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# Intelligent Collaboration among Robotic Agents for Landmine Detection

Vaithilingam Kumarathasan
Department of Electrical Engineering
University of Moratuwa
Moratuwa, Colombo,Sri Lanka
vkumarathasan@yahoo.com

Thrishantha Nanayakkara
Department of Electrical Engineering
University of Moratuwa
Moratuwa, Colombo,Sri Lanka
thrish@elect.mrt.ac.lk

## Abstract

*This study is to develop an algorithm for multi-robot collaboration for landmine search operation in a typical landmine field found in Sri Lanka. The challenge is to enable robots to work together in an intelligent manner to detect landmines as fast as possible. In Multi-Agent System (MAS) intelligent is considered as some thing emerges through interaction and collaboration among different agents in a swarm. Collaboration among robots is based on a decentralized approach in which robots are based on a set of behaviors; such behaviors are designed to increase global performance and are based in local information and shared information from other team members whenever they are in range of communication. Landmine search method is improved using the prior knowledge about landmine field. Simulation was done to test effectiveness of the algorithm.*

## 1. Introduction

Landmines remain as a significant barrier to economic and social development for more than sixty countries including Sri Lanka. Once a conflict comes to an end, the areas where landmines have been laid have to be cleared for human re-settlement. Demining is an operation accompanied with a lot of risk to human deminers because a slight mistake can cause death. Manual demining is boring and repetitive. Analysis of these actions shows that some of them could be more easily and safely performed by robotic systems. From this perspective these robotic systems appear to have an important role to play in finding and removing millions of landmines from around the world.

In this context, robot colonies have some obvious advantages over single robot search operations. Several coordinated robots can be much more efficient and effective than a single robot, since coverage of a large area can be done in parallel [4], [8] .The use of multiple, inexpensive robots minimize the damage due to unexpected exploding mines [7]. Furthermore, a team of robots provides robustness through eliminating single points of failure that may be present in a single robot or centralized systems. Obviously, the solution for the problem requires both the construction of autonomous and reliable machines that can operate in rough terrain, with a good accuracy and capability of mine detection.

The goal is to develop coordination strategy for robotic colony to search and to detect whole landmines in the field and to update the map in a minimum amount of time. Search techniques have been developed to improve detection process by using available information about landmine field. Information sharing among robotic agents is motivated to improve performance. Furthermore, the robots have to construct a global map in order to coordinate their action. Our approach uses occupancy grid maps to represent the field and assumes the field as a plane. The width of grid is determined based on the robot's footprint or the range of a metal detector. The only assumption we make is that the robots know their position and heading with respect to a global coordinate frame during the search process.

The rest of the paper is arranged as follows. In Section II we discussed previous work in the area of multirobot coordination and search techniques. Section III methodology to the problem and describes our search algorithm. Section IV outlines the simulation results. In section V we present our conclusions.

## 2. Related Work

Whereas the search problem has been studied in detail for single robots, there are only a few approaches for robot colony. Balch and Arkin [2] investigated communication's impact on the performance of multirobot team. The studies indicated that robots could cooperate in *grazing* (i.e. coverage) even in the absence of explicit communication. The robots leave physical evidence of their passage through the environment. This is inspired by biological system (e.g. ants). These types of communication are referred to as implicit since they do not require physical transmission system. In many cases physical marking the environment is impossible or undesirable and searching for the physical evidence decreases exploration efficiency.

Latimer et. al. [4] proposed an approach which can provably cover an entire area with minimal repeated coverage, require a high degree of coordination between the robots. The robots start together and traverse the space in a formation covering the first cell of the decomposition. If a robot in the team encounters a critical point, the team divides to cover separate cells and can opportunistically rejoin at some later point. Their approach is only semi-distributed, and fails if a single team member can not complete its part of the task. We are considering the optimum search method for landmines not the complete coverage of whole area as it is time consuming operation.

Simmons et. al. [5] proposed a multi robot approach which uses a frontier based search and a simple biding method. The robots submit bids for frontier cell based on expected travel cost and information gain of the cells. A central agent with central map assigns one task to each robots based on their bids. The significant drawback of this method is that the system relies on communication with a central agent and therefore the entire system will fail if the central agent fails. It is not robust to single point failure.

In the approach of Yamauchi [3] the robot the robots moves to the closest frontier which is the closest unknown area around the robot according to current map. This approach is completely distributed and tolerance to single point failure. However, there is no coordination component for choose different frontiers for the individual robots and thus can not achieve full advantage of the number of robots available.

There are only a few multirobot coordination approaches for landmine search problem. Most of them have proposed methods for complete coverage and others have proposed probabilistic demining but they attempted find mine distribution in the field by determining the landmine laid pattern parameters. It is computationally intensive method and mine dislocation due to environmental effect results in less effective.

## 3. Methodology

Coordination among robot is the activity by which common goal is to be achieved by team by distributing task among the team members. So task creation and task allocation among the team members are main functions in multirobot coordination. In landmine detection operation, task is the area to be covered by a robot in landmine field. Task is created such a way that increases chances of finding landmines in its path. Information about mine field and communication among team members improve the performance of team in mine detection operation.

Basically, the two possible ways of coordinating the robot team are centralized planning, where single robot plan for entire group based on state information gathered from the team, and distributed planning, where each robot is responsible for its own planning [1] [6]. The principle advantage of such centralized approach is optimal planning. However, they suffer from several disadvantages including slow response to dynamic conditions, communication difficulties, and single point failure. In case of distributed approach, it is robust to single point failure but planning could be sub optimal because all plans are based on local information.

To combine the best characteristics from both approaches, we use decentralized approach, where no permanent master or central planner to control the entire team. The robot that has more information becomes master and create task and assign to other individual robots. The robots will carry out the task until new task is assigned to them by new master. New task will be assigned based on the current task or on the current position. The robots are capable to carry out the assigned task using their low level behaviors, such as obstacle avoidance, move on straight-line, land mine detection etc. As execution of task is based on local information, failure in communication will not affect the execution of task.

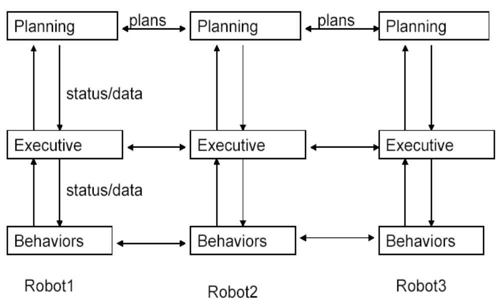


**Fig. 1. Layered multirobot architecture**

In the implementation of multirobot search planning capability is designed as part of a distributed layered architecture for multirobot coordination [1]. This architecture is an extension to the traditional three layered robot architecture (shown in Fig.1).This enable robots to interact directly with the same layer of the robots. The behavior layer coordinates behaviors, the executive layer coordinates task, and panning layer creates tasks and assigns tasks. Search techniques are used to create task optimally.

### 3.1 Use of Knowledge about Actual Landmine Field

In order to make the coordination method more effective, having knowledge about the actual minefield in Sri Lanka is very important. The information about field was gathered from officers who are working in demining when we visited these actual minefields in North of Sri Lanka.

If we know certain information about the minefield, we can expedite the demining process For example, when ground vehicles or humans place mines, they tend to follow a regular pattern. For example, the mines can be laid out using a regular pattern that has rows and columns. By simply identifying the intended inter-row and inter-column spacing, the robot can bypass fully covering the entire region by driving to the probable mine locations.

Information about mine field can also be acquired by using robots that cover a small sample of minefield, and then decodes the parameters that describe the minefield based on information acquired in the covered area. Once the parameters are determined the robot can visit each mine location and does not need to cover the entire field. Landmines are used as purely defensive weapons and laid in a specific pattern in area, such as barriers around the bunkers and along the bund which are built to safe guard the captured area from enemies. These minefields are large areas laid in a specific pattern and marked. In other case mines are laid in a random and un-marked manner to prevent access to facilities, shelters, wells and food.

### 3.2 Task Creation Using Search Techniques

The master uses search strategies to create task for individual robots. Search strategy is based on the assumption that robots search for and detect landmines in a way that maximize the landmine detected $N$ per unit time $T$ spent .Hence they try to maximize a function like

$$\frac{N}{T}$$

So task should be created for individual robots such a way that increases the possibility of finding landmine in consequence of the task execution. Information sharing among team members and having knowledge about landmine field will play important role in effective task creation. We have developed three search methods based on available knowledge about landmine field.

### 3.3. Self Organizing Behavior (SOB)

In Multi-Agent System (MAS) intelligent is considered as some thing emerges through interaction and collaboration among different agents in a swarm. MAS needs techniques for implementing tasks such as communication, negotiation, collaboration and sharing knowledge. Some animal societies and particularly social insects can achieve complex tasks that are impossible to complete individually. When many intelligent agents interact, the resultant behavior is more powerful than the sum of individual behaviors produced without interaction. Self Organizing Behavio*r* is a technique inspired by biological societies. Some animal societies such as colonies of ants and bees, flocks of birds, schools of fish, can be an inspiring model for a self-organizing robotic system. A self-organizing system is a system that changes its basic structure as a function of its experience and environment.

Main advantage of SOB is that simplicity (and homogeneity) of individual agents on a robotic colony decreases the cost of production and the likelihood of the breakdown.

Here we assume that landmines are gathered together in the mine field. This situation is very likely to occur in real minefields. Robot that finds landmine, create artificial potential field around its position in Gaussians pattern in order to organize the other robots to mine area. According to the potential field other robots will change their path by changing the heading. Heading change is proportional to Gaussians function of distance between the robots. Head change *HC* is determined as in Equation (1).If the distance between the robots is less than 1 meter HC is zero. New task will not be assigned for robots, which are with in 1 meter circle around the leader. This is to avoid interference between robots and assigning the same task for more than one robot.

HC Heading chance
D Distance between robots
θ Total Heading change to move towards R1

$$HC = \theta \times \exp\left(\frac{-D^2}{2\sigma^2}\right) \qquad \text{For } D > 1\text{m} \qquad (1)$$

$$HC = 0 \qquad \text{For } D < 1\text{m} \qquad (2)$$

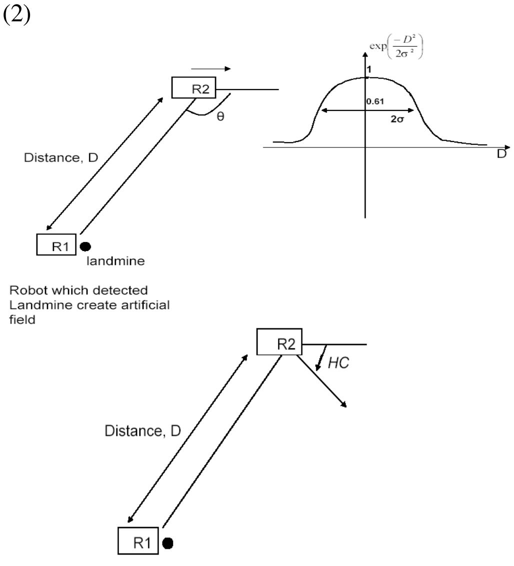


**Fig. 2 Robot R1 found landmine it create artificial field such that the robot R2 should change its heading by *HC*. This is the task assigned to Robot R2.**

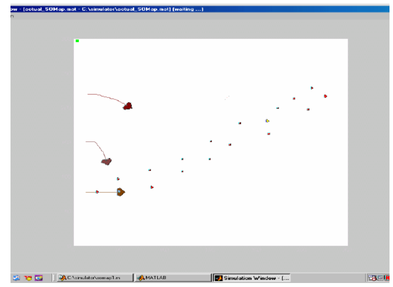

**Fig. 3. Three robots are organised towards mine area by SOB.**

## 3.4. With Some Knowledge about Landmine Field

In some cases we can have some useful information about landmine field such as mine laid pattern in the field. Even the pattern is known robots do not know the orientation of mine pattern in field where robots are going to search for mines. So robots collaborate themselves by sharing information they get. Initially as they do not know the about orientation of landmine laid pattern in the square area where they are going to search for mines, they search with local information and communicate the information they gather. i.e. location of mines which are detected by them

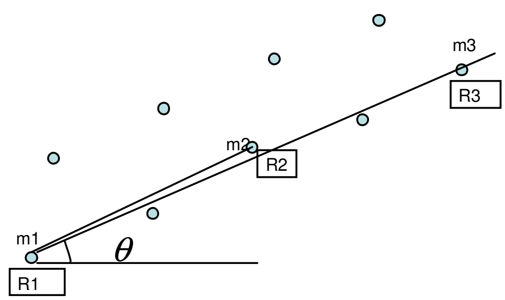


**Fig.4. Case 1: All three robots have found mines from lower layer of pattern.**

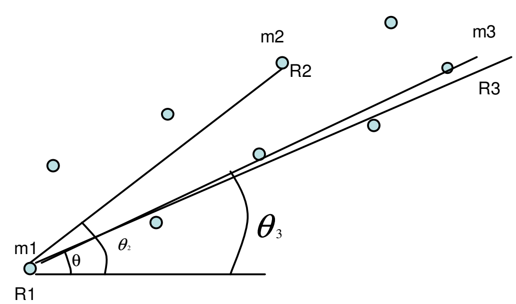


**Fig. 5. Case 2: Robot R1 has found mines from lower layer of pattern and R2 in upper layer and R3 in lower layer.**

After finding some mines, orientation of mine pattern in the field can be determined approximately. Once the orientation is known robots are assigned different areas those are to be covered. The robots will select parallel path corresponding to orientation (fig.8). The method used to find the orientation is discussed below.

### 3.4.1 Determination of Orientation of Landmine laid pattern

Here three samples of detected landmine locations are used to determine the orientation .R1, R2, and R3 are robots and m1, m2, and m3 are landmines detected by R1, R2, and R3 respectively. $\theta$ is mine pattern orientation angle to be determined .

In case 1(Fig.4),

Orientation $\tan\theta$ = tangent of m1m2

= tangent of m1m3

= tangent of m2m3

In case 2 (Fig.5), Orientation $\tan\theta$ = tangent of m1m3

In case 3(Fig.6), Orientation $\tan\theta$ = tangent of m2m3

In case 4(Fig.7), Orientation $\tan\theta$ = tangent of m1m2

In all cases, Orientation $\tan\theta$ is equal to a tangent which is lower than any other tangent of line connecting any two locations of landmine detected. So it is clear that after finding there mines orientation of mine pattern becomes known to system.

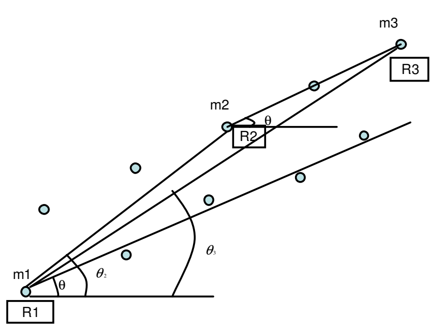


**Fig. 6. Case 3: Robot R1 has found mines from lower layer of pattern and R2 and R3 in upper lower layer**

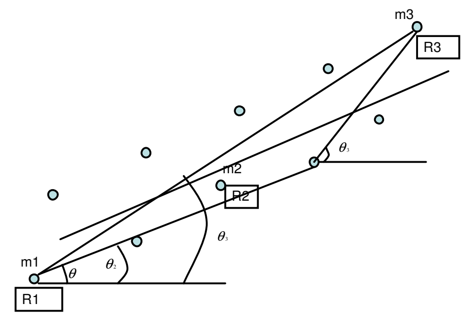


**Fig. 7. Case 4: Robot R1 has found mines from lower layer of pattern and R2 in lower layer and R3 in upper layer.**

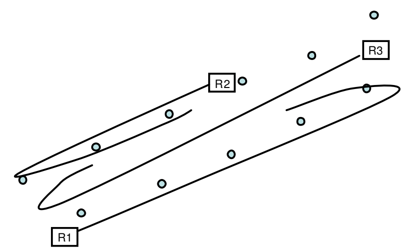


**Fig. 8. Search path of three robots after determining orientation of mine pattern. The robots select paths parallel to mine pattern orientation.**

## 3.5 With Perfect Knowledge about Landmine Field

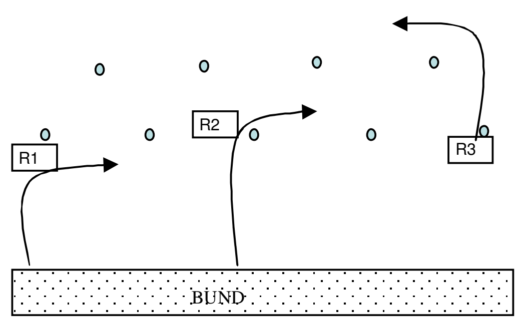


**Fig.9. Search path of three robots after a robot has found a mine**

In some cases we can have some useful information about landmine field such as mine laid pattern and orientation in the field. If there is a bund there are more chances for being mines in some distance from bund. These mines are laid in parallel to the bund. So initially robots move in a path perpendicular to bund. Once a robot finds a mine, other robots are assigned different tasks by it. Tasks are three areas which are parallel to bund. The robots will search in the path parallel to bund as shown in Fig. 9 Robot R3 has found a mine and assigned the task to other robots (R1 & R2).

## 4. Simulation Results

Simulation was done in a multirobot simulator. The robots can sense their location in the field; detect obstacles, mines and other robots, and communicate with other robots. Simulation environment can be created with obstacles and landmines located in different place as we need.10m X 10m landmine field was represented as 300 X 300 pixel field in the simulation with different arrangement of landmines (around 20 mines) in the field in order to test the different search methods. All simulations were done with three robots. Simulation results for search methods are given below. In order to make comparisons among different strategies possible, a performance metric had to be established. For this research, the time needed to complete the task was chosen as the primary performance index.

In the perfect knowledge scenario, knowledge about mine field and information gathered with in 100 steps (time) has increased numbers of mines detected in following steps as shown in Fig. 10. Perfect knowledge method has completed the task in 600 steps where as complete coverage method took 2000 steps (Fig. 11).

In the some knowledge scenario, knowledge about mine field and information gathered with in 500 steps (time) has increased numbers of mines detected in following steps as shown in Fig. 12. Some knowledge method has completed the search process in about 1000 steps where as complete coverage method took around 2500 steps.

For no knowledge scenario we tested the SOB with different σ (2m, 2.5m, 3.5, and 4m) and different separations(2m 2.5m ,3.5m,and 4m) between the robots. For separation of 2m, 2.5m, and 3.5m simulation did not yield consistency results. In some cases where mines are distributed in one side of field area, there are less chances to find mines as they initially do not cover all area of field. So we selected 4m as optimum separation.

Fig.14 and Fig.15 show the result of SOB for separation of 4m between robots with different σ. Results shows that smaller σ improves the performance. It is because difference of heading change (Equation 1) for two different distances (D) is larger for smaller σ than larger σ. i.e. SOB with σ of 2m will assign different task than SOB with σ of 4m.

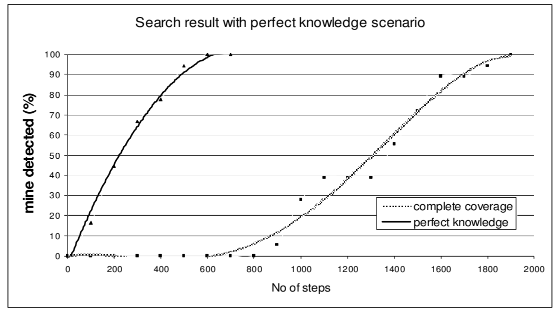


**Fig.11. Total detected mines (%) over simulation steps for perfect knowledge scenario**

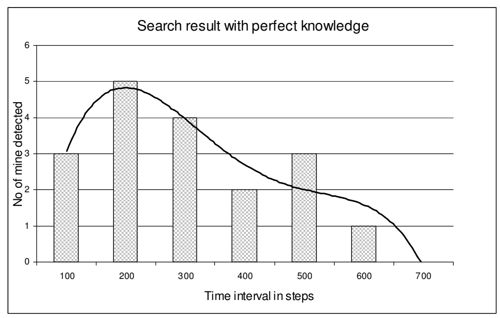


**Fig. 10. Detected mine distribution over simulation steps for perfect knowledge scenario.**

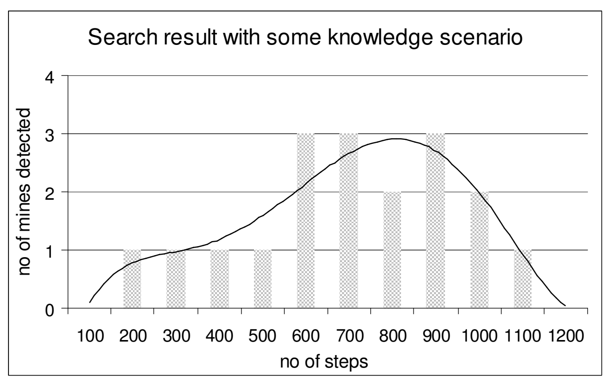


**Fig. 12. Detected mine distribution over simulation steps for some knowledge scenario.**

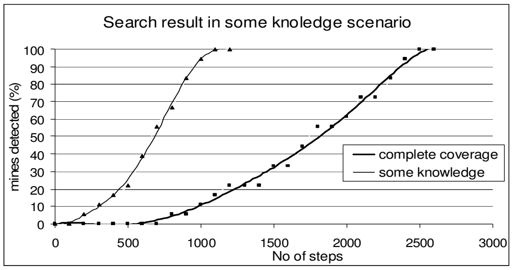


**Fig. 13 Total detected mines (%) over simulation steps for some knowledge scenario**

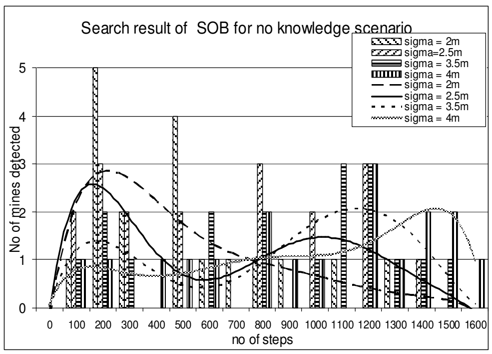


**Fig. 14 Detected mine distribution over simulation steps for no knowledge scenario**.

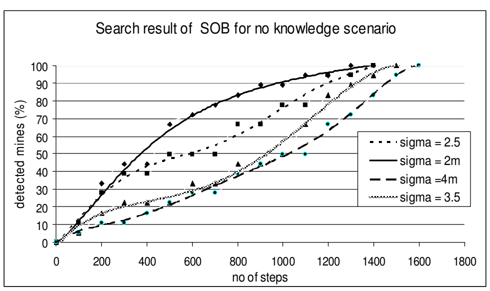


**Fig. 15 Total detected mines (%) over simulation steps for no knowledge**

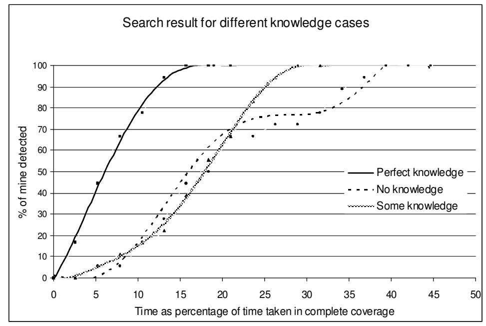


**Fig. 16 Total detected mines (%) over simulation steps**

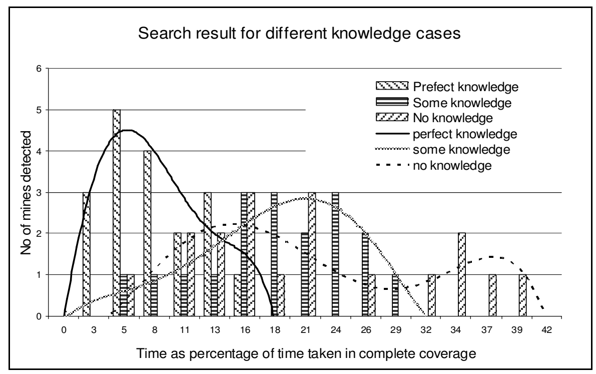


**Fig. 17 Detected mine distribution over simulation steps for different scenarios**.

Fig.16 and Fig.17 show that perfect knowledge method is 6 times (100/15) faster than complete coverage and some knowledge 3 times(100/32) faster and SOB 2.5 times(100/42) faster than complete coverage method.

## 5. Conclusions

Landmine clearance is an important problem where robotic system can bring efficiency and safety to the process. In general, priori information about a landmine field is either not available or it is very limited. In this paper we have proposed a decentralized approach for search of landmine in the field by using available information about the field and information gathered during search process. In this method time taken to detect landmine completely decrease with available information about the field. For demining scenarios where time is limited, this approach will yield optimum results.

Future work will be the implementation of this algorithm in real robotic team.

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