Survey on Area Exploration by Multi-robots

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Abstract: **Many existing techniques are described including cellular approach, Socratic, multi hoping, insect coordination based, and multi-robot tree and graphs approaches. Immunology Distributed Autonomous Robotics Architecture (IDARA) is presented for handling of kilorobots(large multi- robot systems) described on the reactions of the human immunology. The development of the IDARA algorithm for controlling and coordinating kilo robots for exploration process is done in mapping scenarios. By creating and sharing the path of minimal-length for robot when they move through various observation points to explore the desired space. Multi robot Area Exploration of robots described by the means of frontier cells tries to spread the recent exploration and mapping methods of single to multi-robot to enhance the exploration efficiency. Each robot tries localizing itself and identifying the cell in which it is located. When based on a probabilistic model, a frontier cell is selected ,which is not already explored by other robots a new technique is developed for exploration and map building in multiple mobile robots. Several other models are also presented and compared.**

Keywords: **Exploration,MultiRobot,SLAM(Simultaneous Location and Mapping),Complexity.**

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I. INTRODUCTION

Multi Robot Systems is a very crucial topic in Robotics and Artificial Intelligence and so required to perform faster than the previous techniques[1]. A multi robot system might be of utmost use in core robotics. Mobile robots are used for path finding and area exploration in tasks like mining, deploying sensor , search-and-rescue operations, for medical use, natural disasters and in agriculture fields . When multirobots are used, the total performance comes out to be more faster and more reliable. Exploration of unknown environment is also a critical area beacause its so many real- world applications. The time reduces to a large extent be- cause of its concurrency. To have high efficiency,it's necce- sary to have proper coordination among robots.Reliability and robustness also need coordination. The task of multi- robot exploration as seen in Figure 1 [2],which is described as: n similar robots tries to traverse an unknown environment and every robot has enough equipment for sensing operation, localizing each robot , mapping and is also capable of having limited-range communication .

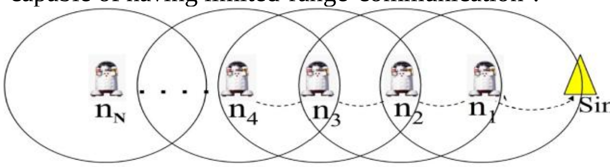

Figure 1. Multirobots moving towards sink after performing exploration[2]

Being Efficient and reliable are the main features of coordination. For being reliable the system has to be im- mune to the robot failure. Algorithms designed for coor- dination in a central manner undergo the single-point-of- failure problem, so we need to go for a distributed coor- dination algorithm for reliability. Efficiency is defined as that exploration task should be done with least cost which may be exploration time or travelling distance of robot etc. Negotiation algorithms decrease the time and travelling interval in multi-robot exploration. Bidding mechanism is adopted sometimes but that is in distributed manner. Also communication is one of the most crucial parameter in coordination among multi-robots [3].

A communication link is available either by direct pas- sage or by using multiple-hop.This might be incorrect in several situations as each robot has its own limited com- munication range, either one or many robots may go out of range and cannot communicate to other robots and so the network may be divided. Interference developed in communication channels is the other reason of division in communication network[3]. Because of division ,robots have various perspectives about the environment they work, which leads to many significant challenges to the planning and implementation of best algorithms developed for coor- dination in multi robots.

II. LITERATURE REVIEW: APPROACHES

A. SOCRATIC APPROACH

1). Sensor Data and Odometry :. Figure shown below shows block diagram of Socratic Approach also known as Hueristic Approach.Reid Simmons in the very beginning used the algorithm on mapping, an on-line method for likelihood maximization which use hill climbing to create maps . It enhances the total utility by minimizing the lapover

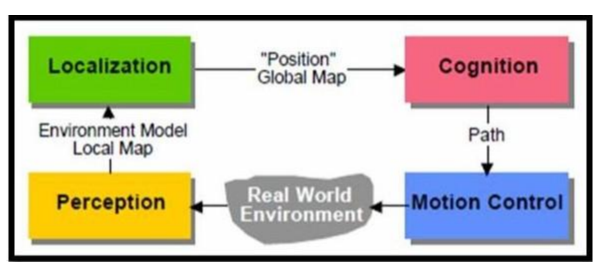

Figure 2. Block Diagram for Socratic Approach[4].

of gain collected from information given by robots. In case of mapping and exploration , most of the computations are in distributed fashion. Their fundamental approach to coordination problems is the same:

- Divide the computation worked upon among the robots and integrate the results asynchronously by global analysis of the data.
- Each robot has its own laser data for creating a reliable and efficient map locally. Central mapper then combines all local maps and create a reliable map globally.
- Robot from sensor measures, frames three things: a MLE for its spot, a MLE,Maximum Likelihood Estimate for the obstacles in neighbourhood, and a posterior density showing the true position.
- A robot constructs a new bid everytime a map update arises from central mapper and are sent to central executive, based on the bids received task is assigned.

Rekleitis [5],[6] used robot teams for exploration with an intention of decreasing the errors arising owing to odometer values. The communication within a robot pair can be divided locally and globally. Global view has the robots are in tandem so making trapezoids(Depth First Traversal) out of the broken area.
Two schemes are discussed and they differ in their team coordination . In the earlier one, the robots act as a single team with the aim of uncertainty reduction. In later , robots form two teams and exchange parts within the current trapezoid area based on position.

2). Molecular and Informative:. Two simple ap- proaches were proposed by Batalin to assign robots team for performing sensor coverage[7]. Both of the algorithms operate at a local scale and influence the overall global structure by dispersing local network.The first approach is Informative,

- Robots distribute out in a coordinated manner.
- Robots creates an identification in the group and locations are observed.
- Robots interact with one another other to widen their network locally and send Dance messages to each other.
- Robots finally spread in order to increase the cover- age.

The second approach: Molecular,

- Simpler.
- Robots behave on their own and move in a divergent way by vector sum calculation in the reverse path of remaining robots.
- No direct connection , only vision is used. The dancer selects opposite direction position so to create a repellent potential field from the nearby robots.

Robots here are taken as non-heterogenous with behaviours: Obstacle Avoidance, Walk, Observe, and Dance.

1) Observe behaviour chooses the most 'promising' vector for area exploration.
2) Dance behaviour indicates the process by which robots disperse locally .

Results show that small interactions also at a local scale are very advantageous in covering an unknown area[8]. Molecular approach outperformed the Informative inspite of being simplistic.

B. CELLULAR APPROACH

1). ANT WALK:. Wagner [9]: introduced ant-based ap- proach. Taking motivation from the ants ,the way they in- form one other for food by using pheromone or any chemical indicators that activate rest of the ants. Wagner provided robots with similar thing while performing coverage and exploration work. Robots deposit a pheromone,having a decay rate associated with them.

Initially they used a cellular decomposition of the ex- plored area . ANT-WALK-1, is a local law that does not needs special memory in robots. Shared memory comprises of the odour tinges that are spread on graph's edges . ANT-WALK-2 works on a modified Depth-First-Search(DFS) technique .

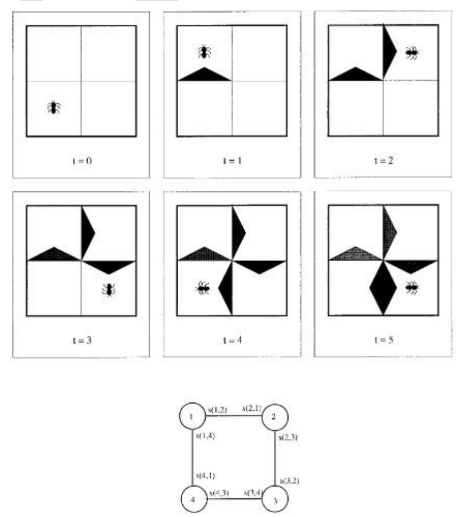

Figure3.Four cycles OF ANT-WALK to cover fourtiles[9].

2). IRADA:. Scott M. Thayer[10]:Immunology- derived Distributed Autonomous Robotics Architecture (IDARA) coordinating of kilorobots(large group of multi-robot) works like human immunity structure like nervous structure serves as a powerful construct for building intelligent sys- tems, the immune system serves as a model for the design of robot software architectures that via stochastic processes, it react and learn. Human immune system has an objective of pathogen control: response mechanism (natural immunity) ,not directed at any particular pathogen,other is anti-body response (acquired immunity) that describes core part of the human immune system like pattern recognition and memory aspects.

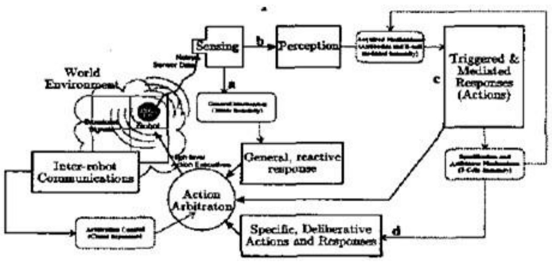

Figure 4. IRADA Software Architecture[10]

The robots were equipped with a proximity sensor and a stereo radio beacon for differential broadcasting communications. The simulator did not give the global state or robot's exact positions. Instead a third party creates the map that used several points around the periphery for to tap the beacon signals.

3).Seed Sowing:. Butler: [11] shows a cellular approach along with seed-sowing to navigate through the cells. Using seed-sowing approach,each cell is traversed, for complete coverage robots explore in stripes. Robots maintain their in- dividual internal maps, and process handlers checks coming instructions. Robots were positioned parallel or they start perpendicular.

C.PROBABILISTIC APPROACH

1). Coordination For Multirobot exploration and Mapping [12]:. A centralized module integrates a semi distributed model. Probabilistic technique was used to build a map globally in a organised manner. Robots must evaluate their local position in an environment as prob.Simmons used probability to give the local position for every robot,problems are so many with indoor environment and then a global map is built by intergrating each robots's local map. Simmonss approach revolves around MLE, a statistical method for mapping model to data.

2). Coordinated Multirobot Exploration[13]:. By 2005, appropriate target points are selected by Wolfram Burgard for the robots in order to together explore various regions of the environment. Utility of unexplored area is reduced while assigning target points. Each robot gets its target location in this way. Algorithm for coordinating robots group works by optimizing the overall utility value and possibility for overlap in information gain in robots. This algorithm takes into account not only the utility of unexplored areas but also the cost required for accessing these unexplored areas.A tradeoff between the cost and the utilities and by decreasing the utilities as per robots those are moving towards this area, coordination becomes very effective. If the distance becomes too wide and cannot be covered through wireless network, robots then explore an area already explored before .

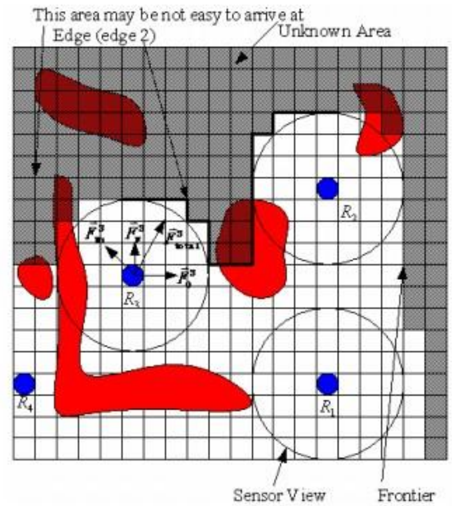

Figure 5. Multi-robot exploration in an unknown environment[36].

3). Frontier Based Exploration:. Frontier Concept of Multi robot Area Exploration was again introduced in 2014.This proposed technique uses the idea of cells in frontier zone. Frontier Exploration by[14] using Mobile Robots (Yamuchi) is a used in various successful techniques for multi-robot coverage and exploration. Here robots behave on their own,without depending on others and form probabilistic decisions for frontiers in an environment. The environment is divided into cells with every cell having a probability factor, which may be any of the three classes: unknown ,open or occupied. A robot will traverse to the nearby non visited frontier, and after reaching does a sensor sweep. After finishing, a broadcast of results is done by the robots, then robots work accordingly by summing probabilities and forming local map for all robots. This method is cooperative and distributed, with decentralized mechanism. Yamauchis approach gave fully distributed approach. Simmons et al., required a mechanism at central level in order to handle map integration and auctions whereas, Yamauchis proposal for integrating map is much efficient and can run on-board.

D. MARKET BASED APPROACH

Jie Zhao[16]proposed an approach on social potential field (SPF) method and approach on market-based(MD) to control the motion of multiple robots. This approach is time discontinous ,which was not there in earlier SPF. Discontinuous SPF and MD are used for coordination globally and to give direction of movement and their target area .Robots move to their target positions using local path planning. Local minima happen most of the times when traditional SPF is used. Normal practise for avoiding local minima is by summation of random disturbances when one or many robots moves into local minima. In Yamauchis experiment, the robot in nearest frontier has to come under line of sight in order to get trapped. In absence of frontier exploration is done for other areas. Haye Lau uses A* algorithm for Path Following to escape robots falling into local minima.In A* minima can be avoided apriori, in which target position and direction of robot are calculated by social potential field, so the robot moves to its destination by path planning . When robots have none of the frontiers to traverse, the robots moves in idle(non productive) state. So market-driven pro- cess is implemented to distribute frontiers in an estimation done globally.

E. MULTIPLE HOP APPROACH

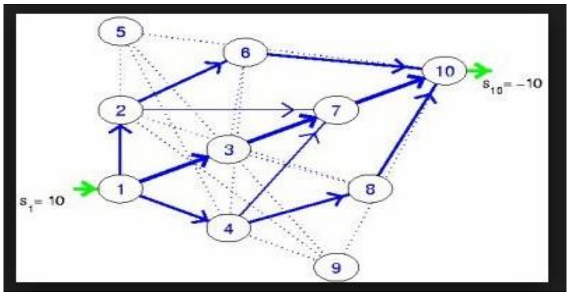

Figure 6. Multihop in wireless communications[18].

Jin Hong Jung[17] in 2009 applied multihop commu- nications in wireless to the path-finding tasks using coop- erative path finding algorithm (CPA) and verified results using Zig-Bee micro-robots and on MATLAB . Capacity and coverage enhancememt are its advanges while delays due to multihop is an disadvantage. In multihop , the data transmitted could be coded by a nearby intruder, leading to security problems and unexpected energy consumption. For an unknown maze comprising of walls and paths, group of robots can be able to escape and reach the exit of the maze quickly. Robot, comprising of sensors helping in walls and paths detection, can store the map studied on their memories and proceed in the required direction. Robot exchanges their information with one another through wireless multihop rules that improves the information rate via map exchanges . Here the performance indicator is the time in which robots move out of the maze.

F. TREE AND GRAPH APPROACH

1).Off-Line Approach:. STC,Spanning Tree Coverage gives full coverage [19], [20] in case of single robot. Hazon [21] extended the STC concept to multiple-robots and implemented the Multi-robot Spanning Tree Coverage (MSTC) algorithm. Assumption is robots have a map of the environment(Apriori). MSTC divides the space into 4D size cells,where D is the robot's sensor range used in simulation. Cell is then again divided into D size quadrants . MSTC first constructs a spanning tree for the graph covering the area. Spanning tree is then divided into parts. Each robot is given a part and it covers that perticular part in a counter clockwise manner. If a robot is not able to finish or is not responding in a given period, that robot is declared as dropped and the robot behind in the section will continue for the failed or dropped robot.

2).On-Line Approach:. On-line Multi-Robot Coverage [22], is advanced to ORMSTC On-Line Robust Multi-robot Spanning Tree Coverage. Robots execute STC(spanning tree coverage) on their own and verify with vicinity robots when assessing a neighbour cell. The objective of the method is to give full coverage in case of many drops or fails too.

Like MSTC, ORMSTC also divides the environment into 4D size cells. Cell is again divided into quadrants of D size.A spanning tree is built locally by robots via exploration, and observes the nature of other robots coming in the target area. Robot when for the first time enters a cell that overlaps with other robots tree coverage , robot stores its relations with the others so it does not have to store entire region information and also will not have huge information sharing demands.

3).Centralized Approach:. Chaohui Gong[23],in 2012 gave an algorithm for mapping an undirected graph using many synchronous operators.This depends on a n agents colony that leave the same starting vertex and diverge to analyze the graph. A centralized tree for graph is consid- ered as closed loop, it is confirmed when agents analyze other agents at common vertex.Powerful mapping can be done by introducing active exploration process where agents non-statically seek rendezvous tasks via rest of the agents present to prove graph hypothesis. Incremental expansion and pruning gives the required results.

4).Decentralized Approach:. Network nodes are car- ried as a payload by a robot in LRV[24]. Robot collects nodes in the environment using local rule. once these are kept in the area, they radiates navigation signals for robot as they moves . Nodes suggests directions that are visited least lately(recent) by the robot, so it is called as LRV. Zheng [25] enhances the work done in [26] and is called Multi- Robot Forest Coverage (MFC). Jizhong Xiao[27] in 2012 - presented an exploration process using Flooding Algorithm, that tends to decrease the time required for exploration and to reduce the total distance travelled by the robots through coordinating their motion . Considering area as a tree,the robots permitted to traverse an edge are controlled. Flooding algorithm[27] allows a number of non-heterogenous robots to examine an area modelled as a finite and nondirected tree. This process needs the distribution of active landmarks that help the robots in the exploration process by marking the places where other robots have already visited.

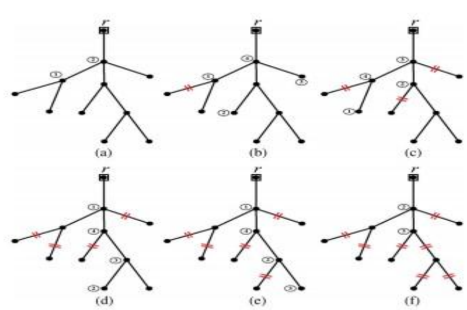

Figure 7. Robots exploring an area by flooding method[27]

5).Opaque Passage:. Peter Brass in 2011,[28]have suggested an method(algorithm) called MR-DFS for non di- rected graph exploration which is unknown and has maxi- mum rate of success on any graph. Here in graph-exploration moment, all robots in starting are all placed at a same initial vertex and search the availablity of an edge. If robots detect one end of that edge, and have information of where that edge directs only then they persue it. Vertices which are traversed earlier are perceived. Bookkeeping devices used are not in connection with one other. This is a very delicate communication than globally shared data, if there is a track of global data ,bookkeeping devices are no longer needed. Exploration algorithm will give good results even when some robots are failed, dissapeared or ruined. An active landmark is a book keeping device which can provide communication and can store information. These tokens gives signals for directions to robots lying in its path. By 2014,an MR-DFS algorithm[29] for exploring an unknown graph with opaque edges by multiple robots was proposed. It is shown that this algorithm is near optimal on graphs with n vertices and super linear number of edges (i.e.,(n) edges), and give an adversarial construction to show that the algorithm does not perform well on cyclic graphs with O(n) edges.

G. HYBRID APPROACH

Large non-homogenous mobile robots makes a signif- icant input in multi-robot area coverage and exploration by 80 non-homogenous robots In [30], a hybrid method is discussed merging clustering and Genetic Algorithm (GA) in Multi Robot Path Exploration case and to search for collision less path, from staring to the end target point followed by a robot. Modelled environment as a complete weighted graph is done showing the locations or points in the targeted area and Travelling Salesman Problem (TSP) solving process based on GA tries to fix this problem. Clustering combines the land marks and rendezvous point, chosen at the meeting point of robots.

- Simultaneous localization and mapping(Fig8) (SLAM) algorithms are helpful to generating a map of the area and localizing the robots.
- Exploration algorithms predict the perfect motion to model the robot to generate a map of the given environment.

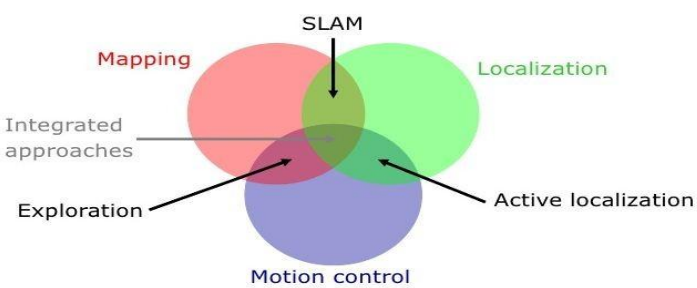

Figure 8. Hybrid Model for Area Exploration[31]

Comparision Tables:

Table 1: Techniques used for Multirobot Exploration

Approaches		
Approaches	Algorithms	Features
Socratic[5,6,7,8]	MLE	Informative And Molecular
Cellular [9-11]	Ant Walk,IRADA	Actions of Human Immune System
Probablistic[12,13-15]	Probablistic Mechanism	Centres around MLE
Market Based[16]	SPF,A*	Uses MD to coor- dinate,Avoids Lo- cal Minima
Multiple Hop[3]	CPA	Wireless Multihop Communication
Tree And Graph[19-25,27-29]	STC,MSTC	Local or Global Tree is built
Hybrid[30]	SLAM	TSP solving ap- proach based on Genetic Algorithm

Table 2: Exploration Time /Complexity for Multirobot Area Exploration.

Complexity			
Author	Approach	Exploration Time/Comp	Simulation lexity
Brass(2009)	Tree And Graph	(2n/k)+ $O(r^{k-1})$	Player/Stag
Jin Hong(2010)	Multihop	-	Matlab
Burgard(2005)	Frontier	$O(n^2 T)$	Real world Ex- periment
Scott M. Thayer(2002)	Cellular	-	IRADA
Batalin(2007)	Tree And Graph	d* O(f(V))	-
Peter Brass(2010)	Tree And Graph	D+m	-
Peter Brass(2014)	Graph	(2m/k)+ $O((k+r)^{k-1})$	-
Jizhong Xiao(2010)	Tree And Graph	D+m	Matlab

III. RESEARCH GAP

A. Robots need not return to the starting vertex or node to complete the exploration . Coming back to the starting point increases the exploration time.

B. Nodes at same level are connected by decentralized approach or may be locally connected and two of them(1+1 redundancy)are connected to the main central node or centralized approach. Edges should be made transparent, at all times so that minimum number of robots are lost while exploration.

C. Due to multi robots interaction ,communication bandwidth and interference may degrade the overall performance. As robot cooperation often requires communication, the bandwidth and interference increases as the number of robots increases so that has to be to taken care of which is not considered.

D. Robot models detail many aspects of the physical robot specifications about the robot mass, friction and size are no where discussed.Not much work is done on considering the edges as transparent in last 15 years.

IV. CONCLUSION

Towards the start we had single robot, the exploration process was completely random: the robot simply wandered about its environment. When compared, multi robot system has a faster rate of area exploration. More reliable maps are obtained because of combining the overlapped data .Future versions of IDARA will incorporate 3-D terrain searches and comparisons to other methods capable of scaling to multi robot operation which will have a significant role in the attainment of kilorobotic colonies .This however has the shortcoming of not operating well in small populations whereas [32], worked only for large populations.

In the non-static environment [33]method has discussed reliability when adapting to changes in environment. By partationing messages in the exploration, it is required to create a system in which robots can assist one other in positioning and creating accurate maps. RW or DFS methods, which are simple are used for coverage, but for extreme situations only. Sometimes mapping and localization are unavailable but the total of available nodes is very large can be considered as unlimited, this algorithm appears to outperform others. There are some major differences between this algorithm and the work reported in [34] and [35].

A. No assumption the robot can traverse from one node to another in any reliable fashion.

B. Sensor nodes which are required for droping is in excess ie unlimited; in [34] and [35],uses a fixed integer of nodes.

C. Senor node which are dropped able to perform simple estimations and communications.[34] and [35], nodes are not active so they cannot perform computation or communication.

A competitiveness ratio of 1.5 is obtained by the MR- DFS algorithm, which is not possible by any other algo- rithm. The mode of communication is weak communication than global shared information. Flooding Algorithm [27] varies in that interaction is achieved not only by the robots but also by the help of the active landmarks.So robots need not to be in communication range with other robots and can move freely. By 2013,C-Forest came, and a comparison of C-Forest Parallel techniques started with others,sampling- based roadmap of trees (SRT) path-planning algorithm is also realized on a message passing architecture [13].

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