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Cooperative Cleaning for Distributed Autonomous Robot Systems using Fuzzy Cognitive Maps

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Abstract

Cooperative Autonomous Cleaning is a simple challenge that can be implemented with the help of Fuzzy Cognitive Maps (FCM) by simulating the actual thinking process of the human. The human mind organizes its thoughts in priorities and this feature could be exploited well if a priori knowledge of the system exists. This technique has been attempted here for a DARS[1].

1. Introduction

1.1. Cooperative Cleaning

Distributed Autonomous Robot Systems (DARS)[1] are used here to cooperatively clean an area of pre-known specifications. Several position identification methods have been used for mobile robots. One of the possible solutions is the use of Fuzzy Cognitive Techniques to position the robots and perform simple robot movements to clean the area effectively.

Cooperation is defined as the association of persons or businesses for common, usually economic, benefit. In this case, cooperation between robots could be achieved by simulating the human thought process with the help of sophisticated *thinking and decision making* methods developed with the aid of mathematical parameters.

1.2. Fuzzy Cognitive Maps

Fuzzy Cognitive Maps (FCM) is a modeling methodology for complex systems, which originated from the robust combination of Fuzzy Logic and Neural Networks. The graphical illustration of an FCM is a signed fuzzy graph with feedback, consisting of nodes and weighted interconnections. Nodes of the graph stand for concepts that are used to describe main behavioral characteristics of the system. Nodes are connected by signed and weighted arcs representing the causal relationships that exist among concepts. This simple illustration permits thoughts and suggestions in reconstructing FCM, as the adding or deleting of an interconnection or a concept. An FCM is a fuzzy-graph structure, which allows systematic causal propagation, in particular forward and backward chaining [2].

A Fuzzy Cognitive Map is a graph that shows the degree of causal relationship between concepts of the map. Knowledge expressions and the causal relationships are expressed by either a positive or a negative sign and fuzzy weights. Fuzzy cognitive map can avoid many of the knowledge-extraction problems which are usually posed by rule based systems [3]. The FCM includes a human knowledge base into building the control system and experts develop rules, concepts and priorities on that base.

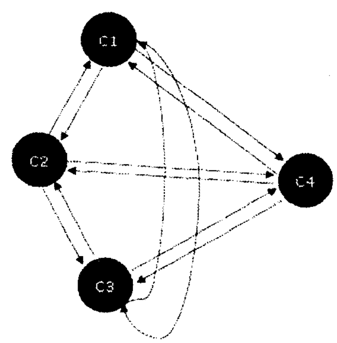

Figure 1. Sample Fuzzy Cognitive Map

Relationships between nodes of an FCM are encoded in the forms of interconnect weights. The value of the weights determine how strongly one concept influences the next concept, positive causality, negative causality or no relation. Each concept represents a state of the system.

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Cooperative behavior of robots entail planned positioning of robots to perform predetermined navigational tasks to accomplish the ultimate goal. The robot positions are chosen in such a way as to imitate the human through stages in cleaning an area of pre-known specifications [4].

Table 1. List of concepts

Concept 1	Robot 1 cleaning TLC Robot 2 cleaning BRC
Concept 2	Robot 1 cleaning BLC Robot 2 cleaning TRC
Concept 3	Robot 1 cleaning CENTRE Robot 2 cleaning BRC
Concept 4	Robot 1 cleaning CENTRE Robot 2 cleaning TRC
Concept 5	Robot 1 cleaning TLC Robot 2 cleaning TRC
Concept 6	Robot 1 cleaning TRC Robot 2 cleaning BRC
Concept 7	Robot 1 cleaning BRC Robot 2 cleaning BLC
Concept 8	Robot 1 cleaning BLC Robot 2 cleaning TLC

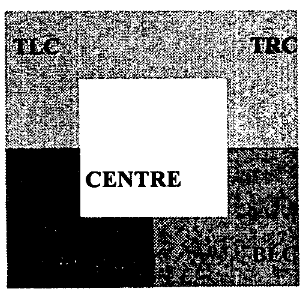

Figure 2. The Cleaning Floor

In this case, the previous value of the concept in a great way determines the successive value or state of the system. The weights that govern the movements between the concepts are continuously changed, so that the robots move from one area to another to perform cooperative tasks.

Experts (mathematical expressions) are used to characterize the edges of the FCM. Each expert individually ascertains the weight for each of the transformation connections, and a collective edge-weight is derived from it. The causal successor is decided as the strongest edge connecting the concepts.
The causality of the system is characterized by numerical measures of the amount on unclean area in different regions in the room[5].

2. Approach

2.1. Algorithm

A general algorithm was developed for the implementation of the system.

Table 2. Algorithm

Step 1	Obtain the Floor Grid and the Present Positions of the Robots
Step 2	Determine the new positions of the robot
Step 2a	Generate the weights of the floor matrixes
Step 2b	Prioritize the weights on the basis of the floor matrixes
Step 2c	Generate the FCM for the contexts
Step 2d	Decided upon on the next event basis of the interconnection weights
Step 3	Localize the robot in the *'most hot'* area in the region
Step 4	Perform robot movements to optimize the cleaning
Step 5	Repeat steps 1,2,3,4

2.2. Determination of the Knowledge Measures

The human experience and knowledge of the operation of the system is used to develop the weights of the Fuzzy Cognitive Map, as a result of the method by which it is constructed, i.e., using human experts that know the operation of system and its behavior in different circumstances.

A few experts are chosen to determine what the next move of the robot should be to determine the priority. Each of the experts comes up with a priority based on one particular facet of the input since the decision of where to clean next is a highly qualitative decision. Each expert should factor in their decision the following,

- Area to be cleaned
- Area already cleaned

Each of the concepts listed would have a priority and the final priority would be the difference in the collective priority of each region with respect to the other region in question as shown in the mathematical models.

Hyper-knowledge Functions

Hyper-knowledge is formed as a system of sets of interlinked concepts [6].

Two parameters are calculated to calculate the priorities associated with the next action. The source and the target grids are determined from the concepts shown in Table 1.

$$K_{clean} = \frac{\text{Clean (Current – Target)}}{\text{Total Area}}$$

$$K_{unclean} = \frac{\text{Unclean (Target – Current)}}{\text{Total Area}}$$

These factors are fed into the cognitive map devised and the priorities are decoded the following way, for calculating the priority for the movement from concept 1 *(Robot 1 cleaning TLC Robot 2 cleaning BRC)* to concept 2 *(Robot 1 cleaning BLC Robot 2 cleaning TRC).*

- K_{clean} and $K_{unclean}$ are calculated for the Robot 1
- K_{clean} and $K_{unclean}$ are calculated for the Robot 2

The final priority index for each movement is calculated as the algebraic sum of all the 4 indexes calculated.

Method 1:

$$\text{Priority}(C1\text{–}C2) = K_{clean}(robot1) + K_{unclean}(robot1) + K_{clean}(robot2) + K_{unclean}(robot2)$$

The final maximum priority could be calculated as the maximum of the individual connection priorities.

$$\text{Final Event} = \text{Max}(\text{Priority}(C1 - C2), \text{Priority}(C1 - C3)\ldots\ldots)$$

Method 2:

A Max – Min operator could be used to select the maximum of the minimum priorities for each concept. This could give out one number that is the strongest link in Fig 1.

$$\text{Max}\left(\text{Min}\left(\begin{array}{c|cccc} C_{1-2} & K_{CR1} & K_{UR1} & K_{CR2} & K_{UR2} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ C_{i-j} & K_{CR1} & K_{UR1} & K_{CR2} & K_{UR2} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ C_{7-8} & K_{CR1} & K_{UR1} & K_{CR2} & K_{UR2} \end{array}\right)\right)$$

Execution
Robot Positioning

Once the regions the robots have to operate on is decided, *each* robot has to be positioned in the region. A window (dimension **W x W**) is slid along the region to determine the most unclean area, and each pixel location is replaced with its relative cleanliness with respect to its surroundings.

$$\sum_{i=x-W/2}^{x+W/2} \sum_{j=y-W/2}^{y+W/2} \left[\frac{1}{\sqrt{sqr(x-i)+sqr(y-j)}}\right]$$

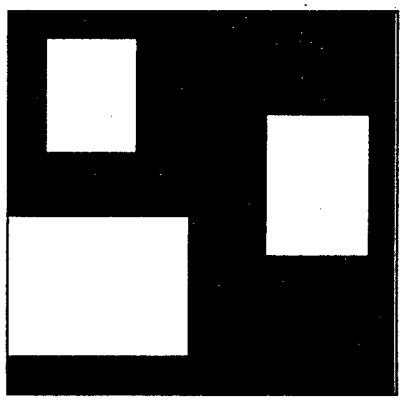

Figure 3. Cleaned Floor

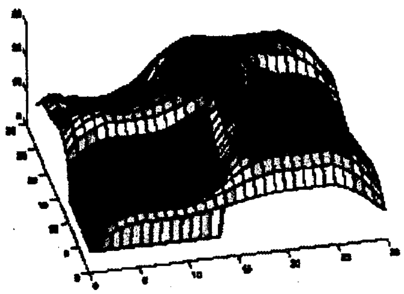

Figure 4. Weight Function

Results

The program was run for a few iterations based on

- Area of the Floor Space
- Different Weight Functions Combinations

Table 3. Average simulation results for 10 executions each

Floor space	Method 1		Method 2	
	Iter	% Clean	Iter	% Clean
50 x 50	25	98	25	98
100 x 100	31	99	33	97
150 x 150	33	96	32	96
200 x 200	35	96	40	96
250 x 250	40	94	45	96
300 x 300	45	93	50	95
350 x 350	50	91	50	92

Conclusion and Applications

Fuzzy Cognitive Map Theory is a new soft computing approach used to model the behavior of complex systems. This technique best utilizes existing experience in the operation of the system, has been examined. For such systems it is extremely difficult to describe the entire system by a precise mathematical model [7]. In this method, the experience of different specialists who can measure the variables and states of a small process and then unify these to construct the final system by integrating the different Fuzzy Cognitive Maps into an augmented one have been utilized.

The techniques adopted here even though comprehensive, break down for complex or more intensive simulations. This is mainly due to the deficiencies of the FCM parameters used to decide. Some improvements and future research on this topic could be,

- Split the area into more regions
- More *expert opinions* and mathematical parameters included.
- A neural network generated to prioritize the movements
- Include measures to reduce *'dance'*, or measures where the robot does not have to move too far between cleaning iterations.

FCM are a type of symbolic methodology, which can increase the effectiveness, autonomy and intelligence of systems. Since this symbolic method on modeling and controlling a system is easily adaptable and relies on human expert experience and knowledge, it can in a sense be considered intelligent.

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