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Generation of Cooperative Behavior of Robots Using a Fuzzy-Markov Emotional Model

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Abstract: This study deals with an emotion-based task sharing approach and its application for a cooperative multiagent robotic system. A stochastic emotion model based on Markov theory is adapted to perform their tasks in a well organized way to achieve goal. The emotional model consists of four basic emotions: joy, anger, fear and sad. Different emotional behavior is obtained by updating the state transition matrix of stochastic model. Perception of stimuli has an impact on emotion inducing factors and thus, affects on emotion dynamics. The task assignment and then task sharing approach depends on the emotional state of each agent. With the developed emotional approach, a Matlab based simulation is performed to analyze the behavior of the agent with the emotional capability.

Key words: Cooperative task, colleague robot, emotion, markovian emotion model

INTRODUCTION

The concept of artificial emotion is expanding and increasingly used to design autonomous robot systems with the augmented capability, such as emotion based experience of environment, emotional interaction, etc. Ortony *et al*. (1990) stated that it is important for artificial intelligence to be able to reason about emotions-especially for natural language understanding, cooperative task solving and planning. There are many psychological evidences supporting the emotional concept to be needed for getting automation in agents. Now it is a matter of thinking whether emotions could have the same functional roles as ones that prevail in natural system. Scheutz (2004) has found such 12 roles of emotions that can be used for artificial agents (may be for single agent or multiagents system) to develop emotional control mechanism such as adaptation, action selection, sensory integration, motivation, alarming mechanism, goal management, representing, memory control, social interaction, strategic processing and self model. We have also notified the roles of emotional intelligence that are useful for creating cooperative agents as shown in Fig. 1.

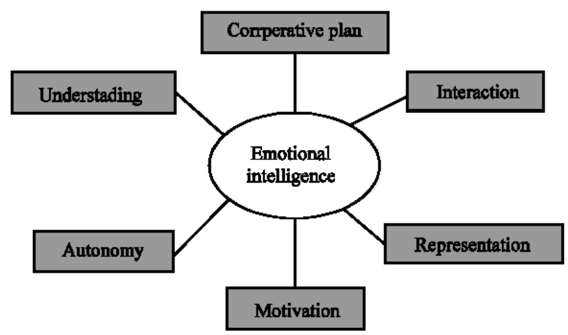

Fig. 1: Basic roles of emotional intelligence

In some cases, we use multi-robot system to distribute the activities and intelligence among the members depending on the complexity of problems. Sometimes, it is needed to divide a complex task into small tasks and distribute the small tasks to members of team when problems are widely distributed and heterogeneous in functional terms. With the limited ability and knowledge, a robot can have a satisfactory role by performing the assigned small task with high performance. When working in a group, a robot needs to develop intelligent behavior with the artificial intelligence. On the contrary, artificial intelligence is facing some critical problems in projecting the common senses into knowledge with some rules. In general, a truly autonomous robot should develop its rules that govern its behavior. If one expands the concept of autonomy by including self motivation, then emotions might play a role because these are considered to be essential for human team with reasoning.

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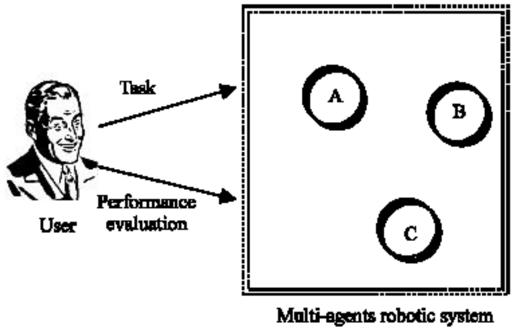


Fig. 2: A multi-robot system for implicit cooperation

The cooperation among the members of a multi-robot system can be classified into two categories: implicit cooperation and explicit cooperation (Baghaei and Agah, 2002). Each member performs individual task for the case of implicit one and the collection of the tasks is targeted to a common goal or mission. For example, when a team of multi-robots is engaged in collecting apples from a tree and putting them in a basket, the team is accomplishing a common mission (to finish the task of collecting and putting apples into a basket) while cooperating in an implicit way which is also called asynchronous cooperation because no requirement of synchronization in time and/or space. On the other hand, the explicit cooperation is synchronized in time and/or space. For example, in the case of heavy weight lifting the robots need to take position properly and then need to hold and lift simultaneously. In our research for preliminary, we have chosen a task allocation for a multi-robot system with implicit cooperation for the task of room cleaning, where robots handle a large number of objects in a large area within a limited time period assigned by the user of the system as shown in Fig. 2.

In this study, we use an approach with an emotional model for a multi-robot system to regulate the behavior of each member of the team and to respond to a request for assistance with the implementation of emotional interaction. Here, robots will not respond to a recruitment call unless their emotional motivation is sufficiently strong enough, which leads to a less communication. The emotions can be considered mainly as a particular type of information that is exchanged among the robots. The emotion-driven autonomous behavior is generated following some interaction rules based on acceptation/ reject-tion patterns, which are much related to human emotional interaction.

RELATED WORK

In recent years, numerous affection based robotic systems have been developed arising many questions and giving hints about the bottlenecks of the emotion based system. Are there any common definitions of emotions for modeling? What is the fundamental mechanism of emotions playing in cognition and action and their integration? What kind of emotion model should be used for an application? What is the best way for sensing, recognizing and expressing emotion during interaction among agents? These types of inquiries are commonly arising and some of them demolishing during procedure of modeling and implementation, although all these inquiries can not be answered by a theoretical view. For creating artificial emotion among the agents, there are different types of emotion models available such as: architecture level model, task-level model, mechanism level model, etc. There are also some special models of human emotions like circumplex model (Russel, 1980), FLAME model (El-Nasr *et al*., 2000), Markovian emotion model (Arun, 1997; Kolja and Martin, 2004), etc. which can be adopted for creating artificial emotion among agents.

To develop emotion based architecture for robotic system, a number of approaches have been used to increase the autonomy and adaptation in the working environment. Shibata *et al*. (1996) created an emotional architecture to produce cooperative behavior within a team of robots inspired by the neurologist and psychoanalyst M. Solms. The generated behavior of each robot depends on its own experience from the environment and the observed behavior of other robots. Our research work is also related to cooperative task, task allocation among the members of the team, task sharing (if necessary) and computational architecture for emotion model. The main areas of research that influence this research are: multi-robot task allocation (MRTA) problem, theories of emotions and communicative interactions.

MRTA problem includes mainly four types of basic strategies (Gage, 2004):

Auction: In this approach, task announcements are transmitted to the robot team and each robot returns a bid that specifies the fitness of the robot for the task. Each task is accompanied with a metric as a measure of fitness and a best-fit selection algorithm is used to select the best robot for the announced task. *Murdoch*, presented by Gerkey and Mataric (2000, 2003) is an auction-based task allocation system.

Motivation-based: In this method, the selection of a suitable action is based on internal motivation mechanism. For example, Parker's *Alliance* is a fault-tolerant behavior-based architecture that assigns task dynamically and robots choose tasks by two motivational mechanism: *impatience* and acquiescence (Parker, 1994, 1998). In *Alliance* approach, each robot has partial knowledge of its own as well as other's state. This knowledge with the 2 motivational functions (*impatience* and *acquiescence*) is used to calculate the activation function of each action.

Team agreement: This approach functions under a general agreement among the members of a team. Chaimowicz *et al*. (2002) used this method for the coordination of robot team of RoboCup.

Broadcasting of local eligibility: Task allocation is based on the local efficiency of a robot. The most efficient robot directly inhibits other robots locating around of it and performs the task. Werger and Mataric (2002, 2001) presented such kind of task allocation method using a technique called *Port arbitration behavior* (PAB) which uses a collection of behavior production modules (BPM). Each BPM is a control software component which computes its own local eligibility and sends it to other robots.

This study deals with a task sharing approach with some emotional intelligence. One of the main issues in task sharing problem is type of task that is going to be performed like: homogeneous task and heterogeneous task. Another main issue of multi-robot system is concerned with large population. It is too difficult to build up such a multi-robot system and to make sure that all are performing well. Lerman (2001) proposed a mathematical method for large colonies of robots (swarms) as stochastic systems to predict the complex emergent behavior of robots. In this research, he analyzed the emergent behavior as Markov property with two capacities: predicting the emergent behavior and understanding effects of each parameter on system. In our work, emotional state of each robot is generated from Markovian emotion model (Arun, 1997) and one robot is recruited for a task depending on its emotional state.

Murphy *et al.* (2002) developed a multiagent control approach for interdependent tasks which imbues the agents with emotions and allows a satisfactory behavior to emerge. In this approach, a formal multilevel hierarchy of emotions was used where emotions modified active behaviors at the sensory-motor level and also changed the set of active behaviors at the schematic level. It mainly focused on interdependent tasks, not purely cooperative and one robot could not perform the other one's task. Our work in this article is different in task mode (each one is capable to do other one's job if necessary). Kolja and Martin (2004) developed an emotional core based on hidden Markov model which has a very close relation with our work in case of emotion modeling.

APPROACH

This study describes the task problem that is considered for implicit coordination method, task sharing approach and emotional model that has been applied for generating emotional state of each robot.

Problem statement: For the simplicity, we consider three robots (robot A, B, C) working in a team for room cleaning. The room is divided into 3 zones for their individual working arena as shown in Fig. 3. Each robot cleans the center part of the floor by pushing laid objects (balls) towards wall side. But in case of any necessary, one robot can go to other working area for coordination in cleaning (for example, if the user of the system says that the arena under robot A needs to be cleaned first within a shorter period of time and robot A is unable to complete this task within this period or robot A is lack of energy and it needs help, then the colleague robots can help the robot A in cleaning task).

Task performing and sharing method: To complete a task each robot needs a specific state label (a set of task related behaviors). In our case, each robot can be in either ‘active’ or ‘inactive’ with respect to cleaning task. When a robot is in active state, it consists of the following behaviors:

Searching: Wandering around the arena in searching of balls.

Pushing: Pushing balls towards the wall side.

A robot in inactive state (not engaged in cleaning) has the following behaviors:

Searching for power source: If energy level reaches to a minimum level, then robot stops cleaning task and searches for power source.

Pausing: When assigned task is finished and there is no workload, the robot takes pause in work and waits for further call.

In the team, each robot has an internal state (condition) which is represented by the emotional state. For simplicity, we have considered only four basic emotions: joy, anger, fear and sad. These emotions are defined as follows for our case:

Joy: A robot is in joy state when it has high energy level to perform task, workload is normal and capable of doing task where workload is defined as:

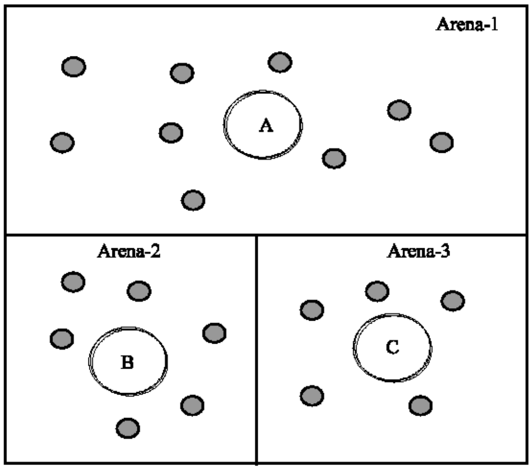


Fig. 3: The arena for three robots

Angry: Angry is activated when getting no positive feedback from any *colleague* robot in response to its recruitment call and also facing barriers in performing task.

Fear: Fear state increases when getting high workload with low energy.

Sad: It increases with ignoring the help messages (recruitment call of other robots). This is an emotional state of becoming sorry for ignoring help messages.

A robot starts to make a new cooperative plan (for task sharing), when its fear state reaches to a threshold value (F_{th}) and it needs help. Our task sharing approach is very close in concept with the work of Ostergaard *et al.* (2001), but we use the emotional state as a metric for selection of a robot. Help messages firstly are sent to the robots which are in happy state. If anyone sends positive reply, then it performs the task with the cooperation of helping robot. If help messages are ignored, then its anger gradually increased. When anger reaches to a threshold value (A_{th}), then the robot makes a new plan for action to be performed. On the other hand, if the sad value reaches to threshold point (S_{th}) by ignoring the help messages sent by other robots, then it definitely decides to help the basic cooperative procedure is shown in Fig. 4.

Emotional model: This study describes the modeling approach which is applied for creating an emotional model to be used for creating a task sharing approach. In our model, we have introduced a new factor named as *emotion inducing factor*, which is very important for the model for emotion generation and will be described on next study.

In our model, we have not included calm (normal) state because we assume that if overall working state is as

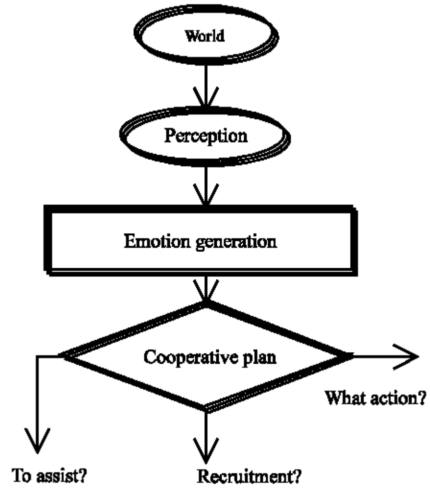


Fig. 4: A basic flow diagram of cooperative plan

usual, then the robot is in happy state to be motivated and to continue its task. An application of Markov modeling theory for our purposes is described by Markovian emotion model as shown in Fig. 5. We have applied it for pure agent's emotion due to its memoryless property as behaviors and commands are highly dependent on emotional present state than the history of arriving the state.

The Markovian emotion model with four states can be expressed as follows:

$$X_{k+1} = AX_k \tag{1}$$

with emotional state points

$$\Omega = \{Joy, Anger, Fear, Sad\} \tag{2}$$

where, X_k represents the current emotional state and A is the emotional state transition matrix (so called stochastic matrix). To get emotional impulses from respective emotion state, we have considered an iterative belief model considering some meta-state of emotions like: e4, e3, e2, e1 for joy, anger, fear and sad respectively as shown in Fig. 5. The intensity vector of emotions is derived from the probability of respective emotion in the belief model. Considering the meta-state, stochastic matrix A becomes as follows:

$$A = \begin{bmatrix} P_{e4/e4} & P_{e4/e3} & P_{e4/e2} & P_{e4/e1} \\ P_{e3/e4} & P_{e3/e3} & P_{e3/e2} & P_{e3/e1} \\ P_{e2/e4} & P_{e2/e3} & P_{e2/e2} & P_{e2/e1} \\ P_{e1/e4} & P_{e1/e3} & P_{e1/e2} & P_{e1/e1} \end{bmatrix} \tag{3}$$

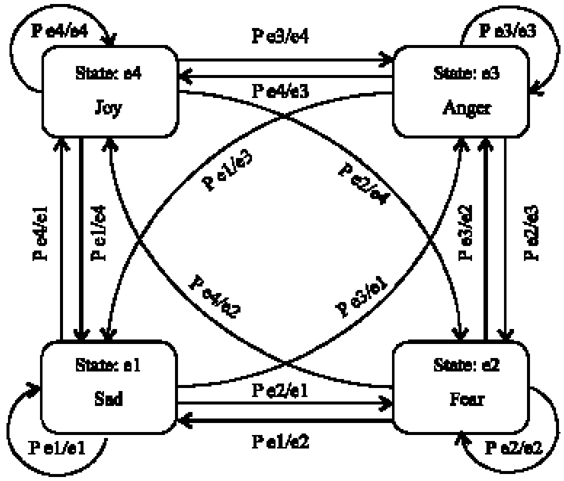


Fig. 5: Topology of Markovian emotion model

In the Markovian emotion model, the nodes represent the emotional states and the arcs/arrows indicate the probability of getting out of states to the directed state. The arc/arrow values are set to initial values (e.g., q_1, q_2, ..., q_{16}) which give the initial state transition matrix of Markov model. These values can be updated later on with the influence of emotion inducing factors: α, β, γ and δ for joy, anger, fear and sad respectively. In this model, there are 4 types of transition probabilities from each of the present state. For example, the probability of state transition (arc/arrow values) from joy to other states can be expressed by following equations:

$$\left.\begin{aligned} P_{e3/e4} &= q_2 + (\beta - \alpha)q_2 \\ P_{e2/e4} &= q_3 + (\gamma - \alpha)q_3 \\ P_{e1/e4} &= q_4 + (\delta - \alpha)q_4 \\ P_{e4/e4} &= 1 - (P_{e3/e4} + P_{e2/e4} + P_{e1/e4}) \end{aligned}\right\} \quad (4)$$

where, q_2, q_3 and q_4 are the initial arrow values for $P_{angry/joy}$, $P_{fear/joy}$ and $P_{sad/joy}$, respectively. For each of the states, there are similar equations combining to total of 16 equations which render new values to the state transition matrix to be updated. With the updated matrix, the next emotional state is generated. More details of the model and computational procedures are given in Arun (1997) and Kolja and Martin (2004).

Workload: Among the environmental stimuli that affects on the *emotion inducing factors*, workload is one of the main component that needs to be mapped from three parameters such as: time (T), area of workspace (Ar) and number of balls (B) that are swept out. These parameters are limited as: 0-120 sec (maximum allowable time for a task is 2 min), 0-10 (using a scaling factor) and 0-20 (considering maximum number of balls that can be handled by the system), respectively. We have used fuzzy inference system (FIS) in Matlab environment to map the workload at different T, Ar and B values using membership functions with fuzzy levels of low, medium and high. FIS consists of 13 rules for fuzzy reasoning and to get the output value (workload), the centroid-area method of defuzzification (Mamdani method) is used. The workload surface at 60 and 120 sec is shown in Fig. 6a and b.

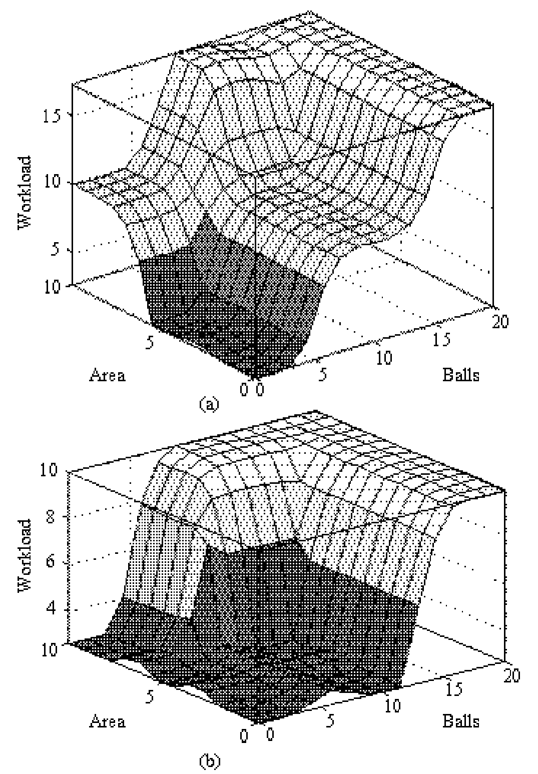


Fig. 6: Workload, where (a): T=60 sec and (b): T=120 sec

Updating of emotion inducing factors: The emotion inducing factors are influenced by the input stimuli which are perceived by the perception system through some basic variables which we called as energy level (e),barrier level (bl) and workload (w). Energy level decreases with the energy consumption while performing task.

Barrier level is a function of obstacles or all other barriers to obtain the goal. The emotion inducing factors are updated in each time step with the inputs from environment. The energy level and barrier level are scaled

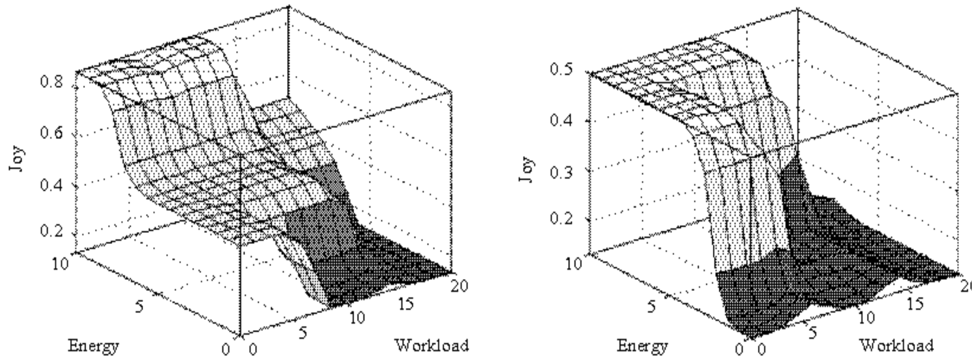


Fig. 7: Joy factor (α), where (a): bl = 5 and (b): bl = 10

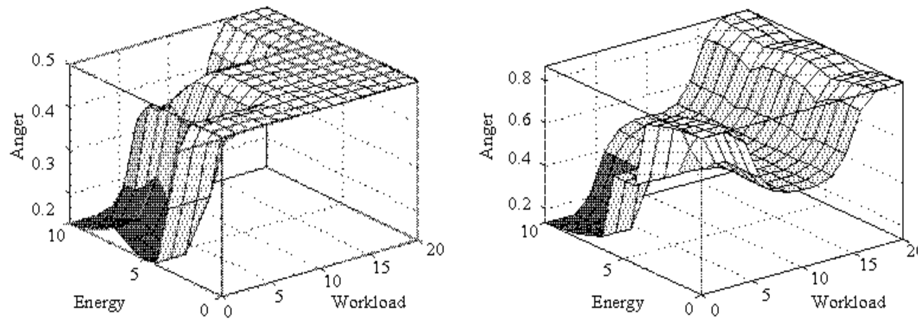


Fig. 8: Anger factor (β), where (a): bl = 5 and (b): bl = 10

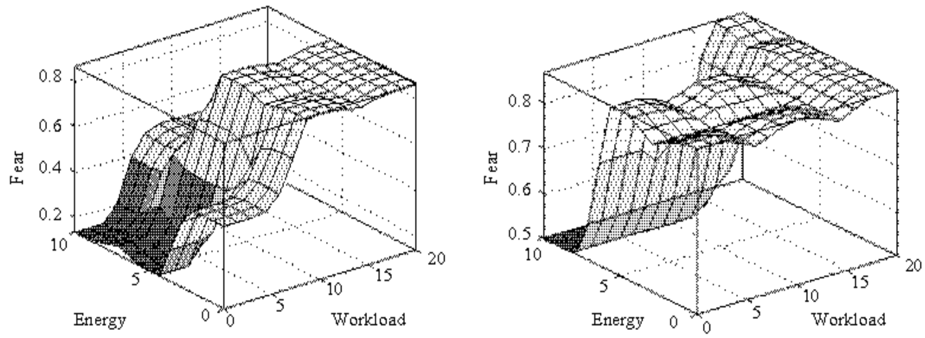


Fig. 9: Fear factor (γ), where (a): bl = 5 and (b): bl = 10

as 0-10. The surfaces of emotion inducing factors (joy, anger and fear factors) are shown in Fig. 7-9 at barrier level of 5 and 10.

In Fig. 10, we can see the updating process of emotion inducing factors and as well as the emotion state generation through the updating process of state transition matrix using the inputs from environment. Three input variables to the FIS are w, e and bl. The FIS transforms these inputs to map the emotion inducing factors.

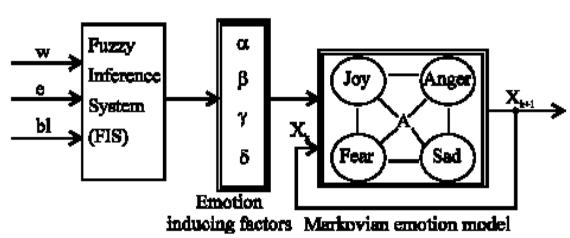


Fig. 10: Updating of emotion inducing factors and generation of emotional state

SIMULATION RESULTS

The simulation is conducted using a Matlab based Khepera simulator (*KiKS* simulator) which can simulate in a very realistic way (Theodor, 2001). For simulation purpose three robots are considered as cleaner robot to clean a room assigned by the user. The workspace is 1000×1000 mm, no. of objects 20 and time limit 100 sec. This workspace is divided among the 3 robots (A, B, C) as an approximate ratio of 2: 1: 1 at the beginning as shown in Fig. 3. Each robot has individual mapping surfaces for joy, anger and fear inducing factors with respect to input parameters as shown in Fig. 7-9.

The emotion eliciting conditions and effects on colleague are created according to the consideration of emotion definition as described:

- A robot has a field of view and is capable of acquiring information from the environment within this field of view.
- A robot always consumes energy when it is in 'active' state and the level of consumption increases with its level of activity.
- If the robot's energy falls below a certain threshold, it goes to 'inactive' state and it needs to search energy source.
- Each robot tries to stay in 'active' state as long as possible and to cooperate with others.
- Each robot has the mechanical ability to perform other one's job which is very important in assisting others.

The dominating emotion plays a great role in the cooperative plan. A robot calls for help when its dominating emotion is fear to a robot which is in better emotional state (preferable one is in joy state). The room cleaning tasks performed by robot A, B, C are shown in Fig. 11 and 12. The dominating emotions are shown in Fig. 13-15 for the robots A, B, C, respectively.

Robot A is firstly in happy state due to high energy level and cleaning progress is good as shown in Fig. 13. Later on, it has faced some barriers that oppose cleaning task as a result its angry state activate for few seconds (about 10 sec). On the other hand, its energy level becomes low and work progress reduced. As a result, its fear state becomes the next dominating emotional state. In fear state, it makes a plan for cooperation by recruitment. It likes to select one robot which is emotionally fit to assist, because emotion indicates the internal state of a robot which is also a reflection of working ability within the environment and also emotional state represents some quantitative physical parameters like: high energy, less energy, etc.

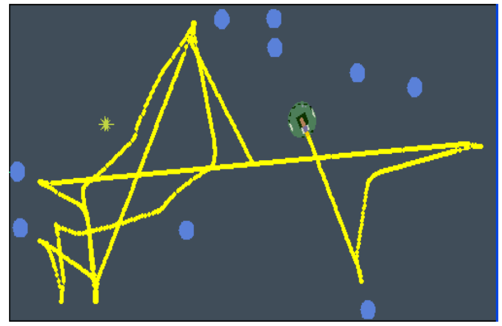
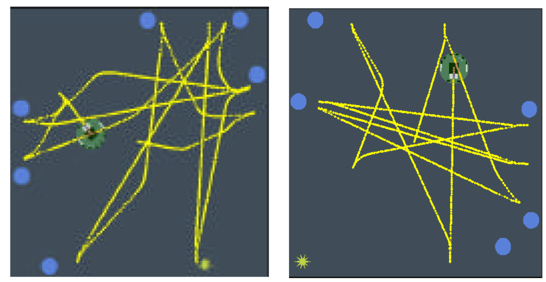


Fig. 11: Cleaning task of Robot A



(a) (b)

Fig. 12: Cleaning task, where (a): Robot B and (b): RobotC

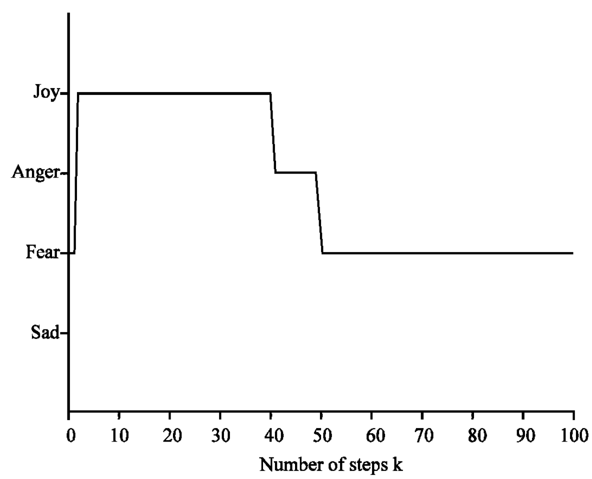


Fig. 13: Emotional state of Robot A

Robot B starts the cleaning task with lower energy level with compare to Robot C. As a result it was in fear state for the first time. After pushing 2 balls to wall side, it searched for power source and get energy from the power source. As a result it emotional state changed to joy state again and complete the task properly as shown in Fig. 14. Robot C is in joy state completely for its period shown in Fig. 15 and it is selected by Robot A for assisting as it has the better emotional fitness with

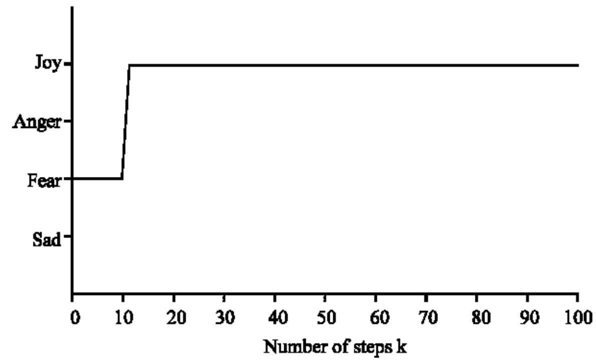


Fig. 14: Emotional state of Robot B

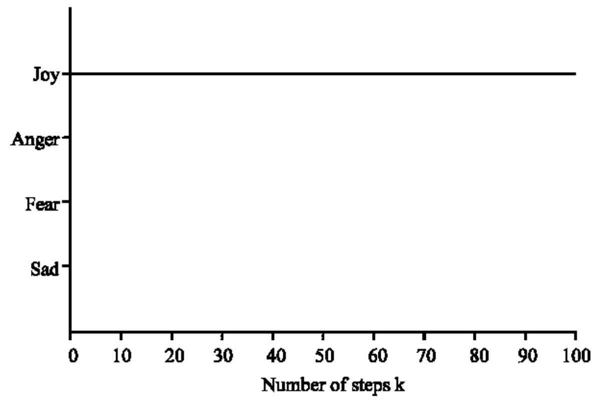


Fig. 15: Emotional state of Robot C

compare to Robot B. A new cooperative plan is developed based on the emotional state information which works as a fitness function for recruitments.

CONCLUSION

The aim of this research has been to explore emotions for generation of cooperative behaviors in a multiagents robotic system. Although, emotion generation is very complex task, here a Fuzzy-Markovian emotion model is applied emphasizing the present state. In agent selection for cooperation in task, we tried to establish the common phenomena that exist in human team (for example, selection of a partner for cooperation who is pleasant and energetic, to assist a feared person, etc.).

To achieve the proper emotional advantages for robotic agents as in human team, it needs more exploration in emotion generation method as well as in implementation. The definitions of emotions that are applied in our case are very specific which need to be clarified in broader sense with introducing more emotions using some hierarchical stages in Markov model which is under our consideration for further development. It is also possible to create space maps of unknown environment by means of emotion fields, which are going to be created and applied in this research. The individuality of agents can be constructed with an emotional space according to the user defined, which is under development of this research. These drawbacks are the pending issues to be considered for future study.

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