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# Non-Deterministic Finite State Automata as Termites Swarm Agent Model

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**Abstract.** Termites lives underground, they are relatively simple beings with their small size and small number of neurons, they are incapable of dealing with complex tasks as a group, therefore their build a mound as a gas exchange system to circulated air inside the nest. Inspired by perturbation caused by nest cavity that implies gas exchange inside termites mound, we proposed Non-Deterministic Finite State Automata (FSA) based on Moore's machine principles to describes termites natural cognitive mechanism arises among individual termites. This Natural Cognitive mechanism become the foundation of termites swarm agent rules. The aims to creating the model are helping beginner researchers or student to understands about termites behavior in case of building multiagent system based on termites swarm behavior if they are have limitations in translating a mathematical equation into real application in swarm robotics, multiagent simulation, etc. This paper is introduction paper for further development in termites FSA so our focus are explaining and elaborate theoretical foundation in order to describe cognition process in each individual agent.

**Keywords:** Termite swarm, cognitive mechanism, finite state automata, Multiagent model

## 1. Introduction

Termites are relatively simple beings. With their small size and a small number of neurons, they are incapable of dealing with complex tasks individually. The termite colony, on the other hand, is often seen as an intelligent entity for its great level of self-organization and the complexity of tasks it performs [termites hill]. For example, a termite is capable of determining if another termite is a member of its own colony by the "smell" of its body. One of the most important of such chemical agents is the pheromone. Pheromones are molecules released from glands on the termite's body. Once deposited on the ground they start to evaporate, releasing molecules of that chemical agent into the air. Individual termites leave a trail of such scent, which stimulates other termites to follow that trail, dropping pheromones while doing so [7]. This use of the environment as a medium for indirect communication is called stigmergy [2, 9].

Stigmergy in colony level is an implication of cognitive mechanism inside individual termite. Cognition roles as an intermediate process between behavior and the environment that cause the changes directly on termite behavior and indirectly participating the environmental changes [12]. Cognition arises as an internal state of individual that influence by an event in the environment and the output become responsive behavior with intent to adapt from environmental changes, behavior will change the environment direct or indirect and the environment provides the conditions under which agents exist and it mediates both the interaction among agents and their access to resources [10].

Many swarm intelligence researcher used the mathematical approach in order to describe the behavior of insects such as ant, bee, termites etc. This approach is very practical to create many optimization algorithms based on that inspiration. This paper the main focus are explaining and elaborate finite state machine in order

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to describe cognition process in each individual agent and it is also focused on an individual cognitive mechanism in case of nest breach.

Finite State Automata, in short FSAs, are formalisms that have been used for decades to describe the behavior of systems, an intelligent entity can use an FSA to represent its belief about the behavior of the world that surrounds it [8]. I prefer using Non-deterministic finite state automata basic on Moore's machine as the main model rather than a conventional mathematical approach in order to create the cognitive architecture roles at an individual level. The difficulty to use a formal language to represent reasonings in a computational environment has discouraged most beginner researchers from exploring this trend [8]. If the model is accurate, we hope the model can help beginner researchers or student to understands about termites behavior in case of building multiagent system based on termites swarm behavior if they have limitations in translating a mathematical equation into a real model.

## 2. Theoretical Foundation

### 2.1. Termites Swarm Colony

Termites live underground, therefore, they're building a mound as a gas exchange system to circulated air inside the nest [14]. The nest is an environment that plays important roles in protecting the queen and termites worker from the outside [12]. In the case of perturbation caused by nest cavity in a termite mound, it can dramatically change the environment and it is also very harmful to the colony.

There is some factor that changes the environment condition in case of mound breach, first, changes in wind direction, intensity, humidity, temperature etc., in both various quality and quantity [12], all of this factor will be accepted by termite through the cognition process inside termites individual so each individual will react differently. This trigger will change the "internal state" within individual, if a termites do an action based on their perspective then the external state will change to termite behavior state, laying down pheromone on the environment is one of the examples of termites behavior states and as a consequence it will change the environment and collaboration process among the colony member. Distributive cognition emergence [13] if there is an internal states sharing among individual that can influence the effectiveness of collaboration process among them (social level), The phase is run in the competitive way where every individual compete to become the major influence in unpredictable circumstances [12].

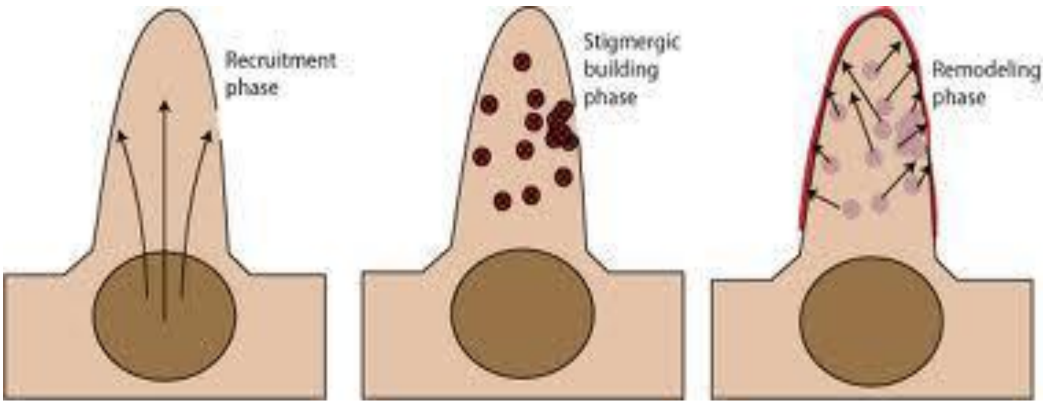


Fig. 1: Termites mechanism to handle nest cavities [12].

Fig. 1 describe that termites response to the perturbation by approaching the source, some termites directly take an action on the perturbation meanwhile at the same time they also lay the pheromone in the environment as a "clue" about the actual situation. The other termites are not taken an action directly but they take response based on the recruiter pheromone, to recognize the condition or decides to lay down pheromone to attract other termites are acquiring cognitive ability within individuals this is part of the recruitment phase. Recruitment phase involving cognitive ability within the individual to make interpretation and decide further action in uncertain condition [12] The first modality is tactile inputs that arise through physical contact between termites, or between termites and physical objects in the environment. These can include the self-constructed environment of the mound.

Stigmergic building phase is essential phase that triggercollaboration between individuals [9, 11] When the termite decide to do any action, they laying their pheromone along the path to attract other termites and as a guidance toward the nest cavities, this process mediated by the environment to provide indirect communication between individual and this is imperative phase to emerge collaboration in social work level [9].

It is essential to describe clearly about how an agent behaves in order to adapt its environment, this behavior is fundamental to creating self-organizing agent [4]. Self-organization is a dynamic and adaptive process where components of a system acquire and maintain information about their environment and neighbors without external control [5]. In the multiagent system, Self-organization is also played an important role in the formation of emerging situation. This phenomena become interesting in perspective of a multiagent system where self-organization among individual agent possible to create complex structure in collaboration process among individual as a single group [7] by mean, in this paper individual termites are modeled as an agent. Using Finite State Automata (FSA) we try to describe briefly, about micro-macro process based on natural termites behavior, FSA is not a physical machine but a mathematical model of a system that receives discrete input and output [8].

Definition 1: A finite state automata M is a tuple (S, F, Q, T, ), where Q is the set of states of M, S is the set of input actions of M, F is the set of output actions of M, sin ϵ S is the initial state of M, and Σ ⊆ S x I x O x S is the set of transitions of M. [8] Where :

S = Start / Initial Position States,

F = Finish states /output,

Q = States, Σ = Transition,

ɣ = Transition function

The basic concepts of automata is constructed using Moore machine. In more machine, it is possible to produce more than one output F and the transition function applies as input or output to the next state [1]. The main focus in this paper are explaining and elaborate finite state machine in order to describe the cognitive process in each individual agent in case of nest breach.

## 3. Discussion

Before In this section, I proposed three different finite state machine in term of agent-based termites behavior, the differences between each finite automata are based on termites initial position when the perturbation occur. There are three different initial positions, imminent, moderate, and far initial position. The mathematical approach of initial positions is based on Lenin equation (2014) [6]:

$$\vec{x}_i(0) = Init\ (i, s)\ 1 \leq i \leq N$$

where Init(i, s) is the initialization function which link arbitrary position to the termite *i* in exploration spase *s*

The reason why using different initial position because in real world, termites are scattered around the nest from the center of the nest to the top of the mounds. Different initial position means received the different intensity of stimulation. Based on Turner (2010) when the breach happened on the mound, there are some changes in nest situations, for examples changes in air pressure, humidity, wind direction, temperature. When the changes raise rapidly, it caused some implications on the nest situation and raises the reaction of each member of the colony of termites.

Fig. 2, we describe changes that occur on the condition that termite agents are at far distances from the source of disturbance on the mound. In this phase, the first condition is a change with the emergence of random movements caused by rapid environmental change. It is characterized by the random movement to give each other sign by pheromones, but not all termites move actively, some termites patiently waiting for the pheromones pattern formed from the movement of other termites and then take an action based on the instructions from the highest intensity of pheromone. This phase can be considered as the recruitment phase.

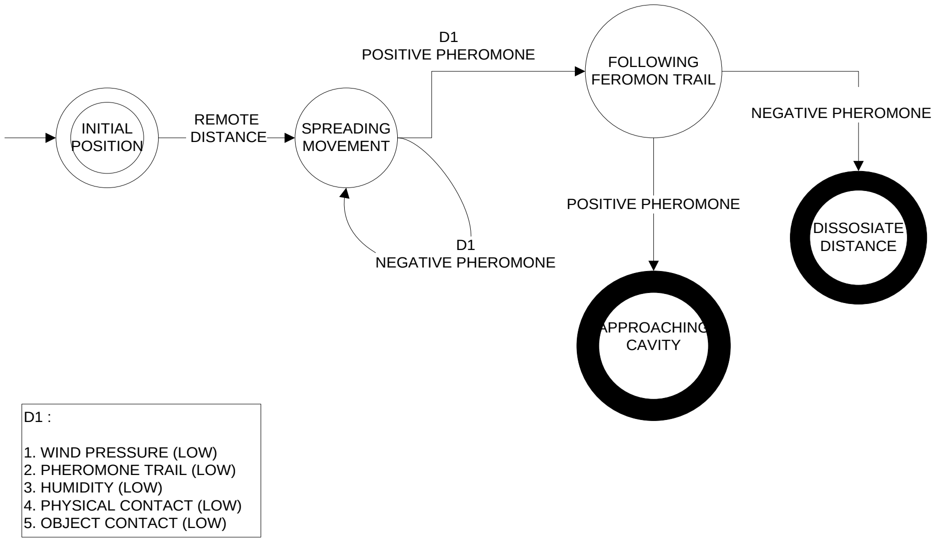


Fig. 2: FSA termites agent in far distance initial position.

where :

S : {Initial_position}
F : {Dissosiate_distance, approaching_cavity}
Q : {initial_position, spreading_movement, following_pheromone_trail, approaching_cavity, dissociate_distance}
Σ : {remote_distance, positive_pheromone, negative_pheromone, D1}

I assume that pheromones have implications in a movement of the entire colony, the result of a movement that directs the colony members to approach the source of interference (solution) is positive while the pheromone trail pheromones which do not provide a solution I called negative pheromones. The mathematical approach of calculating pheromone level at the current position is based on Lenin (2014) equation [6]:

$$\tau_i(t) = (1-\rho)\tau_i(t-1) + 1/(fit(x_i)+1)$$

where ρ is an evaporation rate of pheromone and τ(t) as a pheromone level at current and earlier position of i termites in a phase in which the movement starts from the furthest part of the mound, It has not produced a solution in case of improvement of the nest damaged because termites that far away do not know the exact location of the nest destruction. Termites with one or more visited position in their neighborhood may select a more profitable position and move toward that position [6]).

Using the Equation 1, the next position choose by termite is to represent by Rw (Random walk) function that depends on current position and radius of search τ. The Bigger value of τ enabling termites to travel along the wider region but as a result, the movement is less accurate than the small value of τ. This phase is reaching a positive solution when there is a movement between colony members approach the source of damage to the mounds.

In Fig. 3, we can see the same concept also applies to termites that are at medium range distances from the center of distractions, but the movement intensity of termites became more intensive and more easily to find the pattern of movement towards the source of the interference. in this phase, random movements are influenced by the activity of pheromones, negative pheromone creating a path away from sources of interference while positive pheromones create new patterns in strengthening the invention that the process of recruitment solutions.

In this process, there are a few termites that directly move towards the source of interference emitted pheromones as he continued along these lines these termites are not recruited by other termites through pheromones but actually they indirectly recruit other termites by pheromone trail left by that termites.

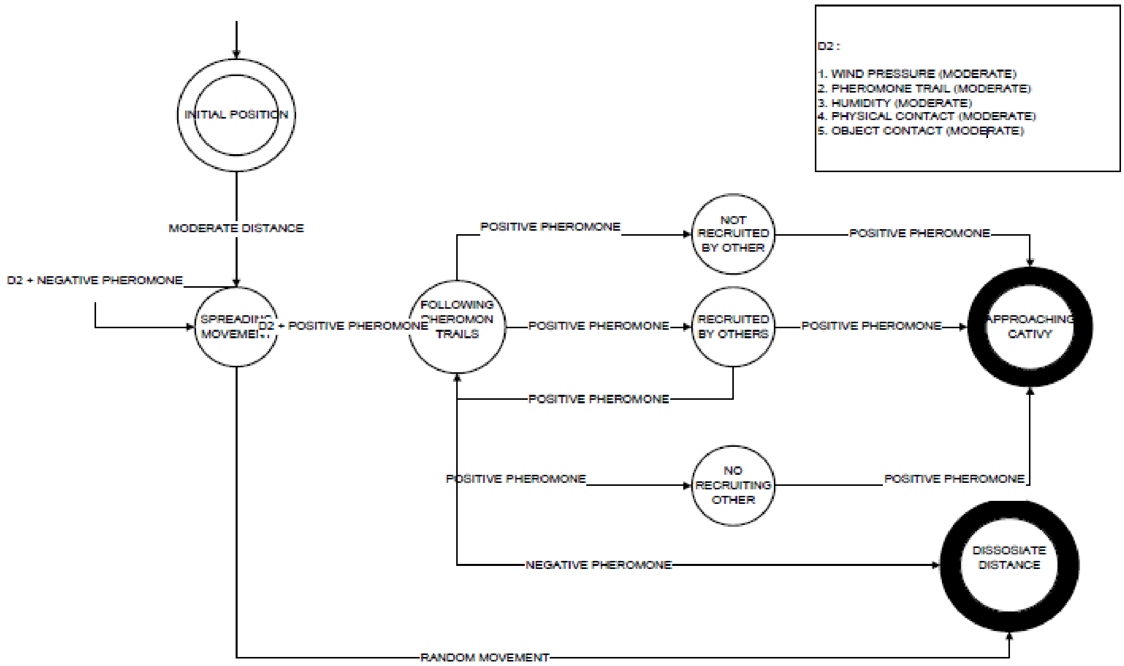


Fig. 3: FSA Termites agent in medium range distance.

S : {Initial_position}
F : {Dissosiate_distance, approaching_cavity}
Q: {initial_position, spreading_movement, not_recruited_by_other, recruited_by_other, no_recruiting_other, approaching_cavity, Dissosiate_distance }
Σ : {moderate_distance, positive_pheromone, negative_pheromone, random_movement, D2

In addition to the trail pheromones, D2 in Fig. 3 play important roles gaining solution, in this case, other stimulation also involved strengthening solutions such air pressure, humidity, physical contact between members of termites as well as contact with the object. The object in question is a granular soil that is useful to cover the holes in the mounds but at a distance being, contact with objects too small to be a solution to cover the holes with precision because termites intentionally put the object it not too far away from termites take the object. Many distractions around termite stimulation that are likely caused termite misplaced in case putting the object in the correct place. Medium-range impact on the intensity of stimulation received by individual termites. the farther the distance locations within the nest against disruption in the mound then the less the intensity of stimulation at that location. In the case of medium initial position, the positive solution achieved where a joint movement patterns emergence to the center of distraction.

The principle of distance – stimulation also apply in all near position, in Fig. 4 we can see all stimulation are in high intensity, this logically happen because when the termites is closer to the center of interference then it will receive the higher outside world feels that impact on the environment, it come from outside into the nest through the hole located on the mound. In Fig. 4 at initial position, we can see there is a lot of pheromone diffusion because this position is the final destination that termites must reach in order to fix the mound. This is highly competitive pheromone influence that only the best position or path with the highest intensity can impact to the final solution. the final solution itself is closing the hole on the mound with the shortest possible time and with minimal resources in terms of effectiveness of work.

In near position, individual termites will receive intensive stimulation (D3) but also the large intensity of pheromone as a guide to emerging optimal working pattern. Large intensity of wind pressure and humidity potentially accelerates pheromone evaporation so it can be a constraint in order to get the effectiveness of work, to keep the process, the pheromone intensity must be greater than the rate of evaporation (ideal position). In Fig. 4, we can see that termites will use all information received from the environment of the environment as a guide in conducting a reaction to the existing problems.

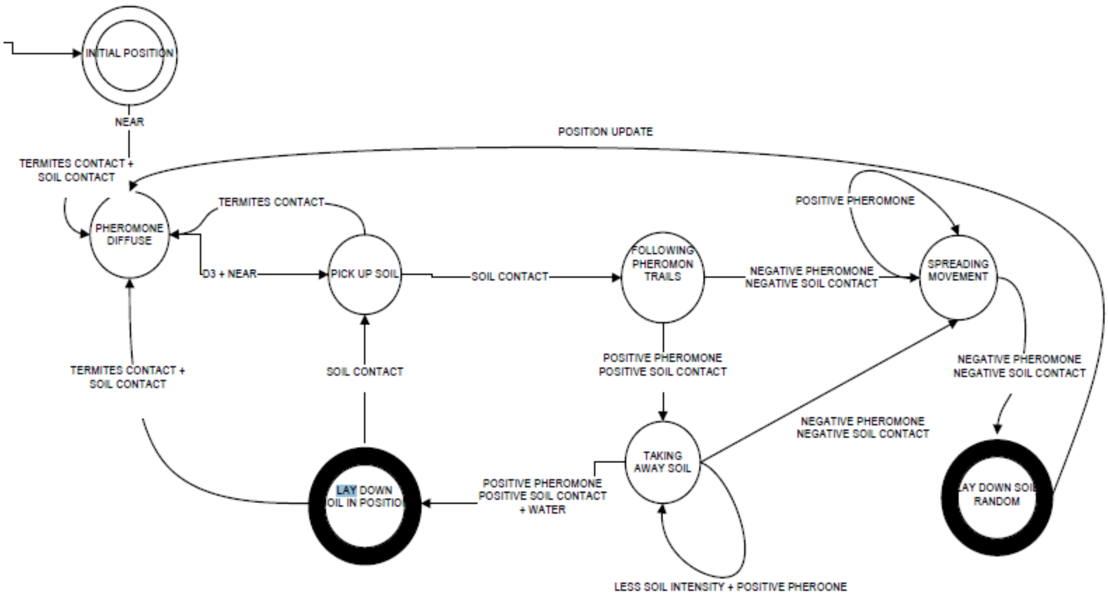


Fig. 4. FSA in near distance from the Perturbation.

While following the pheromone and comes in contact with soil or granular sludge which has been marked by other termites, the termite will necessarily take a grain of the soil, then follow the trail of pheromones, if termites inadvertently discovered the negative pheromone, the possibility of termites contribute to the solution could be small and likely they would put the soil in a random position, whereas if inadvertently following the positive pheromone then it is likely potential to achieve the expected solution, which is meant termites carrying soil to be put in the right place. The final goal or a solution of this phase is to close the hole as soon as possible

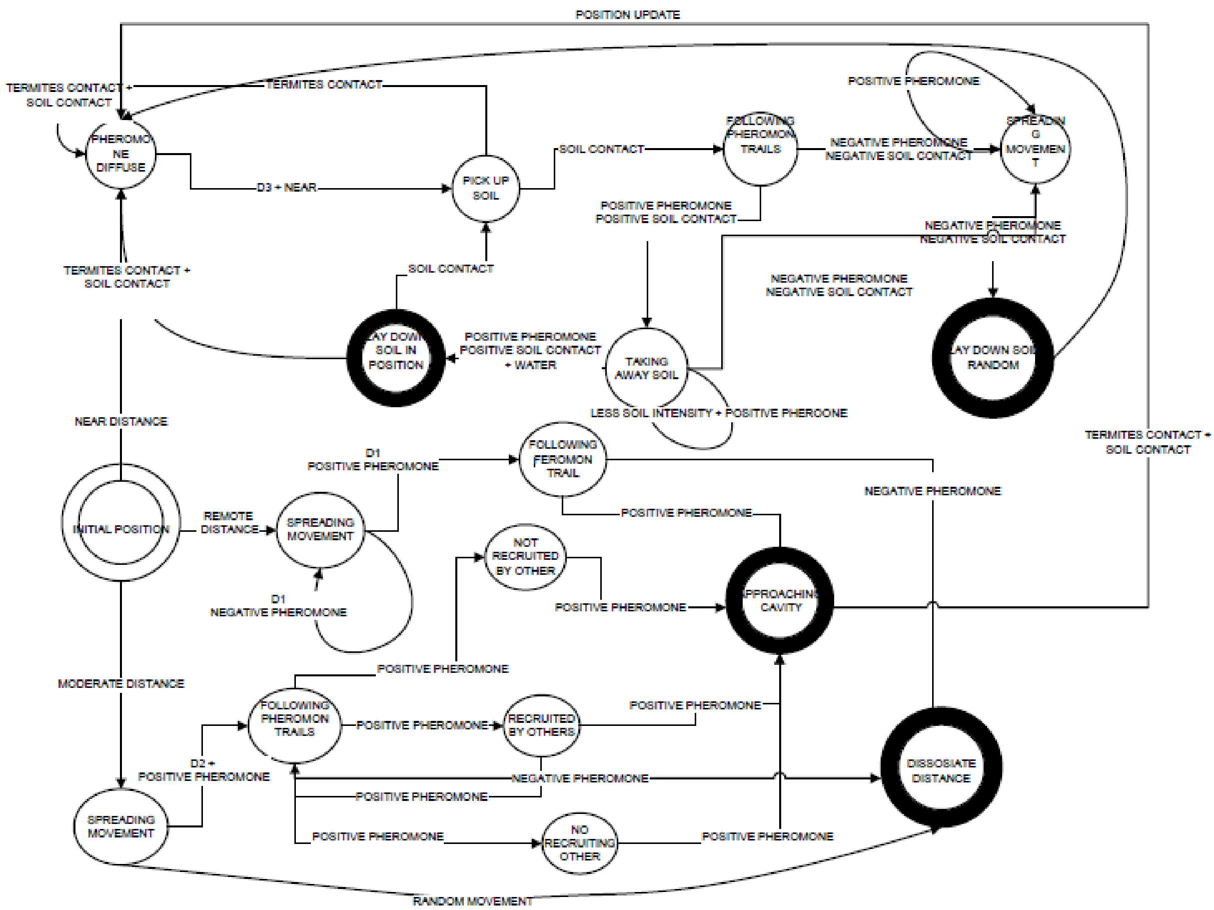


Fig. 5. Aggregation of FSA.

In this section, all three finite state machine are merge into a single finite state machine. I used concatenation technique to merge these machine. This merging process is intended to represent three different behavior by individual termites agent when perturbation happened. All individual termites will act based on its initial position (remote, moderate, and near position). By using the combined technique (union) three engines are combined. The combined automata machine is the representation of the overall individual behavior of termites.

Fig. 5 **Describe that** all termites start randomly in an environment that we called INITIAL_POSITION or start state from the machine. As a finish states, there is four state (represent by bold state circle). When individual termites reached one of the finished states, it doesn't mean all process has stopped, all process are run iteratively that means when each termite agent reach one of the finish internal states they probably have the option to move to the other state which is connected to the current internal state. It is possible because termites are acted as an agent so they autonomously choose the next state or decide to stop in the current internal state as they act Nondeterministic.

## 4. Conclusion

As I mentioned above, it is important to understand how termite agent behaves as an individual. One of a method that able to facilitate the understanding of termite agent is a finite state machine, using this approach, agent designer and engineer can directly view the internal status changes that occur when the agent receives a stimulus or react to the changes of surrounding environment. For beginners researcher who has limitations in translating a mathematical equation about the behavior of termites, finite state automata can be one effective alternative to understanding the behavior of agents termites, so they can be more focused on the case to complete rather than trying to focus on understanding the behavior of agents termites they use. The next research will try implement automata machines that have been formed into a multiagent simulation to improve the better solution, especially in swarm robotics.

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