Path Planning and Visual Servoing Applied to Coordinated Tasks

in Air-Ground Robot Teams.

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1. Introduction

The aerial and ground autonomous robots have been recently used for a wide variety of applications, the flexibility of the aerial vehicles and the robustness of the ground systems are very important to perform specific task in any kind of missions. As the complexity of the missions increases, there is a need to integrate manipulators and several types of robots in a single team, by using their diverse capabilities, the benefits and probability of success increases [1]. Although the advantageous are evident, the aerial robots have a major drawback caused by their high energy consumption and limited payload capacity, which prevents the heterogeneous robotic team to work together for long time. To increase the working time of the robotic team is necessary to provide recharge or replacement of the UAV (Unmanned Aerial Vehicle) battery. Many approaches have been proposed solutions for this kind of connection like [2] and [3], however a more robust and safe system is required.

Our study, has been proposing a docking process to perform physical contact between a UAV and the robot arm of a mobile manipulator. The focus has been on handling the UAV relative position information, calculated from the image of an eye-in-hand camera, to control both the UAV and end effector position to perform an UAV tracing task. This system was tested on simulation achieving important results summarized in [4].

For the next step of this research, the focus is in the 6 DoF (Degrees of Freedom) robot arm movements, which includes great complexity because requires considering its own structure and the unknown environment to perform precise movements for UAV tracing and contact.

This paper summarizes the design of a novel control system which merges path planning and visual servoing to perform the UAV tracing task and contact.

1. General description of the docking system

Our proposed docking system is composed by a UAV and a mobile manipulator, the first platform is a quadrotor with a fiducial marker attached at the bottom, and the second is a mobile ground platform with a 6 DoF robot arm fixed at the top deck, see Fig. 1. The arm has a camera fixed to the end effector configured as eye-in-hand device, which is the main source of information for the controlling process of our system. Also, we include a coupling device which has two pieces with complementary conical shape, these two pieces are fixed one in the UAV bottom and the other in the end effector with a correct alignment with the rest of the parts, this device was designed to correct small position errors in the final step of connection and to allow a magnetic fixation.

The complete process can be divided in three sequential phases (Approach, Follow and Contact phases) that allows the docking since the first meeting until the final connection state.

In addition, a failure handling task has been programmed to give solution to the problem of lack of quality in the tracing of the UAV movements, in this situation the end effector will decrease the altitude in order to expand the field of view and recover the tracking, and if the UAV is still not visible to the camera, then the arm will return to its original low position and the process will restart.

The mobile platform is being controlled with a completely independent loop following the orders by a human operator or by a higher-level mission, our controllers doesn’t affect its trajectory which make our system ideal to be included in a prioritized queue of tasks in critical search and rescue missions.

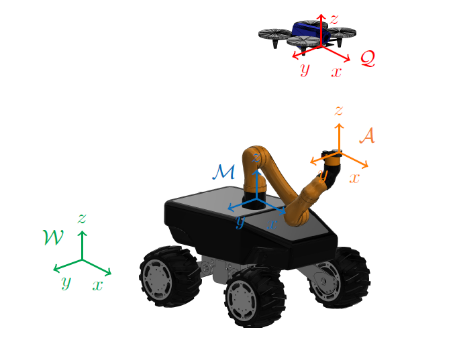
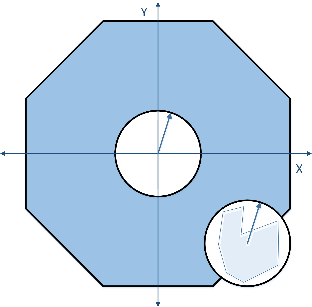


Fig. 1. Robotic platforms and reference frames

1. Path planning and visual servoing control system.

One of the main issues present in this type of systems, is to maintain the end effector pose inside the arm workspace and to avoid prohibited positions without affecting the correct behavior of the arm meanwhile avoiding collision with external elements. The prohibited areas can be, for example, the center of the arm when it is moving in a low position, or a detected obstacle which impedes de movement of the arm and that means a potential risk for the system, see Fig. 2.



*Allowed arm workspace*

*Prohibited*

*areas*

Fig. 2. Prohibited areas modeled by a circular shape

During the *Follow* and *Contact* phases, the arm is performing a UAV tracing task from below, moving along a horizontal plane in a low altitude. In this task, the UAV position could fall in an area where the arm cannot follow, in this situation the end effector should stay inside the arm workspace staying as close as possible of the desired position and maintaining visual contact. Also, the end effector must follow, from the allowed workspace, trying to anticipate the UAV movements being prepared when the desired position returns to the permitted area.

The proposed controller system combines a purely reactive controller with a motion planning algorithm which allows to include prohibited positions and environmental constraints to manage the arm end effector position. The challenge here is to execute both with a real time specification as the system is intended to control an UAV on-line tracing task. An outline of the controller can be seen in Fig. 3.

The controller has as input the UAV marker pose measured with respect with the mobile manipulator coordinates frame . This pose is calculated by adding the UAV marker pose in camera coordinates , with the arm end effector pose, that comes from the forward kinematic relation of the manipulator , and with an offset value .

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With this calculation, the UAV and end effector pose can be controlled easily in manipulator coordinates simplifying the complete process.



Fig. 3. General scheme of controler

* 1. Visual servoing:

This is a purely reactive section of the controller which is calculated with simple equations that transforms the pose error between the UAV and end effector, into torque commands. This simplicity, allows the controller to be executed in real time without any major consideration. However, it does not include any obstacle avoidance and prediction process.

* 1. Path planning:

Traditionally, this technique consists in the calculation of a future trajectory by which the end effector will move to reach a desired pose. Once the trajectory is available, the end effector will move by following the middle trajectory points. The trajectory is calculated by searching an optimal path in a random set of positions inside a local region. Then by selecting and modifying carefully the 3D space of application, the external obstacles and the self-prohibited positions can be included in the movement prediction.

The great inconvenient is that, once the path is calculated, the end effector will move blindly until reaching the final position. It means it does not consider dynamic obstacles. Also, the calculation is complex, and it cannot be executed in real time.

The path planning applied in this research tries to be executed near real-time frequency, for this, the path search space is reduced to a volume which surrounds a predicted trajectory . This trajectory is calculated for a fixed extension, representing a possible movement of the arm for 1 second in the future.

Let assume the prohibited position can be modeled as a single circular shape of radius , drawn in the horizontal working plane of the arm. While the UAV projection falls in the restricted area, the end effector will stay at the border of the circumference. The arm will be positioned depending of the angle which is formed by the axis and the point as follows.

Where and are cartesian components of the point which is calculated using the Eq. (3).

The and values are the first derivatives of the arm movement, and the factors and depends on the radius of the circle and the quality of the tracking.

This method tries to use the information of the arm movement in order to propose a suitable position to follow the UAV in case of finding a restriction in the arm workspace. Because of the use of the first derivative of the arm position, the desired point will tend to be placed in direction of the movement and also allowing the inclusion of another factors that affect the system.

By using the angle is possible to use common trigonometric equations to calculate the desired position , where the end effector will move to continue capturing the image and waiting for the UAV to enter the workspace. If the arm needs to move a long distance, many points are calculated also following the circumference until the desired position, thus the arm will follow an arch trajectory.

1. Future work

Our future work will focus on adding more functionality to the system to achieve a complete docking in more complex situations and different environments, improving the controllers to bring quality responses and allow movements at higher speeds. For the arm movements, we plan to consider the study of the predictive approach to bring a better response in the handling of prohibitive positions, and considering the different noise effects for a more robust controller.

1. Conclusion

We have studied a system for the docking of a quadrotor using a mobile manipulator and visual information. By executing sequential phases, the heterogeneous robotic team can perform a safe and robust approach from the initial UAV detection to the final connection state without affecting its exploration mission. We also introduced in this paper a general idea to handle the situation when the arm cannot reach a desired position due to restricted workspace. Finally, we mentioned some ideas for the future work in this project.

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