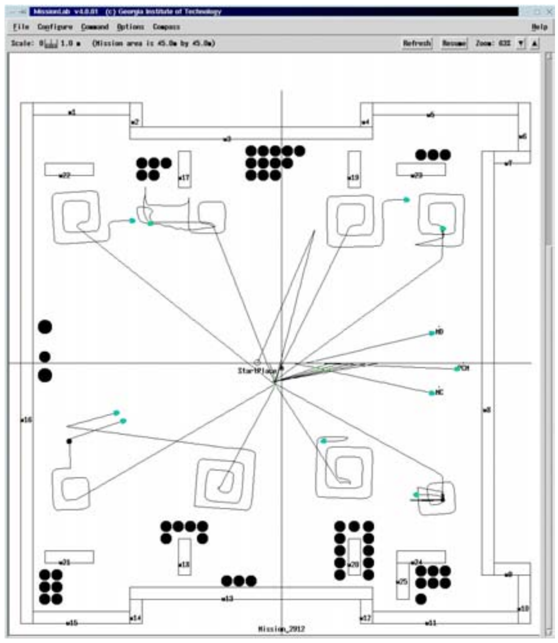

Figure 6. The implemented framework: the bomb disengage phase (two robots are involved).

The scenes are referred to a typical bomb-defusing mission with 11 robots adopting the Conservative strategy. In Figure 4 the election of a new government and the consequent assignment of the sub-areas to the citizens is shown. Figure 5 shows each robot reaching its assigned sub-area and the related intelligent exploration phase based on a spiral movement with memory. The exploration phase culminates in the bomb detection. Figure 6 shows the disengage phase in which a second robot is supporting the first one.

The disengage phase of the support robot can be also viewed in the new 3D CSAI Lab environment that we are developing starting from the Mission Lab environment (Figure 7). Figure 8 shows the Robot State Automata Diagram: in the figure each stable state is representative of a executive political team. The mission begins from the START state. Then, we have an immediate transition to the FIRST-ELECTION state, that takes care of calling the first elections of the mission. In this stage, the first global approach to the mission is decided, i.e. if the first used politic evolution will be conservative or progressive. Moreover are outlined the robots designated to cover the government roles (PCM, MC and MD), while the other robots, that they have not received government roles, will be the citizens. It is important to underline that before the end of the elections, every robot

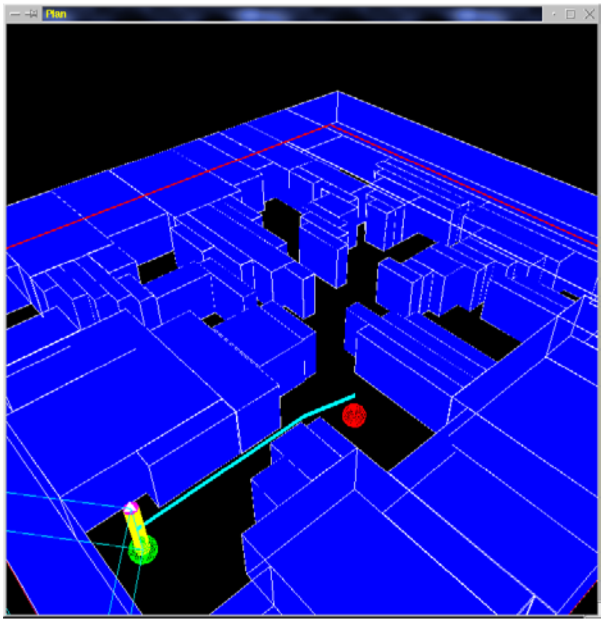

Figure 7. The disengage phase in the new 3D CSAI Lab environment.

has the same behavior. After that the roles have been decided, every robot assumes the behavior assigned during the election maintaining it until the next election.

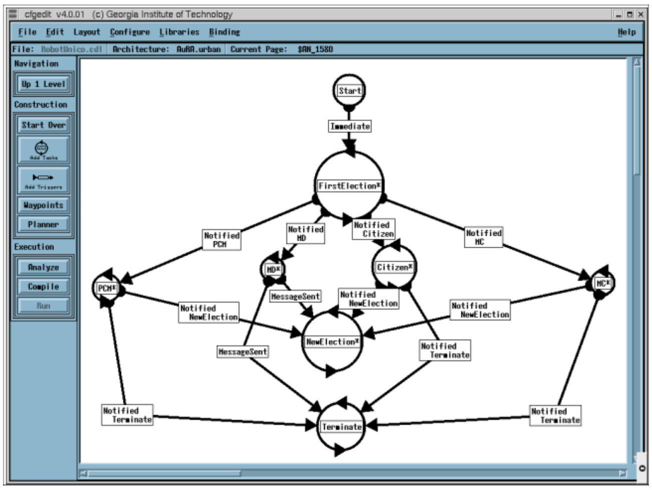

Figure 8. The Robot State Automata Diagram.

5 CONCLUSIONS AND FUTURE WORKS

The innovative features of the proposed paper are connected to the type of architecture used for the control and the coordination of robots colony: the implementation of a political management system inside a robot society similar to actual human political system. Currently we are involved in the development of a communication language between agents based on the Golog language and in the development of a neural network based approach for complex environment exploration.

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