Technical Paper of HITCSC for The 8th International Aerial Robotics Competition

Ningyuan Wang, Yi Hou, Ning Hao
Harbin Institute of Technology

ABSTRACT

This manuscript introduces the scheme and progress of HITCSC Team for the 8th International Aerial Robotics Competition in 2018. To present our scheme, we mainly depict the conceptual and physical design, and the planning, control and navigation methods. A hierarchical decision, planning and control architecture is applied to drive the multiple agents to autonomously search, track and monitor. To improve the ability of agents, global planner and local planner are running in parallel based on the global map and the real time local map. A mapping technique which doesn't rely on the GPS is applied, and therefore, a localization module based on the map can be used to solve the localization problem when GPS is denied. Deep network model are trained to recognize the dynamic factors in the environment, and then to update the local map. In the end, the latest progress is illustrated.

INTRODUCTION

Problem Statement

Mission 8 of the International Aerial Robotics Competition, requires a group of highly intelligent aircraft to search the objects in a confined indoor square arena and help operator to avoid the danger and fetch the objects. Under the circumstance of indoor arena where GPS is denied and attackers are moving around, the aircraft are required to autonomously search for the reactor and recognize the code. Between operators and aircraft, there must be no any electric communication except for voice, gesture and etc. The aircraft can have the ability of curing operators by emitting light to the receivers of the operators. All in all, fully autonomous aircraft are needed to aid operators to accomplish tasks by non-electric interaction.

Conceptual Solution

The goal of this competition is to design intelligent aircraft which can do non-electric interaction with operators and do autonomous actions under the dynamic environment. To accomplish this task, precise perception of the aircraft's states and the environment is essential. Therefore, robust motion perception devices and exteroceptive sensors are important, which are combined with advanced estimation methods, like mapping and localization techniques. To do human-robot interaction, sounds signal are detected and identified to help the aircraft understand the command of the operator. To do autonomous decision, planning and control, a hierarchical architecture is applied and the model-based methods are used to generate commands. For real time and sub-optimal performance, global and local planners are running in parallel threads, which can be robust and plastic to the dynamic environment.

SYSTEM OVERVIEW

According to the specification of the 8th International Aerial Robotics Competition, a complete conceptual design of the system is illustrated below, as Figure 1. As shown in Figure 1, the planning and estimation modules, which belong to the algorithm design task, are depicted in detail, and the physical design of the platform is only introduced briefly, which will be completed later on. In the estimation module, localization, mapping, detection and speech recognition are the main tasks to serve for decision and planing, from where, the core idea is to do map-based actions. In the planning module, a hierarchical architecture of decision and planning is applied to do the cooperation decision and the planning, as shown in Figure 1. A priority-based strategy is used to arbitrate the operators' and the aircraft's decisions.

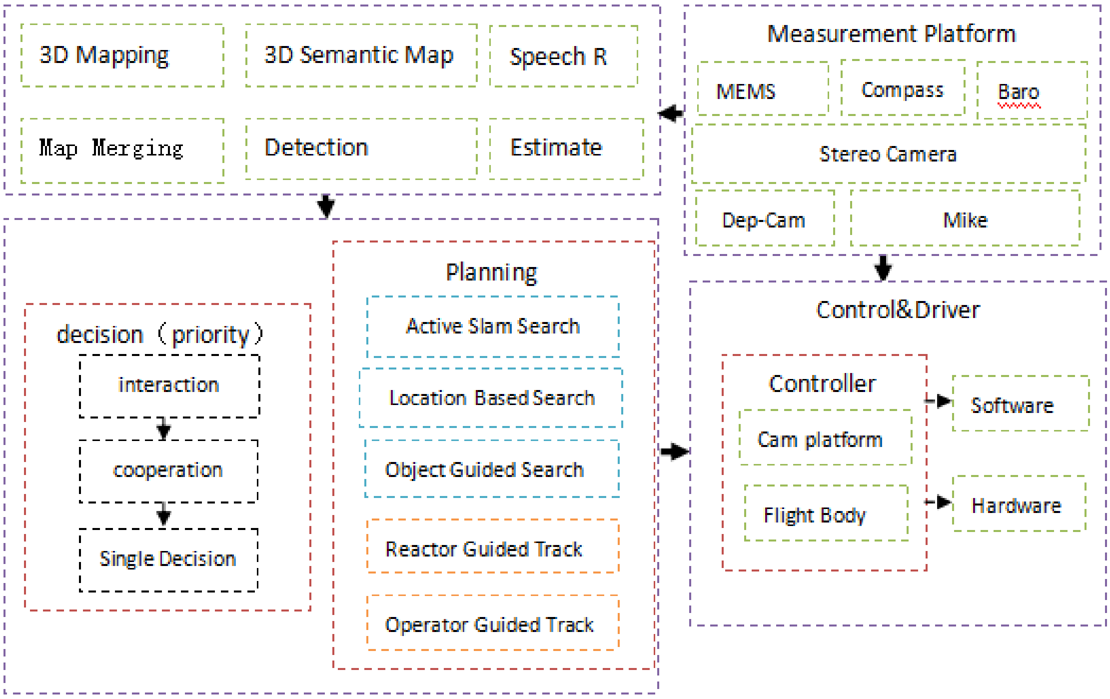

Figure 1: Conceptual Design of Aircraft System

The platform for information sampling and the one for task execution is demonstrated right in Figure 1. The measurement devices include micro electronic mechanical system (MEMS) for motion estimation, like accelerometer, gyroscope and so on. Also, a set of cameras are configured towards multiple orientations to enhance the robustness of system. The cameras downward is used to do dead reckoning and the one forward is to do mapping and localization. Apart from these sensors, the Mike is used to monitor the voice of operators for speech recognition. The aircraft body here is not introduced anymore, for that a quad rotor aerial platform is chosen as in the 7th International Aerial Robotics Competition. Note that, a software platform to simulate the real ones is designed to make experiments more effective.

Sensors Configuration

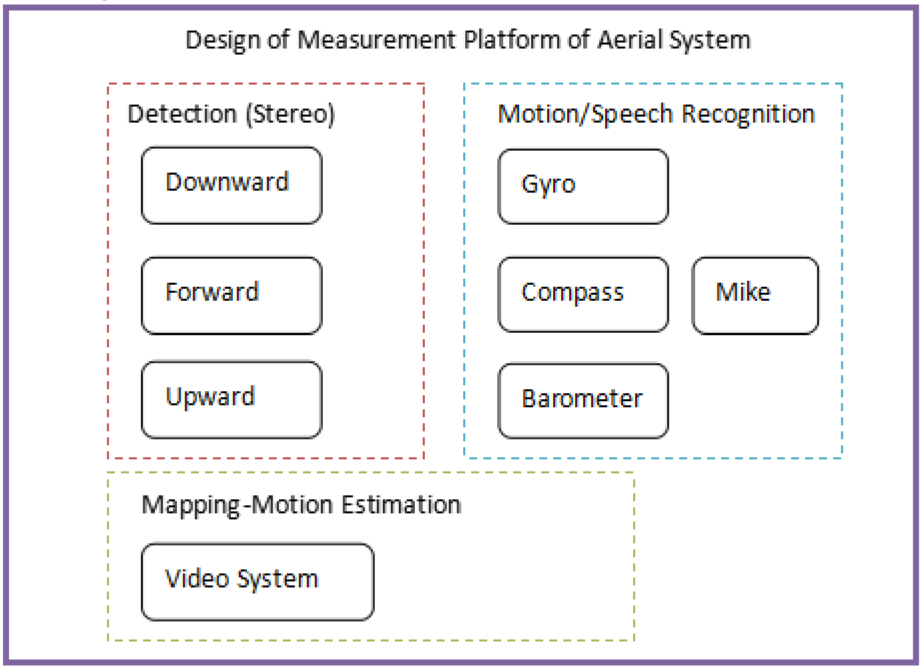

Figure 2: Measurement System of Aerial Flight Platform

In this section, the sensors configuration is depicted more concretely. As shown in Figure 2, the devices can be classified into 3 modules, which are to do detection, mapping and motion estimation respectively. Among the sensors, cameras are the main one. Cameras provide rich information of the environment, which can be used to model the environment and estimate the ego motion. 3 stereo cameras are installed in the platform pointing to downward, upward and forward respectively, which are used to do local map for real time local planning. The video monitor system on board is to do mapping and localization for global planning, which is with high resolution and provides rich environment information. The MEMS devices with low cost and light weight, are to estimate attitude of platform and do motion tracking for real time control of platform. As for the Mike or sound card, which is to be chosen further, is to serve for human-robot interaction by speech recognition technology. Now, the pocketsphinx speech recognizer is being redeveloped to do human-robot interaction.

Security Measures Design

Security for human beings is a key feature for robots to be into human's life. To achieve that, there are active and passive techniques, like automatic obstacle avoidance and safety configurations. For aerial robots, the two techniques are all essential. Here, we introduce the conceptual design of passive techniques for security. For aerial vehicles relying on the aerodynamic effect, naked propulsion is inevitable, and the only chosen is to trade off the structure and performance. So, a lightweight and small air frame is more friendly for human because of its harmlessness. Based on that idea, our focus is to improve the integrity and reduce the size and weight. Apart from that, a compact net-like shell is designed to cover the propulsion to avoid accidental harm.

Low Power Communication

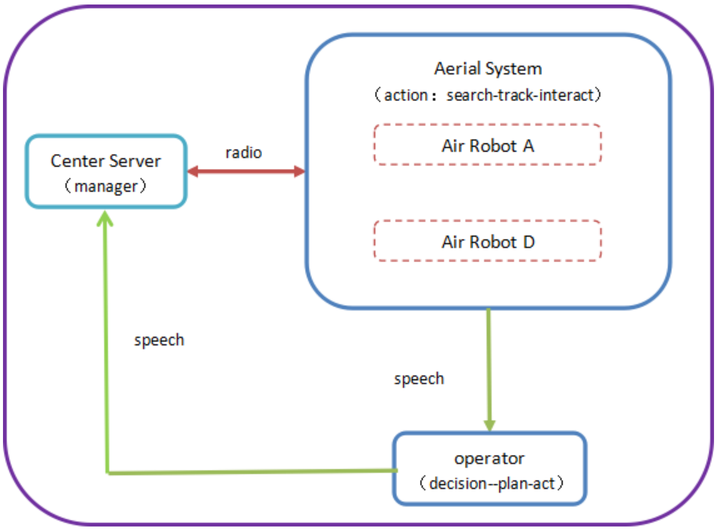

Figure 3: Topological Communication Architecture of Aircraft Formation

The 8th International Aerial Robotics Competition, requires a group of highly intelligent aircraft to cooperate to autonomously accomplish tasks. To do that, the communication network is the key basis for the aerial robots to share measurements and to do cooperation. The topological communication architecture is designed as in Figure 3. Here, a centralized topological communication architecture is applied for its high bandwidth, and the center of the network can be configured as a server to do huge computing or a monitor to manage the system. Due to the application in confined area, an enhanced 2.4GHz emitter-receiver is used to construct the network and the protocol is designed according to the TCP/IP protocol.

ALGORITHM DESIGN

Path Planning Algorithm

Since the mission 8 needs four quadrotors working together, we divide the whole planning and control algorithm into two parts. One is about group cooperative and the other is about motion control for single quadrotor. Firstly, we design the path planning algorithm for multi-quadrotor. Secondly, we give the motion control algorithm for single-quadrotor.

The major task for all quadrotors is to determine the locations as well as the codes of all bins autonomously. When the quadrotors have managed to this major task, the contestant only needs to command quadrotors to cover him while retrieving the required critical replacement component. In this case, the major task can be summarized as a collaborative search task.

Since the locations of all the bins are unknown and each piece of code will be updated periodically, we divide the collaborative search task into two subtask: area coverage and target coverage. In area coverage task, the whole arena will be covered by the visual field of all quadrotors. When area coverage task is accomplished, the locations of all the bins will be determined. In target coverage task, all the bins will be covered by the visual field of all quadrotors in the same code update period. When target coverage task is accomplished, the whole password will be determined.

We use the improved backtracking MSTC(Multi-robot Spanning-Tree Coverage) algorithm to deal with the area coverage task. Firstly, a whole path(called coverage path) for all quadrotors will be calculated through constructing a Spanning-Tree. Then, the coverage path will be divide into four segments and each segment will be assign to one quadrotor. To ensure that the total coverage time is the shortest, this divide will be as uniform as possible. When quadrotors move along the coverage path, their visual fields will coverage the whole arena. Since the coverage path will not cross any static obstacles or cross itself, every quadrotor will not collide with static obstacles or other quadrotors.

We improved the traditional backtracking MSTC algorithm and make it more adaptable to our scene. When a moving obstacle(for example, a hostile sentry aerial robot) threats to a quadrotor, the movement along the coverage path will be suspended and the avoidance motion will be determined by the motion control algorithm. When this avoidance motion is finished, all the segment will be re-assigned, then all quadrotors will move along the newly allocated path segment. When some quadrotors fail and cannot continue performing tasks, all the segment will also be re-assigned and other quadrotors will continue to complete the area coverage task. The coverage path in an area (with or without a static obstacle) is shown in Figure 4.

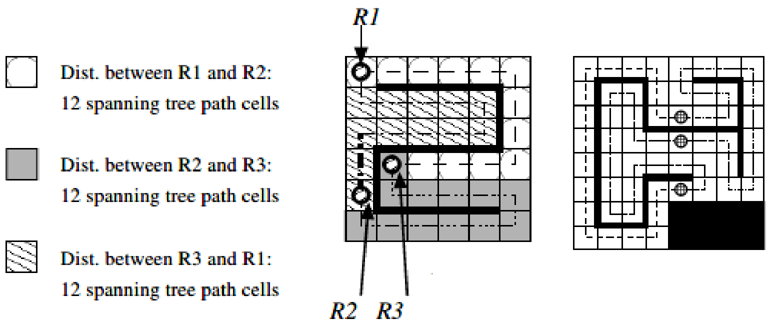

Figure 4：Coverage path

We use the improved C-CAPT(Centralized-Concurrent Assignment and Planning Trajectory) algorithm to deal with the target coverage task. The C-CAPT algorithm is a sample-based method. The algorithm will first seek a series of path segment through the straight-line planner. These segment will constitute paths from the initial positions of quadrotors to the goal positions of quadrotors(the locations of the bins). Then, a vector field will be constructed through the desired velocity derived from these paths. Through this vector field, all points near the paths converge to the appropriate paths. This paths are generated in an iterative manner. The whole process is composed of

four steps:
(1) Generate paths. This step is to give the whole paths from initial positions to goal positions. In this step, all static obstacles will be checked and all paths generated will not cross any static obstacle.
(2) Remove cusps and loops. This step is to make every path not cross itself and remove meaningless path segments.
(3) Exchange path segments. This step is to avoid different paths cross with each other.
(4) Smooth paths. This step is to make the paths shortest as well as avoid collision.

We improved the traditional C-CAPT algorithm and make it more adaptable to our scene. Firstly, the possible fault of quadrotors is considered in the target assignment, we will seek for a unified assignment method for n(n≤4) quadrotor and four targets(bins). This method will generate a time-optimal assignment to make sure that all codes are observed in the same code update period. Secondly, similar to the improved backtracking MSTC algorithm, when a moving obstacle threats to a quadrotor, or some quadrotors fail and cannot continue performing tasks, all the targets will be re-assigned and paths will be re-calculated. Paths generated by the algorithm in four steps are shown in Figure 5, where there is a static obstacle and quadrotors move from X’s to O’s.

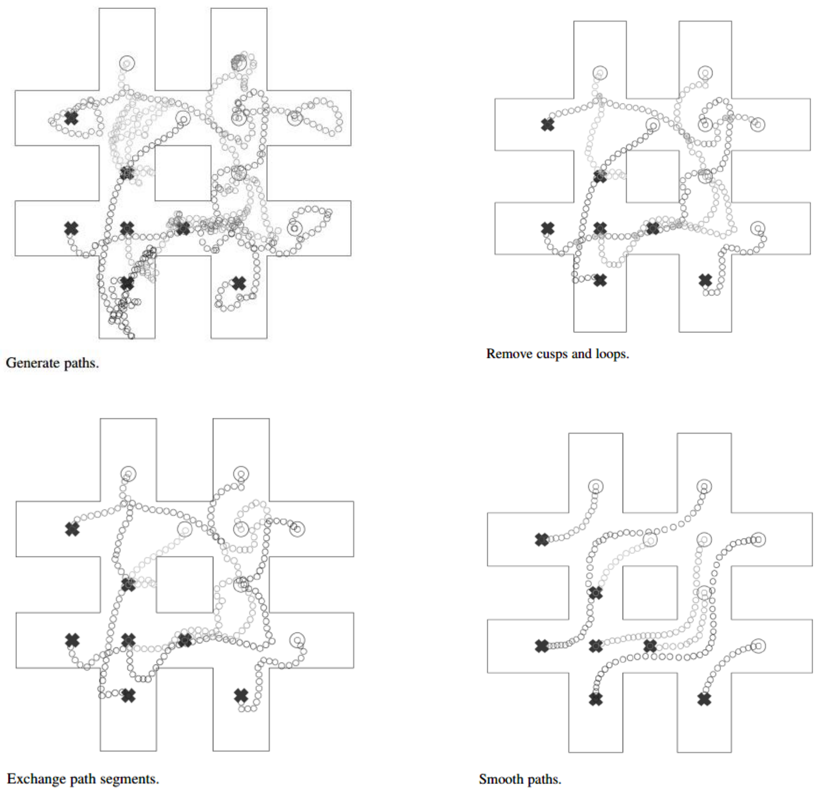

Figure 5：Paths generated

Motion Control Algorithm

Since the desired velocity has been designed in the path planning algorithm through the generation of the desired path, a control law formed of proportion and desired rate of change is applied into the controller design, including both the position loop and the velocity loop of every quadrotor. As an example, if the quadrotor need to track a desired path, it actually track a desired point moving along the desired path, and the position-loop controller calculate the desired velocity of the quadrotor, which is a sum of two parts: (1) the velocity of the moving point; (2) the desired velocity given by the proportion controller to minimize the position error between the moving point and the quadrotor. For the velocity loop, the controller has the similar form.

As mentioned above, the motion control algorithm should deal with the situation that a quadrotor is threatened by moving obstacles. Since the quadrotor need only to avoid the collision between any moving obstacle and itself, a potential-based method is applied into the design of avoidance algorithm. With the effect of the potential field, quadrotors will keep safe distance with all moving obstacles. Furthermore, since that these obstacles keep moving, quadrotors can always return to their desired position after avoiding these obstacles. The diagram of the obstacle avoidance controller is shown in Figure 6.

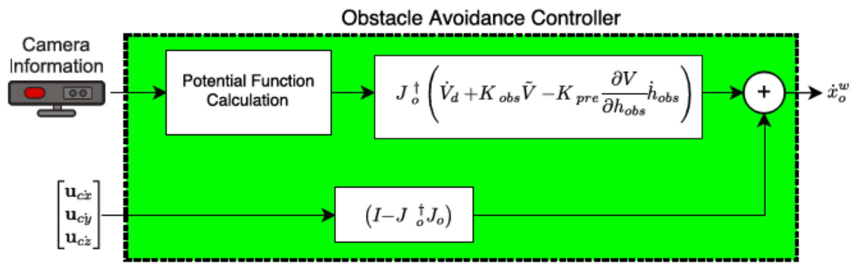

Figure 6:Obstacle avoidance controller

The path tracking part and the obstacle avoidance part are unified into one controller through a null-space-based approach. This approach mix the two output from path tracking controller and obstacle avoidance controller, and always ensure the safety of quadrotors, which means that when obstacle avoidance and path tracking conflict, the quadrotor will avoid the moving obstacles and give up tracking the desired path temporarily. The diagram of the unified controller is shown in Figure 7.

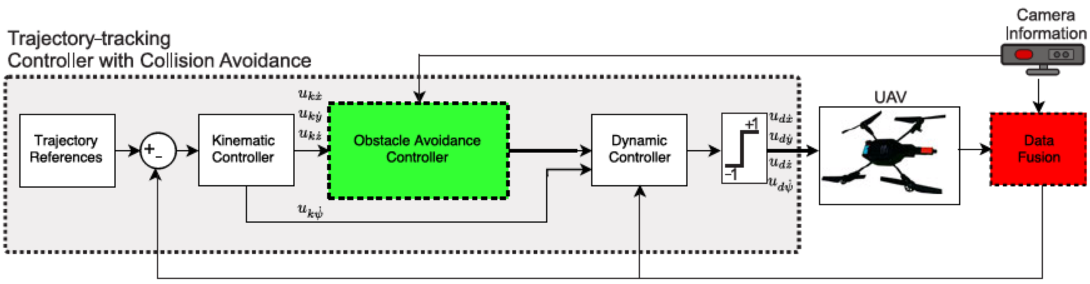

Figure 7: Unified controller

Mapping and Localization Algorithm

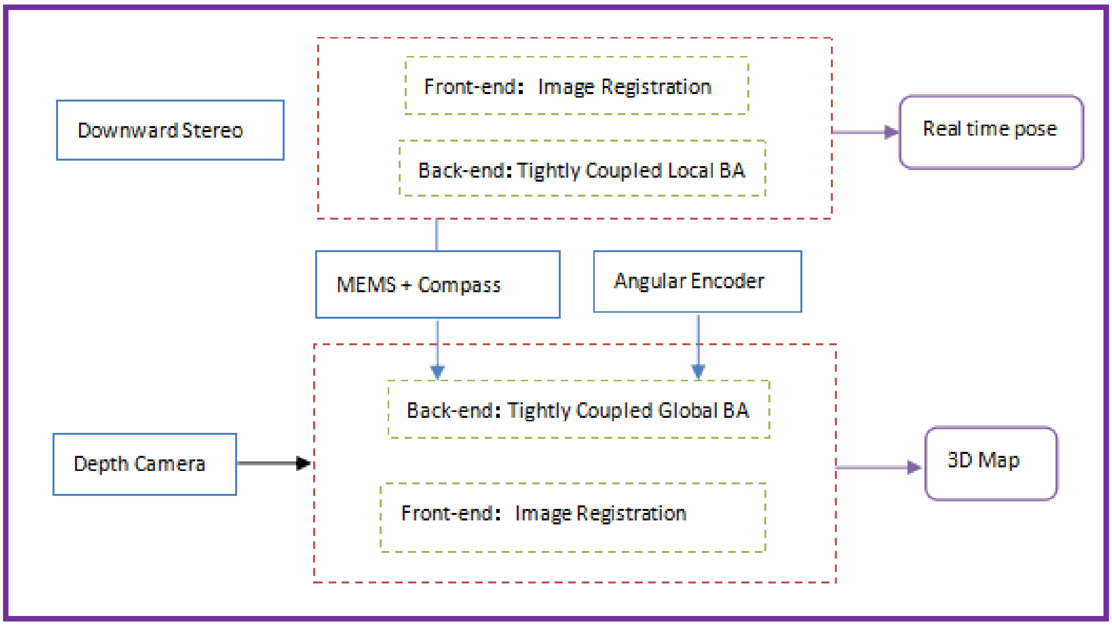

Figure 8: System Architecture for Motion and Map Estimation

In this part, the architecture of motion and map estimation system is introduced as in Figure 8, from where a global bundle adjustment optimizer and a local one are applied respectively for odometry and map estimation. The global optimizer is based on the batch-optimization theory and running off-line. The local optimizer uses the sliding window optimization technique to get real time motion estimation. Once the map is estimated based on the global bundle adjustment optimization, the local optimizer degenerate to a pure-pose optimization module for localization.

As for the image registration, a hierarchical scheme is designed. In the first step, a global descriptor of the image is constructed, the image retrieval is done by traversing the image database based on term frequency-inverse document frequency principle. After that, the local descriptor is extracted and matched between the image pair, and a initial guess for the pose between them can be retrieved by PnP method or iterative closet point method. The result of the image registration is used by the optimizer to do estimation.

CONCLUSIONS

This manuscript introduces the aircraft's architecture and the algorithms for mission 8 of the International Aerial Robotics Competition. Up to now, the configuration of the aircraft was finished partly and is undergoing test and validation. Based on the measurement platform, the mapping and localization are being revised and test, but there are still a period for the module to work normally. The planning algorithms is proved to be feasible in off-line simulation tests, but the decision module need to be designed and test further. In the following days, we will focus on the estimation module of aircraft and begin to design the decision module.

REFERENCES

[1]Junwei Yu. Vision-aided Navigation for Autonomous Aircraft Based on Unscented Kalman Filter. Indonesian Journal of Electrical Engineering, ISSN 2302-4046, 02/2013.

[2]Dewei Zhang, et al. The Quadrotor Dynamic Modeling and Indoor Target Tracking Control Method. Mathematical Problems in Engineering 2014(2014).

[3]Kangli Wang, Shupeng Lai, et al. An Efficient UAV Navigation Solution for Confined but Partially Known Indoor Environments. IEEE International Conference on Control & Automation(ICCA),2014.

[4]Courbon, Jonathan, et al. Vision-based navigation of unmanned aerial vehicles. Control Engineering Practice 18.7(2010):789-799.

[5]Feng Lin, Ben M. Chen, et al. Vision-based Formation for UAVs. IEEE International Conference on Control & Automation(ICCA),2014.

[6]Mellinger, Daniel, Nathan Michael, and Vijay Kumar. Trajectory generation and control for precise aggressive maneuvers with quadrotors. The International Journal of Robotics Research(2012):0278364911434236.

[7]Long J, Shelhamer E, Darrell T. Fully convolutional networks for semantic segmentation. Procession of the 28th IEEE conference on CVPR. 2015

[8]Girshick R. Fast RCNN. Proceedings of the 2015 IEEE International Conference on Computer Vision. 2015

[9]Ren S, He K, Girshick R, et al. Faster RCNN: Towards real-time object detection with region proposal networks. Neural Information Processing Systems. 2015.

[10]Hyeonseob Nam, Bonyung Han: Learning Multi Dimain Convolutional Neural Networks for Visual Tracking. CVPR, 2016.

[11] N. Agmon, N. Hazon, G.A. Kaminka, Constructing spanning trees for efficient multi-robot coverage, in: Proceedings of IEEE International Conference on Robotics and Automation (ICRA-06), 2006.

[12] N. Hazon, G.A. Kaminka, On redundancy, efficiency, and robustness in coverage for multiple robots, Robotics and Autonomous Systems 56 (2008) 1102–1114.

[13] Matthew Turpin, Nathan Michael, Vijay Kumar, CAPT Concurrent assignment and planning of trajectories for multiple robots, International Journal of Robotics Research, 2014, Vol 33(1) 98–112.

[14] Kloder S, Hutchinson S, Path planning for permutation-invariant multirobot formations. IEEE Transactions on Robotics 22(4): 650–665,2006.

[15] L. V. Santana, A. S. Brandao, M. Sarcinelli-Filho and R. Carelli. A Trajectory Tracking and 3D Positioning Controller for the AR.Drone Quadrotor. In 2014 International Conference on Unmanned Aircraft Systems (ICUAS). Orlando, FL, USA, 2014. pp. 756-767.

[16] M. C. P. Santos, C. D. Rosales, M. Sarcinelli-Filho, R. Carelli. A Novel Null-Space-Based UAV Trajectory Tracking Controller With Collision Avoidance. IEEE/ASME Transactions on Mechatronics, vol. 22, no. 6, Dec. 2017, pp. 2543-2553.