Cooperative Multi-Agent Approach to Dynamic Coverage in Multi-Robot Activities

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Abstract. Dynamic coverage is a problem of multi-robot systems based on wireless ad-hoc networks. The issue of dynamic coverage occurs notably in post-disaster survivor rescue, search operation, and planet exploration. In this paper, we introduce an novel algorithm of dynamic coverage in a realistically restricted environment for robots.

1 Introduction

We address the problem of deploying a mobile sensor network into an environment with the task of maximizing sensor coverage of the environment. We restrict ourselves to the case where every node in the network is a mobile robot. All the robots can calculate their own the position by dead reckoning and/or GPS (Global Positioning System). All the robots have wireless communication facilities. Our proposal claims that the robots make the field search as robustly and efficiently as they can in the range which they do not miss each other. Our system is mainly made based on two approaches, Multi-Agent-System and Dynamic and Distributed Voronoi Diagram. .The first one is the Multi-Agent-System approach.

2 Related Works

Exploration and map building by multi robots in an unknown environments has benn studied[1]. Although [1] is efficient, the devices of beacon are needed for others with the robot which searches. And Voronoi Diagram is the algorithm often used in a sensor coverage problem, and hos been studied by several authors[2,3].

3 Definition of Coverage Problem Solution

In this section we present a formal description of the planar boundary coverage problem and provide high efficient solution of the problem compared with the existing research. We then provide a solution based on Voronoi Overlay, with complexity (n log n), assuming that all the robots in the network have the sensing range which is defined for every robot and knows its own range with each robot. We also make the assumption that each device knows its two dimensional location. This is a reasonable assumption since in the absence of this information, the boundary of coverage cannot be uniquely

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determined (i.e., from topological information alone). Moreover, the technology of the position acquisition system which does not need a global system is realizable. We now formally describe the coverage of a device. And parameters which used in this paper are defined below. We use the notation dist (p1; p2) to denote the Euclidean distance between two points p1 and p2.

3.1 Definition

Definition 1 *The communication range of a robot agent RA with planar coordinates (x ,y) and sensing range R (which is graphically explained in Figure* **??***) is a disk with center (x, y)and radius R. R is the greatest range with which each robot can communicate. A robot determines the division which he should patrol within the limits of this area. Moreover, in order that he may not separate with other robots completely, the guarantee other robots are within the limits of this periodically is required.*

Definition 2 *The base position VP (voronoi position) of each robot agent on the field is held for every robot agent, and determines a search area by VP. That is, each robot agent collects the bases of other agents within the communication limits = R, and calculates a search area using Voronoi Diagram. Each robot changes each base by negotiation.*

Definition 3 *The search area VA (voronoi area) of each robot agent on the field is calculated by itself, and holds it. A robot searches by moving the inside of this area. Moreover, a robot holds the information on the obstacle of the range which searched once. Each robot determines this area using Voronoi Diagram from VP of each robot of his communication within the limits.*

Definition 4 *Each agent has the obstacle information OI, and this information is updated as it develops the field. By using this information, each agent calculates ignore area ID dynamically so that its area in its duty may not be divided. That is, in this agent's ID, other agents calculate VA as if this agent did not exist. An agent can determine ID for every renewal of obstacle information without other agents information. With our algorithm, only from other agents' VP and ID, each agent can predict other agents' VA and can determine his VA. Since each agent does not need to re-calculate VP and ID for every request from other agents, he can hold down the amount of communications to minimum.*

Definition 5 *VP changes with negotiations between each agent. A robot moves similarly to change of VP until each robot agent's VA is decided. That is, VP cannot change by the width of the velocity VEL more than a robot's top velocity. Therefore, the highest of the VEL of VP is restricted by MAXVEL (max velocity).And we define the move vector of VP in one step as VVECTOR.*

Definition 6 *An EVALUATION VALUE is used in the case of VVECTOR determination. Since each agent calculates VVECTOR based on the EVALUATION VALUE acquired from other agents, an EVALUATION VALUE can interfere in other agents' action. In other words, negotiation is performed through an EVALUATION VALUE.*

Definition 7 *The Dynamic Coverage Problem Given a set of n robots in the plane, each with a sensing range r, patrol a plane with a random obstacle and acquire the state of the plane on real time. Figure* **??** *expresses figure-description of Coverage Problem. And take notice of two points which the next raises. The first point EXPANDING TIME is time until a robot's area is spread and decided in the field to the maximum extent. The other point PATROLLING TIME is time concerning a robot patrolling VA.*

3.2 Solving the Coverage-Boundary Problem with Voonoi Overlays

We divide each robot's area in his duty (A) for the field using voronoi overlays. The time concerning a robot going round is proportional to VA. PATOROLLING TIME which described our point is equal to the largest time of all robots. That is, making VA equal as much as possible leads to improvement in PATROLLING TIME. Theoretical most efficient PATROLLING TIME can be expressed as follows.

$$PTmin = \frac{Sa - So}{Numa} \tag{1}$$

$Sa \cdots sizeoffield$
$So \cdots sizeofobstacles$
$Numa \cdots numberofagents$

Our purpose is moving VP (the greatest move width of VP is equal to MAXVEL) so that PATROLLING TIME may be brought close to PTmin as quickly as possible. And this time is just EXPANDING TIME by convergence of VP.
We developed new approach of Voronoi Overlay of dynamic and a complete distributed type. This approach has the low amount of communications, and is efficient (EXPAND TIME is small) compared with ordinary approach.

4 Architecture

The agent carried in each robot acts using a technique which is described below. Moreover, the technique is taking into consideration restrictions of a realistic robot which stated by definition, and is the general-purpose thing which can set up each parameter.

4.1 Algorithm Description

Distributed and Dynamic Voronoi Overlay. As for each agent, each calculates its VA. An agent takes only a disk of a radius R focusing on its VP into consideration in that case. VA is calculated using Voronoi Overlay from VP of other robot agents who are inside the disk. Although the agent besides a disk is disregarded here, since VA is a set of the point that the agent is the nearest, even if it does not take a far point into consideration, a bad influence does not give calculation of VA. And it becomes clear also from the result of a simulation experiment that this thinking is right. Moreover, by this, since it communicates only with other robots of communication within the limits, there is no necessity of doing the communication work of multi-hop etc., and the amount of communications can be stopped low.

The flow of VA calculation. Each agent calculates VA by the flow shown below. Simultaneously, the EVALUATION VALUE used in the case of negotiation with other agents is also calculated.

Step 1 *Obstacle Prediction*

The agent predicts the obstacle of non-searched area by using from the obstacle information and exploitation information in his communication area. And the agent determines the area which he divides.

Step 2 *Information acquisition*

The agent acquires VP and a ignore area ID from other agents within the communication limits.

Step 3 *Voronoi Overlay*

The agent divides the area calculated at step2 by Voronoi Overlay using VP and ID which were acquired at 1.

Step 4 *Calculation of EVALUATION VALUE*

An agent computes an EVALUATION VALUE using the size of VA and other agents' VP which were acquired at step3. This value is used by the negotiation explained later.

5 Expelimental Result

We performed comparison with DDVAS which we developed, the existing distributed approach (molecular algorithm), and the theoretical optimal value paying attention to EXPANDING TIME and PATROLLING TIME which are two points shown in Coverage Problem Definition. Moleculer Algorithm which is the existing research that we compare doesn't guarantee that PT becomes below fixed. So we cann't measure spec for every PT. Then, we measure PATOROLLING TIME and EXPANDING TIME of the present Moleculer Algorithm and compare with the value. And each robot's parameter was divided into two portions, the parameter to fix and the parameter to change. The fixed parameters are the things which we judged that it is realistic and it is not necessary to make it change.

The fixed parameter is created based on the actual robot which is also used in moleculer algorithm. These parameters are fixed in order to prevent comparison of performance becoming complicated, although it can change arbitrarily inside a program.

5.1 Performance Comparison of PATOROLLING TIME

We measured EXPANDING TIME for every PATOROLLING TIME using parameter of Table 1. PATROLLING TIME is equal to the time concerning a robot with the biggest area in his duty in a robot going round. We set EXPANDING TIME that is the time until PATROLLING TIME becomes below the defined value (MAXPT). MAXPT is based on the optimal value of PAOROLLING TIME and it can imagine easily that EXPANDING TIME becomes smaller as MAXPT is large. So our approach has guaranteed that PATROLLING TIME is below arbitrary values, when agents' VD is converged. The optimal value of PATROLLING TIME is equal to PTmin shown in Definition. We calculated the time which it takes when a robot moves the optimal value of EXPANDING TIME to the optimal arrangement in a straight line for every map. In 6.1 MAXPT is changed, in 6.2 the number of agents is changed and in 6.3 a time step which is the time of one cycle of agent action is changed. And the performance was compared every three maps. We use the value which averaged the result which carried out the simulation 100 times in three different maps of which sizes are 500(m) $\times$ 500(m).The first map has no obstacle,the second map has only one obstacle,and the last map has many obstacles.

Table 1. Used Parameters in Comparison of PATOROLLING TIME.

type of parameter	parameter name	used value at this section
Fixed parameter	R	100(m)
	MAXVEL	1(m/s)
	map size	500(m) $\times$ 500(m)
	Number of Robots	10(robots)
	Time Step	10(s/cycle)
Changing parameter	MAXPT	$105\% \sim 200\%$

Although the number of agents is fixed in 10 here, comparison of this change is performed.

Result shows that DDVAS shows the outstanding performance compared with molecular algorithm. However, the difference with the optimal value is large as map becomes complicated. And, as expected, EXPANDING TIME becomes small as MAXPT becomes large.

According to simulation,EXPANDING TIME is large when time step is large. Therefore, as for a time step, it is desirable to make it as small as possible.

6 Conclusions

We have presented a novel distributed solution for solving Dynamic Coverage Problem that is based on a multi-agent system. In our approach, each robot can act intellectually, without needing the server of central control. We are making each agent control a

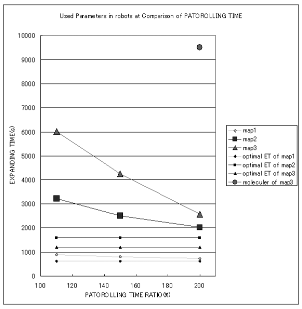

Fig. 1. Comperison of PATOROLLING TIME.

motion of each robot, and have realized performance superior to the conventional approach. Moreover, we verified that this approach was also excellent also in robustness as a multi-robot system.

7 Future Work

We introduced the distributed and dynamic approach using Voronoi Overlay for Coverage Problem of strange area. However, still, the environment which we defined is not realistic enough. As first inadequate point, the environment which we assumed is 2D. Naturally the place where a robot works is 3D. Therefore, it is necessary to bring close more nearly actually by making environment into 3D (a hill, a mountain, etc). As second inadequate point, an unreal point is that it is completely the same in each robot's performance. A robot is considered that each performance (max velocity, communication range, etc) changes according to his feature. Therefore, we should do the simulation which also took the difference of an each object into consideration. As third inadequate point, it is that many room for EXPANDING TIME to approach the optimal value is left behind.

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