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Task Allocation for Multirobot: A Survey

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ABSTRACT

This paper is a research on multirobot systems with multirobot decision making. Multirobot systems are a collection of robots operating in same environment and main aim of these robots is to perform some cooperative performance activities to achieve some goal that are mostly difficult for single robot. Currently multirobot system is becoming very much important area of research in robotics and many robotic research communities are exploring and researching on different areas in multirobot task allocation, localization, collision avoidance, multisensory and develop the new concept decision making. Multi robot system benefits over single robot system in many ways such as improved capacity to resolve task complexity, increasing performance, reliability & easiness. Many researchers are attracted to all these benefits and hence started to investigate design & develop multi robot system problem such as complex task distribution, group creation and cooperative object finding & tracing, message transmitting. This paper emphasis on different techniques used in multirobot systems

***Index Terms*:** Coordination method, Decision making, Game Theory Based, Localization, Multirobot, Multisensory, Task allocation.

1. INTRODUCTION

Multirobot task allocation is a challenging issue in the robotics. In late 1980's researcher started investigating problems for multirobot systems, because complex task could not be finished by single robot. As robot become integral part of human life, people incur them for the simple task such as, house cleaning and for difficult task such as industrial and applications, health services, deep sea exploration, search & support in war zone, automated transport etc.

"Robotics is a field of different engineering sections and it deals with design, construction & operations of robots". Multirobot systems developed tremendously in the previous few decades & are more superior to single robot because of stability, higher efficiency and better adaptability. Aim of the multirobot is to minimize cost to distribute *M* tasks to *N* robots.

For minimizing cost researcher form various algorithm on market strategy or behavior strategy. To improve the performance of multirobot systems efficiency, robustness & feasibility used. In this paper, we have chosenan important research field of multirobot systems i.e. task allocation, game theory, localization, multisensory, image processing.Multirobot task allocation is defined as set of robots that performs the task properly in the same/different (known/unknown) environment. To accomplish the target by finding out the task performed by individual robot.Purpose of multirobot task allocation is to form different algorithm and aim of those algorithms is to lower the cost (with regards to distance and time) i.e. time to reach the goal and distance travelled. If, team size is larger, then complexity increases. Our aim is to search best solution. Fig. 1 shows different interactiontypes of multirobot systems i.e. collaborate, coordinative, cooperative and collective.

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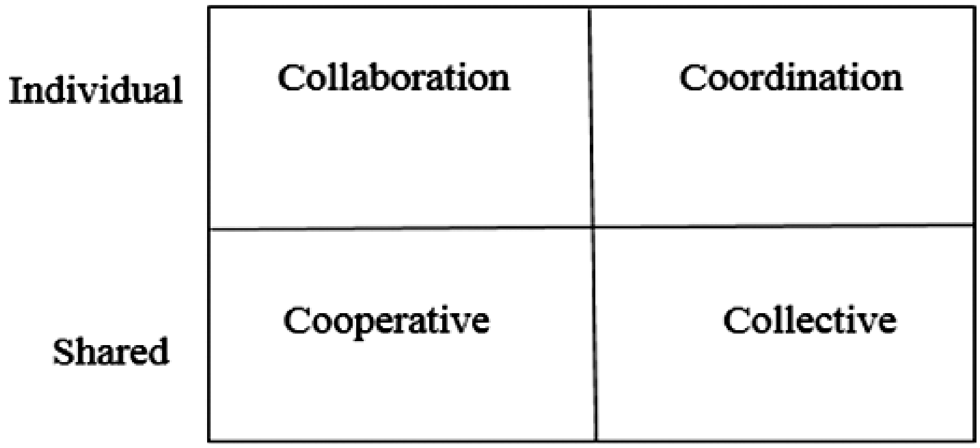

Figure 1: Interaction Types in Multirobot Systems.

1.1. Collective

Collective is the simplest method, a bunch of robots share goals and actions that are helpful for group members. The team members are unaware of each other. For example: Biological relevant task such as, swarming, flockingand foraging.In case of swarm robotics [1], path planning is one of the challenge. It includes, searching path from the source to its destination of robot. Addition of obstacle to the environment develops complexity. This paper deals with numerous obstacles. Author presents path planning of underwater swarm robot based on genetic algorithm.

1.2. Cooperative

Cooperative [2] means set of robots share their goals and are aware of other members of team. The task of each robot is known by all robots. For example: box pushing task. Multirobot task allocation, in that multiple robots and evader are there & aim of that robot is to catch the evader cooperatively. It is one type of real time hunting problem. Algorithms are used for formation control & dynamic alliances. Many situations happen such as some robots breakdown, known or unknown environment may have various boundary shapes, obstacles links with different shapes unknown environment may have various boundary shapes, obstacles linked with different shapes.

1.3. Coordination

Coordination [3] meansdifferent robots having the knowledge of each other, but they does not exchange their goals also they don't assist on other group member. The goal of each robot is different. For example: Traffic control management system. Intelligent Transportation System [4] uses multirobot communication with the advanced RFID and which is also a key area of research. With advancement of technology in GPS, RFID, vision sensing element in last couple of year, investigation on multirobot communication is increasing to solve the problem related with road accident, traffic control and catastrophe management.

1.4. Collaboration

Collaboration is one of the type of interaction in systems, itappears when the robots has their own goals and they have knowledge about their group members. Also, they assist other group members to achieve their goals.

Multirobot systems are described in following groups:

1) UAV (Unmanned Aerial Service)
2) UGV (Unmanned Ground Vehicle)
3) UUV (Unmanned Underwater Vehicle)

1) *UAV used for domestic application such as, aerial imaging and survey services weather forecasting etc. Author proposes to improve aerial service system which is used for inspection techniques in different areas such as industrial plants and buildings. To develop these control system, three scenarios are used such as, Task Planning, Executive Control, Path Planning, Re-panning, 3D mapping[5].*

2) *UGV* used for civilian & military operation such as, ordnance disposal, fire-fighting, logistics. Author proposes to use ground robots in precision agriculture. Which will be used to develop new informative path planning problems. Paper also mentioned about developing path planning algorithms for the UAV+UGV system which will be used for Nitrogen (N) levels estimation in an agriculture plot. The first problem is Traveling Salesperson Problem with Neighborhoods (TSPN) which considers both measurement and travel cost. This is motivated by scenarios in which unmanned ground vehicles (UGVs) are used to obtain time-consuming soil measurements data [6].

3) *UUV* used for mine disposal, search and rescue, naval operation, commercial offshore exploration. Authors in paper [7] developed an algorithm through bio-inspired neural network. The algorithm can be used in Autonomous Underwater Vehicle (AUV) in actual route planning in three-dimensional (3D) environment. Shunting equation of the neural network model gets improved with the help of this algorithm.

2. TASK ALLOCATION

Task allocation is the way by which tasks are chosen, assigned, subdivided, and coordinated. Generally, the question arises "which robot should perform which task?" Multirobot systems solve this problem. While allocating tasks some of the issues needs special attention such as, cost reduction, efficiency improvement, optimizing global robustness & resources distribution without interference.

Jianjun Ni and Simon X. Yang [8] described the way in which multirobot allocate tasks. This paper mentioned about multiple robots and evader. The aim of the robots is to catch evaders effectively. It is real time hunting problem. Formation control & dynamic alliances algorithms are used for task allocation. Different situationsmay arise such as firstly, few robots may breakdown,and secondly, known or unknown environment may have various boundary shapes and thirdly, obstacles linked with different shapes. Also there are different cases such as only one evader, multiple evader etc. The robots do not have information about the situation and positions of evaders, robots only knows where the evader stay, with this much information evader needs to be caught. The hunting task was completed by partial sensory information and slight communication problem, without knowing the location of the evader, without any information about the active environment.

Jingjin Yu et al.[9] describes problem of optimal multirobot path planning (mpp) on graphs and they examine difficultyin optimal paths planning which used for multiple robots having their own goals. In this collision among robots will not be accepted which might happen when different robots moving in similar vertex or move laterally the similar path in different directions. It propose integer linear programming(ILP) model, which computes least arrival time and lowest cost distance solution for multi path planning algorithms. Different issues arises such as time optimality, distance optimality & cost. ILP algorithms must be the performance improvements & Lerner. Multi path planning algorithms are used for solving difficult multi path planning problems such as 25 puzzles or 35 puzzles for gaming purpose through the heuristic method.

Lingzhi Luo, Nilanjan Chakraborty and Katia Sycara [10] consider MRTA problems where task has to be completed within its deadlines. They shows a distributed auction algorithm for this problem & demonstrate that result is optimal. Designing distributed algorithms is the main goal of task allocation with task target and restriction on the number of tasks which robot can perform.

2.1. Benefit

1. Resolving task complexity: Single robotis not capable in completing the complex task.
2. Increasing Performance: If robots doing task cooperately, then completion time of task are decreased
3. Increasing reliability: In criticaltimes, only one robot is congestion for whole system, that time redundancy occurs. But, in multiple robots if one robot is fail that time another robots works properly.
4. Design Simplicity: Less robots is simple & economical forimplementation.

2.2. Multirobot Task Allocation Planning [25]

1. Single Task (ST) verses Multi Task (MT), capability to perform simultaneously task.
2. Single Robot (SR) verses Multi Robot (MR), Quantity of robots required for task completion.
3. Instantaneous Assignment (IA) verses Time Extended Assignment (TA); robots perform scheduling for allocation of the tasks.

Single Task means individual robot is able to perform at least one task. Multi Task means robots perform various task concurrently. Single Robot means individual robot is required to perform task. MR means some task required multiple robots for performing. IA means information concerning robots, tasks & environment. TA is used for planning purpose only [24].

Two approaches used for task distribution:

i. Decompose-Then-Allocate:

The complex task decomposes to the sub-tasks & all these sub-tasks allocate to the teammates.

ii. Allocate-Then-Decompose:

The critical task is assigned to mobile devices & mobile devices complete these tasks locally.

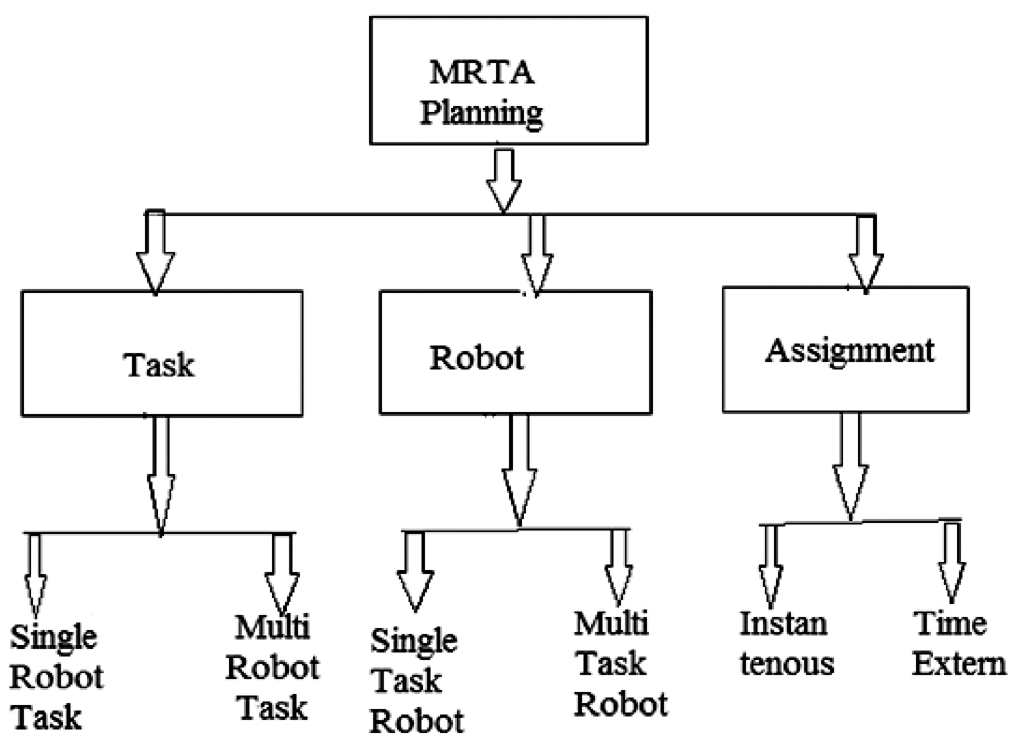

Figure 2: MRTA planning

2.3. Multirobot Task Allocation Problem

The most critical problems of MRS is a desirablyallocated task to set of robots, with optimizes overall performance with respect to number of constraints.

Divided into two problems,

1. How collection of tasks is allocated to collection of robots?
2. How the nature of the robot group is synchronized to complete the task effectively.

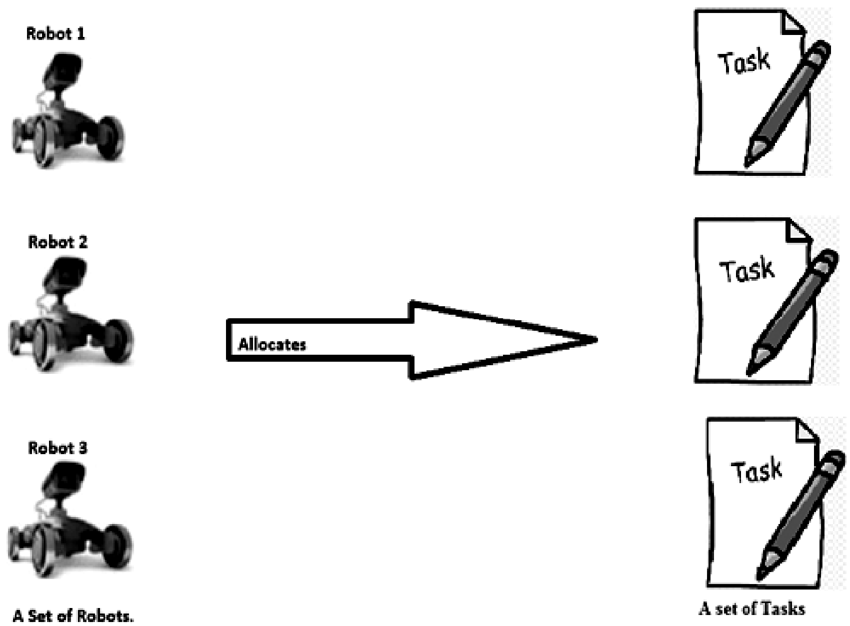

Figure 3: Multirobot Task Allocation Problem

2.4. Multirobot Task Allocation Approaches

MRTA approaches are classified into two types.

2.4.1. Centralized Approaches

In this centralized system, [11] one primary robot connects with different secondary robots to allocate the tasks. Then the secondary robot sends all information to central robot to execute the assign task. It benefits in saving in resources, reduction of time and cost, minimizes duplication of work.

Barry L. Brumitt and Anthony Stentz et al [12] introduces in unknown environment, multiple robots that can be used as mission planner. Research in autonomous mobile robots has attained a level of maturity. Where robotic systems can be expected to capably accomplish complex missions in natural environment involving multiple agents. Basically, three types of planning are supported. First, mission planning is the method of finding out activities to be performed by robot to complete the target. Second, dynamic planning is the method of mission plan updation (i.e. modifying individual robot's plan or existing goal location) when the mission-planner's directions are not followed by the robot. Third, distributed planning allows the other types of planning to happen in a decentralized manner. It is impractical to imagine all robots to communicate all information about the domain to a single central planner which then modifies the plans and send instructions to the separate robots.

2.4.2. Decentralized Approaches

Decentralized is the method of allocating robot tasks and permission to the agent of multiagent systems. In this type of approach, no centralized agent is available for allocating task purpose. Each agent is sending its data to different agents with the other agents. Individual agent can work independently without concern of the others.

Yifan Cai and Simon X. Yang [13] introduces MRTA. In this paper decentralized decision taking environment is used with as various robots in the system. For solving this problem, they designed a distributed Hungarian Method.

Luc Brunet et.al. [14] proposes task assignment in the organized group of unmanned vehicles and designing two decentralized algorithms: consensus-based auction algorithm (CBAA) and Consensus-based bundle algorithm (CBBA). These two algorithms uses a market-based strategy for the decentralized task selection.

3. MULTISENSORY SYSTEM

Multi-sensor technology is any type of robotic intelligent control system. In this system different types of sensors are proposed to indicate internal relationships & characteristics. It integrates data collection, signal processing, visual perception. For example : During earthquake search and rescue operation, unmanned sensors allocates the task such as, detect injured people & monitor collapsing building which helps in saving life.

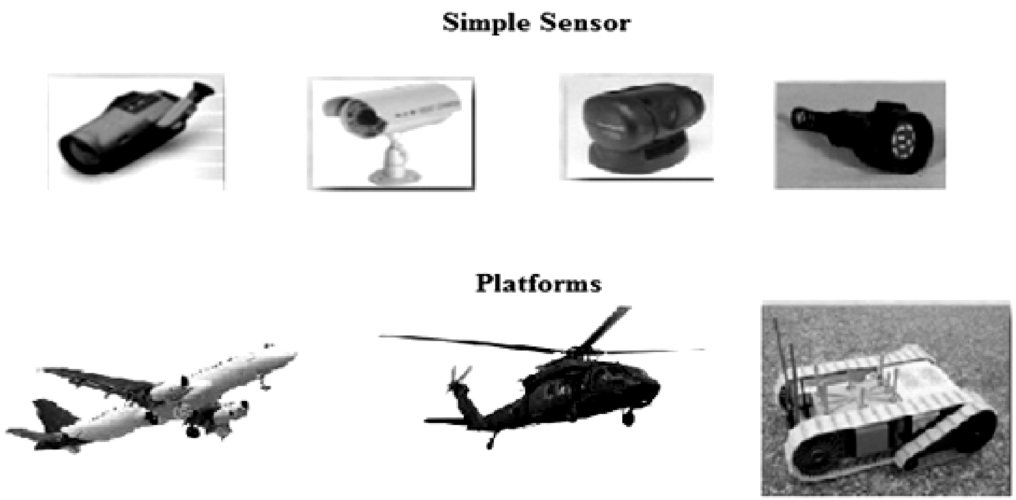

Figure 4: Types of Sensors

Michael Tornow Ayoub et al. [15] describes gesture based humanoid device interface for machine control. Here, mobile robots can advice people in disaster management perception by constructing a multirobot team working as a distributed device actor system. In this paper, they describe a gesture & hand posture based human machine interface. In this paper robot will control the HMI related 2D/3D information which is used for real world application. Kinect sensor is used for hand posture acquisition. It is used for recognizing hand gesture.

Jaychand Upadhyay et al. [16] describes Intelli-mirror, an augmented realism based Internet of Things (IOT) system for garment & accessory demonstration. The intelli-mirror uses image processing methods to find a user & then shows garments image on the individual. The Intelli-mirror offers the user with the facility to change the selections available in an entire clothing. There are different approaches used, body scanner, 3D customer's model, fitting room with 3D solutions, 3D solutions, augmented reality. Three algorithms are used namely, sizing & detection of user's body, detection of reference point of face detection and superimposition of clothing.

Wenyao Xu et al. [17] describes noninvasive & continues blood pressure monitoring using wearable body sensor network. In this paper, they presented a mobile based body device network to count the beat transit time of human body in actual time, based on which BP continuously monitored. Generally, body sensor network is used for monitoring the medical health. BSN system estimates BP for using PTT signal through ECG & PPG. It contains three parts first, wristband is worn at the wrist & calculate PPG signals. Second, Heart rate belt is worn at the chest & calculate ECG signals. Third, smartphone by using Bluetooth. In this way continuously BP is estimated.

4. LOCALIZATION

Localization means figuring out robots position in an environment. The localization is to estimates the position of the robot that moves in known/unknown environment. Map learning, path planning, robot navigation are the problems of the localization.

Reza Sabzevari and Davide Scaramuzza [18] describes the difficulty of continuous estimation of ego motion for intelligent vehicle. The motion of numerous moving objects is captured through a monocular vehicle attached cameras. Here the authors describes the localization of numerous moving objects &valuation of their motions, it is vital for independent vehicles. KITTI dataset is used, this dataset supports visual odometry algorithm which is developed for simultaneous segment & multiple objects motion estimates.

Kevin K. Leung and Garratt Gallagher [19] describes simultaneous localization and map building (SLAM). Strategy to discover unfamiliar situation. Various robots are arranged in anonymousregion& mandatory to localize individuallywhile discovering. A dynamic spanning tree is executed for multirobot coordination. Observer nodes should be monitor the distance of their explore nodes. Observer node known as parent node and explore node known as child node. Exploration strategies like edge of exploration, visual range and available empty spot are used. There are two cases first, two robots and observer-talk motion scheme. Second, there are multiple robots & behavior based tree structure. Different behavior were studied like to explore behavior, recycle behavior, move-to behavior, and observe behavior, corner behavior.

John G. Morrison et al. [20] describes scalable multirobot localization and mapping, Multiple Operator Augmented Relative (MOARSLAM) algorithm is used for scalable purpose, it gives extended solution of cooperative localization & mapping of robots. Algorithms used front end, adaptive bundle adjustment, loop closure, SLAM map and server interface.

5. GAME THEORY BASED

Game theory is the intelligent decision maker. Game theory can be used in biology, computer science, economics and many more. Basically two types of game theory are there i.e. Cooperative & non-cooperative. In robotic, pursuit evasion depends on game theory for single player pursuit evasion game & multi-player pursuit evasion game.

Alexander Alexopoulos and Essameddin Badreddin [21] describes multirobot games for decomposition approaches. In this approach, one evader & two pursuer pursuit evasion games with unmanned aerial vehicles (UAV’s) are used.

Hongpeng Wang et al. [22] describes pursuit evasion in game theory. Pursuit evasion is important concept in the artificial world. Generally pursuer run faster than the evader, but here evader is also faster. Question arises how faster pursuer is capable to detect an evader? It shows dynamic formulation from bioinspired neural network & dynamic framework of agent to model of live-or-death pursuit evasion. Two possibilities, first is the non-trivial discharge of evader at the level of separable runs of system and second is non-trivial discharge zones the sharp transition.

Qingsi Wang and Mingyan Liu [23] describes pursuit evasion games that supports stationary or heuristics behavior on the one side and countermeasure in another side. In this paper, author describes an intelligent pursuer/evader that gives the performance guarantee. Two cases were used, in first case pursuer and evader used learning algorithm of greedy nature whereassecond case pursuer/evader used mutually optimal algorithm.

6. CONCLUSION

This paper reviews the different methods of multirobot task allocation problems. Applications of multirobot systems are autonomous ground vehicles, robot on military purpose, port security, navigation & mapping software. In this paper, we reviewed last decade's works on multirobot task allocation & main feature of multirobot system that is task allocation, localization, multi-sensor system, game theory based. Table 1 shows the different robotics techniques with their principles, parameters, algorithms, advantages & limitations.

Table 1
Difference of the techniques

Techniques	*Principle*	*Parameter*	*Algorithms*	*Advantages*	*Limitations*
Task Allocation	Multirobot task allocation finds task-to-robot assignments & every time generate the question "which robot perform which task? "It is used for finding the optimal assignment solution.	Path planning, hunting, multigoal navigation, canonical multirobot foraging tasks, distributed robot systems, collision avoidance of multirobot, distributed constraint optimization.	Hungarian algorithm, auction algorithm, task assignment algorithm, bidder algorithm,dijkstra's algorithm	It is used for search & rescue mission. Multirobot task allocation is advantage over a single robot because of, time saving, cost effective.	It always tries to minimiseof cost function. The cost function is totally depend upon time & distance Parameter.
Localization	Localization means finding out the position of robots & moving the known or unknown environments. For performing task two important things used position & orientation in localization.	Position tracking, global localization, single or multirobot localization, robot motion model, measurement model, map learning, path planning, robot navigation	Simultaneous localization & mapping, kalman filters, bayes filter, expectation maximization algorithm, concurrent mapping & localization	It is used for easy to find out map, Ex: google mapIt is successfully perform the task.	In robot's environment, problem of spatial mode acquired in robotic mapping.
Multisensory System	Multisensory intelligently controls the robots. The electrical & mechanical devices are used for maps the known or unknown environment attributes to a measurement to a measurement.	Detection, localization, tracking & identification, radar, electrooptic imaging sensors.	Kalman filter, continuous time control system, central limit theorem, Bayesian network.	Improved system performance. Improved robustness. Shorter response time.	Difficulties arries in signalpropagation, we can not usage of large number of sensors in real time applications are impractical.
Game Theory Based	Game theory is based on the mathematical model & computer science perspective. It includes the cooperative games & competitive games.	Pursuit evasion games, heuristic, phase transition, pursuer-evader.	Bayesian game approximation algorithm, heuristic algorithm, algorithms for run-time communication, residual gradient fuzzy actor critic learning algorithm.	Improved efficiency, performance, run-time communication policy.	It cannot works with convex polygon domain, Confinement escape problem.

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