Hierarchical Hybrid Fuzzy Decision Making in Multi Agent Time Critical Environment

Maziar Ahmad Sharbafi, Omid Amirghiasvand, and Saeed Ansari Ramandi

Abstract—**In multi-agent decision making, the agents' ability to coordinate with each other to accomplish a common goal is one of the most significant multi-disciplinary problems. Combination of centralized and distributed approaches namely hybrid approach is the main contribution of this paper which is applied to a crisis management after occurrence of earthquake. Choosing the proper technique fitting exactly to this attitude is another complexity of such problems. In our investigations, Fuzzy Decision making which is the most similar method to human ones, was selected. This approach, in addition to elevate the flexibility of the decisions, is the best choice to prepare hybrid decision making. The rescue simulation is considered as the test-bed for our performance evaluations; our results are compared with the powerful teams in RoboCup 2008 competitions.**

Index Terms—**Centralized and distributed cooperation, hybrid fuzzy decision making, multi-agent decision making.**

I. Introduction

Uncertainty, noisy input data and stochastic behavior which are obvious difficulties of such environments make decision-making more complicated. Two primary decision making approaches to address coordination problem in multi-agent system are distributed and centralized decision making [1]. In the center based decision making all agents send their information to a center that makes the decisions, and sends them back their duties. In distributed attitude the decisions are made locally by agents, but they should result in a global behavior achieving group's goal [2]. In this method every agent's aim should be determined With regard to team's goal achievement like ant colonies.

A perfect solution which works for all conditions in a multi-agent dynamic, complex and time-critical environment does not exist and sub optimal methods may be the preferable solutions. To evaluate our sub optimal approach with the mentioned characteristics, the situation of a city after happening a crisis, is selected. In such conditions, coordination of the rescuers and their rational decision making can reduce the depth of calamity. The main purpose is to provide urgent decisions supported by integration of disaster information, prediction, reinforcement learning [3], planning, and human interface. Rescue Simulation environment, one of the RoboCup competitions league, has prepared the aforementioned situation to test the AI based techniques with the aim of coordination in crucial conditions.

The experiments are performed by MRL rescue simulation team, the champion of 2006 and 2007 and the second team of 2009 RoboCup competitions. The experience of using artificial intelligence results in promotion of multi agent decision making in our previous works. Some of our noticeable results of using such methods in a time critical and dynamic multi agent environment presented in [4], [5] and [6], encouraged us to apply such approaches even more in rescue simulation.

II. Rescue Simulation Environment

In Rescue Simulation as one of the RoboCup competitions league, teams should solve the multi-agent coordination problem in a simulated environment of earthquake which is in the center of concentration of many researches recently. This environment simulates a city, destroyed by an earthquake. As a direct result, the buildings collapse that cause the ignition in ruined buildings, the obstruction of the roads and the injury of the people. There are three groups of rescuers; the fire brigades try to extinguish the fires, the ambulance team agents rescue the injured and buried people from collapsed buildings and the police force agents clear the blocked roads and make them passable for others. In this system, communication between agents is based on a limited messaging system. These constraints include many items from the number and size of the messages to delays in sending and receiving.

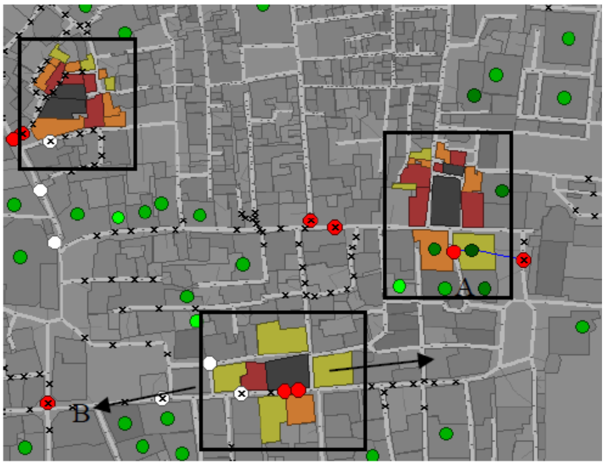

Fig. 1. Sample scenario from rescue simulation environment. A: single burning building, B: burning fire site.

The quality of these agents operations are evaluated by the score which depends on the total unburned area, the number of alive humanoids, movement (energy consuming) and messaging The last two factors should be minimized in

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contrary with others. One of the events that are simulated in rescue simulation is spread of the fire after occurrence of earthquake; the score reduction happens in two ways: the direct effect is from total area of burnt buildings and another one is from burning civilians. Thus, the selection of the cluster of fire and burning buildings with the highest priority to extinguish, are the most important and challenging parts of agents' action. In such a multi agent system, the coordination between heterogeneous agents has the key role too.

In Fig. 1 a distinct part of a map including three fire sites and many burning buildings are shown. The colors yellow, orange, brown and black show the severity of the fire in buildings respectively. The fire site is a set of burning buildings which are in the neighborhood of each other as shown in Fig. 1.

III. Hybrid Decision Making

In corporative multi-agent systems, like Rescue Simulation environment there is two primary approaches to accomplish coordination. First one is a fully distributed approach in which each individual agent plans autonomously and separately just based on his own perception of the environment and also some undependable information gained through messages received from other agents. Due to possible dependency between agents' activities and interactions during executing them, giving permission to the agents to plan individually may lead to very inefficient solution. Second method is a centralized approach in which all agents just send their local perception from the environment to a center agent and the center creates a coordinated plan and sends agents' task back to them in every simulation cycle. The main drawback of this mechanism is communication overhead. In addition, it makes the agent heavily dependent to the communication system (they need to get order from the center agent every cycle). In Rescue Simulation environment, the ultimate goal of each fire brigade agent is to extinguish all fire sites. In a Normal scenario there are about 4 or 5 fire sites with different sizes (various number and size of the buildings) and properties (position, distance to trapped civilians, building type and etc) in a city and about 15-20 fire fighters. It is pretty much clear that sorting the fire sites based on importance and selecting the most vital fire site and assigning enough fire brigades to it, have the most significant effect on final result. So to accomplish a good performance in coping with the fire, fire brigades team needs a good coordination mechanism to select the best fire sites and then extinguishing the most dangerous buildings inside them. So as we explained, using a fully distributed mechanism is not a good solution, especially for our environment with limited communication between agents. Because it is considerably hard for the fire brigades to coordinate their plans for extinguishing a fire site when there are noteworthy differences and inconsistency between their world models that makes a coordinated plan so difficult. This mechanism in rescue simulation environment usually leads to uncoordinated planning, repeatedly target changing and switching between fire sites which prevent us from extinguishing them efficiently because of unnecessary movements. Therefore, it is concluded that using central and distributed techniques together covers the drawbacks of each one.

In this hybrid mechanism, the decision making is organized in two levels with a hierarchical manner:

1) In the higher level center makes decision for agents, via choosing the most critical fire site and sending it to relevant agents. As an effect of this structure, the switching between different fire sites will be reduced, because in this method all high level decisions have been made from a unique world model (the world model of the center agent).
2) In the lower level, the agents individually decide and choose the building with the highest priority based on their direct perception of the situation of the fire site. Obviously, sending these data to center and waiting for its command to select building is not reasonable. The delay between the centre decisions and the buildings' states makes the decision irrational; e. g. about 4 cycles delay occurs from sending the status of a building to the center and receiving the command by the agent. This time may turn a building with high percent of fieriness to a burned down one which should not waste the water of the fire fighters. Note that the fire site status which is influenced by several buildings, changes slower than each building. Thus, this layer of decision can be made by the center.

IV. Fuzzy Hybrid Multi Agent Coordination

A. Problem Description

The target of fire brigade agents team is putting out the fires as soon as possible with the minimum damages to the city buildings and civilians. Each fire brigade has a water tank with a volume equal to 15000 liter. It can fill the tank in refugees which are few in the map with the rate of 1000 liter per cycle. It can pour 1000 liter on the fire in every cycle. Many items should be considered by the fire brigade agent when he wants to decide about moving to a fire site, refugee or even searching for a fire or an open road to the destination. In this paper only selecting the best fire to extinguish is considered. To detect the most important burning building, there exist some significant parameters stated in the following:

1) *The size of the burning area*: The required water and respectively time to extinguish a fire set is directly related to its area. Sometimes it is better to extinguish small fires to save time and water in future. From another point of view, if a big fire is not put out, its spreading may turn it to be uncontrollable. Therefore, a tradeoff between selecting the fire sets based on their size is necessary.
2) *The Ability to spread*: According to spreading rules inspired from physics, a parameter namely connection value is extracted to determine the connectivity of each building to other ones. It shows the ability of the burning building to spread the fire. For more details see [7] and [8].
3) *Distance to Center*: If the fire site is placed in the center of the map it can be expanded more extensive than when it is located on the edge of the map, far from the center.
4) *Distance of the agent to the fire*: Time to reach the fire is influenced by the distance of the agent to the fire.

Therefore to assign a group of agents to a site this parameter is important to save the time.

5) *Other parameters*: Civilians near the fire, distance to refugee, distance between each fire cluster to the other ones and many other parameters may affect the decision results too.

As described before, in our approach the importance of the fire sites are determined by the center agent based on the information gathered by the other agents. In addition, the center calculates the required number of fire brigades to put out a fire site and assign the nearest ones to it. Therefore, in the next section we only describe the algorithm of decision making to evaluate the fire importance and further information about the general operation of the agents can be found in [8] and [9]. The mechanism to select the fire site is explained in the next section and attitude for building selection is similar too. Of course the parameters and the decision maker are different. For example, the number of civilians near or inside the buildings is an important parameter here and the decision maker is the fire brigade agent (not the center).

B. Solution

In RoboCup2006 the linear estimation [7] was implemented to choose the fire cluster and building utilizing some important parameters of the fire cluster and building. All of the assumed coefficients were gained empirically and based on observation of the rescue process.

This method was not sufficiently reliable, because an immediate change of a parameter may lead agents to the wrong decision. In other words, linear control enforces some constraints to the solutions which can be ignored by nonlinear ones like fuzzy controllers. In the following we describe our new fuzzy based approach for selecting a Fire site. Regarded to this point that fuzzy logic is inspired from the human decision making system [10] and [11], we selected it to choose fire site and building. The most important parameters of the Fire site are specified for designing fuzzy rules. The main parameters of objects are as follows:

1) Fire Site: Distance of the agent to the fire site (DF), Distance of Fire Site to the center of map (DC), Total fieriness area of the fire site (TFA) and Connection Value (CV).
2) Building: Fieriness, Burning start time, Total Area.

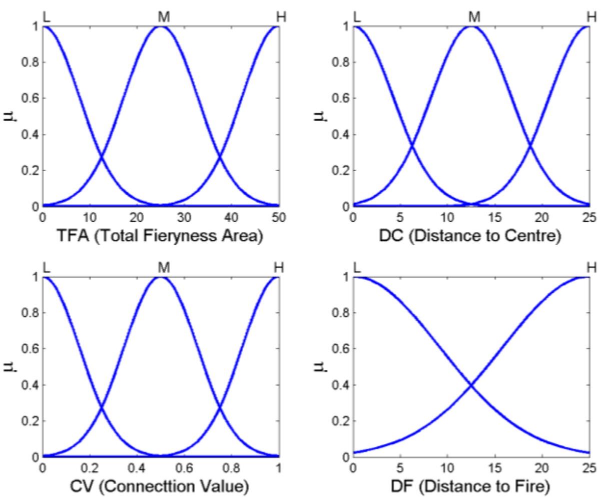

Fig. 2. Membership functions for different decision making parameters.

In our implementation we used Gaussian membership function (1) in which m is the mean and σ is the variance. Membership functions are shown in Fig. 2. It demonstrates that three of parameters have three memberships (Low, Medium and High) and the remained one has two memberships (Low and High); thus Combination of them results in 54 rules for the Fire site.

$$f(x,\sigma,m) = e^{\frac{(x-m)^2}{2\sigma^2}} \tag{1}$$

The priority of a fire site is computed by Takagi-Sugeno inference method that is the weighted average of all rule outputs. Then the final output (y) is computed as follows:

$$y = \sum_{i=1}^{N} w_i z_i \Big/ \sum_{i=1}^{N} w_i \tag{2}$$

where z_i and w_i are the output and membership of i^{th} rule respectively. Efficient computation and straightforward implementation are some advantages of this inference system.

TABLE I: THE RULE TABLE (DF: DISTANCE TO FIRE, CV: CONNECTION VALUE, DC: DISTANCE TO CENTER, TFA: TOTAL FIERINESS AREA)

DF, CV DC, / TFA	LL	HL	LM	HM	LH	HH
LL	b	b	g	b	g	g
LM	m	m	h	m	m	h
LH	s	s	l	s	l	l
ML	b	h	b	b	g	b
MM	m	l	m	m	h	m
MH	s	t	s	s	l	s
HL	h	h	b	h	b	b
HM	l	l	m	l	m	m
HH	t	t	s	t	s	s

Table I shows the rules determined based on the designer knowledge about the environment. In this table the outputs of the rules can achieve 7 values (**t**iny, **s**mall, **l**ow, **m**edium, **h**igh, **b**ig and **g**reat). For example, the sixth rule that can be extracted from the last column of the first row of the table (LL/HH) can be expressed as follows:

If Distance to fire site is high & the Connection value is High & Distance to the centre of map is Low and the total area of the site is Low then its value is great.

This rule is obviously reasonable. The only strange thing in this rule is that in spite of the high distance of the agent to the fire site it has the most attainable value. The reason is when the other parameters are so suitable; the importance of distance will be negligible.

Our method was evaluated by comparing it with our earlier algorithm. The better operation of the new system compared with the MRL algorithm which was the first team in RoboCup 2007 among 20 team shows the superiority of the new fuzzy decision making [8] and [12] technique.

V. RESULTS

In this section some of our simulation results which show the advantages of this approach are presented. The performance of the recent method is compared with two first teams of the previous year competitions (ZJU and RedSun 2008). The source code was MRL code (our team) and only the fire brigade agent was replaced with two other teams' strategies. Although ZJU got the first place in 2008 competitions, the performance of RedSun was better in most of the maps (it is better than ZJU in 60% of the maps).

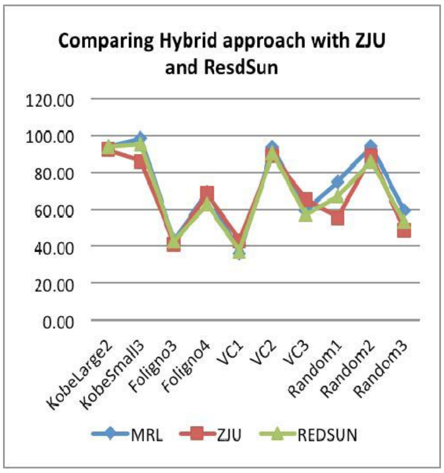

Fig. 3. Comparing our new approach with ZJU and RedSun, the first and second teams of RoboCup 2008 competitions. The results are the average of running 10 times for each map.

Fig. 3 shows the average of 10 times runs for different maps which are selected from evaluation maps of final round of 2008 competitions. This figure illustrates the advantages of our method respect to two others. It shows that in 70% of the maps MRL new code is the first, in 20% is the second and only in one map it is the third one.

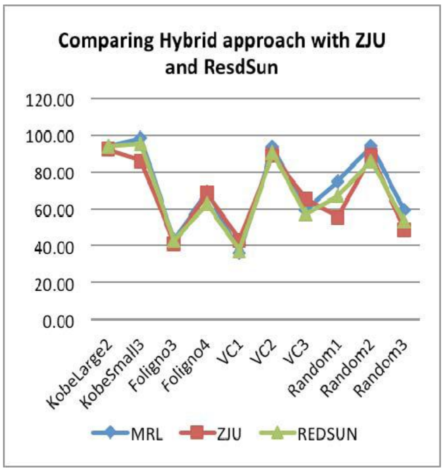

Fig. 4. The results are the average of running 10 times for each map. Comparing our new approach the old algorithm.

To evaluate the improvement of our code in Fig. 4, we compared the Hybrid approach with our previous year code. It is notable that the only difference between these two codes was their fire brigade agents. In 2008 competitions our team (MRL) attained the forth place that shows its acceptable quality. In this figure it is shown that only in VC1 the old approach gained better performance and in all other simulations the hybrid approach is considerably preferable.

In 2009 competitions, this algorithm was implemented and our team became the first in semifinal and only one mistake resulted in becoming the second team in the final round. This is also another superiority of this mechanism.

VI. Conclusion

In this paper two primary approaches to multi-agent decision making were studied; center based and distributed mechanisms. A dynamic and stochastic environment (the RoboCup Rescue Simulation environment) as a test bed was chosen for evaluating these approaches. The idea of using both distributed and center based decision making together with appropriate structure in order to make better coordination between agents was proposed. In Rescue Simulation environment, decision making problems are very similar to human decision criteria. Therefore Fuzzy decision making was applied in those approaches to get more similar decisions as human does. The outcome shows that the hierarchical hybrid decision making will result in better performance and better decision. Two layers of decision making are designed to use the advantages of each method in a hierarchical manner. High level action selection and task allocation is performed by the center and low level ones are done by distributed multi agent decision making.

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