Original Research Article

Study on algorithms for stable hover of UVA withSingle joint robotic arm during operation

Zehui Zhou

Southwest Jiaotong University Deyang City, Sichuan Province 618099

Abstract: The potential applications of unmanned aerial vehicles (UAVs) are vast and exciting, yet their scope could be significantly expanded if they could be equipped with robotic arms. The primary objective of this study is to introduce one possible algorithm for stable hover of UAV with single-joint robotic arm during operation. After a brief introduction for PID algorithm, a usual algorithm for UAV's operation, and Newton-Euler dynamic equation, a common method for dynamic modelling, this study finally discusses the combination of both as well as the probable application of the UAV with single- joint in daily life.

Keywords: UAV; Robotic arm; Hover; PID algorithm; Newton-Euler dynamic modeling

1. Introduction

Recently, the four-rotor UAV(Unmanned Aerial Vehicle) has been widely concerned because of its characteristics of small size, easy to carry, low cost and multiple degrees of freedom, constantly updated by science researchers. However, for now, UAV is usually used in aerial photography and detection. In the future, when UAV needs to carry out some "contact" with other objects, such as the grasp or transfer of items, a robotic arm is needed to be installed to complete the task. In this way, it can participate in the transportation of the logistics industry, the sorting of materials on the industrial assembly line and other similar work. As the robotic arm is added to the UAV system, some of its original algorithms of motion and hovering should be changed to ensure the stability of the system because of the reaction force and torque caused by the robotic arm. This study will focus on the research of the hovering algorithm of UAV with single joint robotic arm.

In China, due to the relatively late start of UAV research, most researchers still mainly focus on the optimization of UAV aerial photography cruise. Nonetheless, some companies in China, like ShunFeng and MeiTuan, are trying to adopt the UAV carrying the goods or take-outs to complete transportation, which is still experimented. In universities, the Harbin Institute of Technology has designed a quadrotor with catching hands to clean objects in dangerous areas.

Compared to China, other countries carry out more experiments about UAV with robotic arm. In the University of Pennsylvania, researchers designed and installed a mechanical claw under the center of mass of the UAV, and then modeled the dynamics of the longitudinal plane of the whole system to realize the trajectory tracking control in the longitudinal plane, enabling the claw to grasp objects. The laboratory of Drexel University manufactured a UAV with two three-DOF robotic arms and build a physical test platform to conduct dynamic modeling for the flight models of the system and the actuating models of the robotic arms.

Based on the relevant literature in China and other countries, for UAV with robotic arm, the most common algorithms include PID algorithm and Newton-Euler equation, which are the content this study focuses on, and these equations are mainly used to model the three-dimensional dynamic system and calculate the compensation required by the reaction of the rotor system on the basis of the rotor control system.

2. PID algorithm

The PID algorithm has been one of the most widely used algorithms in industrial application, which has a history of more than 100 years. In closed-loop system, PID algorithm can automatically adjust the control system accurately and quickly, and has been applied in balance car, temperature controller and so on. In the field of quadrotors, PID algorithm is also widely used, including the realization of UAV hovering.

This part gives a simple introduction to PID algorithm:

PID algorithm consists of three parts: P(proportional), I(integral), D(derivative). Their relationship can be roughly represented by the graph below.

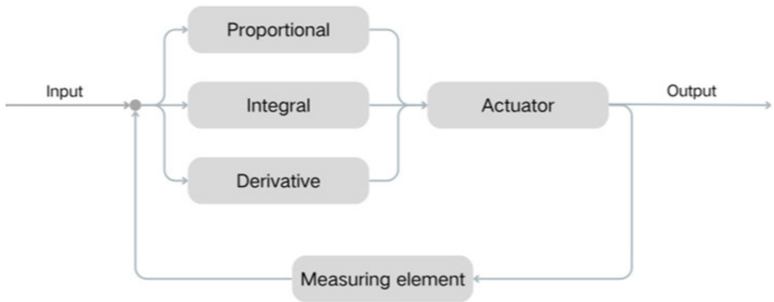

Figure 1. PID algorithm flow.

The following introduces the function of each part respectively:

2.1. P(Proportional)

Proportional means corresponding in size or amount to something else in mathematics and the P algorithm is mainly based on the error between the value of the controlled quantity and the target value to determine the speed of the change of the controlled quantity so as to improve the efficiency of whole process. When UAV hovers relatively far away from the target position, P algorithm allow UAV to achieve destination as fast as possible base on the distance between them. Similarly, when the distance is close, the speed will be slower.

2.2. D(Derivative)

Derivative means an expression representing the rate of change of a function with respect to an independent variable and the D algorithm plays a role as buffering or damping. The UAV might vibrate around the target point constantly instead of hovering precisely with only P algorithm applied, when D algorithm bases on the speed of UAV to influence the system. If the UVA runs too fast, D algorithm will neutralize part of the lift generated by P algorithm to maintain the stability of the system.

2.3. I(Integral)

Integral is an algorithm in mathematics and I algorithm can be a supplement to P and D algorithms. In some cases, approximately due to the influence of environmental factors and other factors, when almost achieving the target hover point, the small feedback value of P algorithm is not enough to generate enough horsepower to make the UAV approach the hover point and hover in the wrong place. Due to the lack of speed, it is also difficult for D algorithm to change this situation. The function of I algorithm is to continuously integrate the error between the position of the UAV and the target position with respect to time. Even though the error may be small, with accumulation of time, the system can finally realize the current position is not the destination and make some changes. To avoid decreasing accuracy of the I algorithm caused by the instantaneous increase of the integral due to the large error at the beginning of the system, the integral restriction is necessary, so as to ensure that its function is only to reduce the error in the static case.

3. Newton-euler dynamics modeling

To realize the control of the robotic arm, the basic dynamic modeling of it is essential, and the common dynamic modeling methods include Lagrange methods and Newton-Euler method. Because Newton-Euler method adopts the form of recurrence, calculates in a more convenient way and is widely used in mechanical engineering, aerospace, robotics, especially in robot dynamics modeling, adopt Newton-Euler method to model the robotic arm on UAV. The following is a brief introduction to Newton-Euler dynamic modeling.

The basic principle of Newton-Euler dynamics modeling is to set out the dynamics equations separately by simplifying the motion of a rigid body to the translational motion of a particle and rotation around the axis of the center of mass, which is mainly based on Newton's second law and Euler equation. The dynamics equations gained can describe the state of the motion of the object and, meanwhile, obtain the position and attitude information of the object.

When modeling, analyze and divided whole rigid body system into several independent rigid bodies or subsystems. For the case of UAV with single-joint robotic arm discussed in this study, it can be simply divided into two rigid bodies for analysis. After determining how to divide the system, various parameters, such as the mass of the rigid body and the position of the center of mass, can be determined. Then the kinetic equations of translation and rotation can be established for each rigid body, and the interactions between rigid bodies should be taken into account and reflected in the equations. Finally, the equation can be solved by numerical method or analytical method to get the motion state of the rigid body, including position, velocity, acceleration and so on. When the rigid-body system is simple, the Newton-Euler method can obtain the result more quickly, which is also an important reason for adopting the Newton-Euler method in this study.

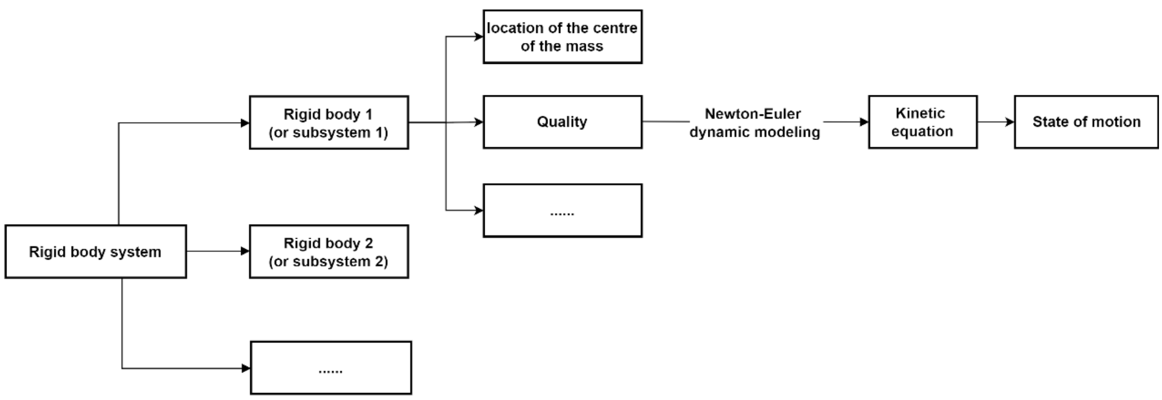

Figure 2. Process of newton-euler dynamics modeling.

In general, the single-joint robotic arm system on the UAV in this paper is divided into two rigid bodies for analysis, and the dynamics equations after their related parameters are obtained, so as to solve important parameters such as the position and pose of the robot arm, which can be used for subsequent adjustment of various parameters in the PID algorithm.

Considering that in actual tests or application, the robotic arm usually needs to bear a certain load. This load can be regarded as a point with mass at the end of the mechanical arm, or it can be regarded as a certain force at the end of the mechanical arm, in short, no matter what method is taken, this load needs to be reflected in the listed dynamic equations.

4. Combination of PID algorithm and newton-euler dynamic modeling

After basic introduction of PID algorithm and Newton-Euler dynamic modeling, this part will mainly discuss the possibility of combining the two methods to achieve stable hover of the UAV with single-joint robotic arm during operation through giving examples.

When combining, PID algorithm still plays an important role in UAV hovering, while Newton-Euler dynamic equation can analyze the attitude of the robotic arm-UAV system at every moment in the operation process, so as to obtain the overall gravity distribution, which can provide a prediction for PID algorithm, making the whole process stable and smooth.

Take one very promising application of UAV with robotic arm, food delivery, as an example. Under this circumstance, a weight sensor should be installed on the system, then the quality of the takeaway can be read, when the robotic arm is attached to it. Meanwhile, the value of the quality is reflected in the parameters of the PID algorithm to optimize the process. If the robotic arm simply drops vertically, then the effect of mass on the PID algorithm for hovering should be easy to summarize, and may even not need to use the Newton-Euler dynamics equation. However, when the delivery drone needs to make a series of actions such as “pass” or “take”, it is obvious that the posture of the robot arm becomes particularly important. In this case, it is necessary to use the Newton-Euler dynamic equation to analysis, and apply the mass of takeaway to gain the dynamic adjustment of each parameter in the PID required at each moment’s attitude. By this mean, the entire system will not “flip” at the moment when the center of gravity changes because of the changed attitude of the robotic arm. As can be seen from the above example of takeout UAV, while PID algorithm and Newton-Euler dynamic equation perform their respective functions, the conversion relationship between them is particularly important for the combination, that is, how to adjust the parameters in PID algorithm according to the results of Newton-Euler dynamic equation are obtained. For such a transformation relationship, it may be necessary to combine theoretical analysis with experimental tests to determine finally.

The following is an example of the possible influence of the change of the pose parameters of the robot arm on the P algorithm in the PID algorithm to show how the two are combined more intuitively.

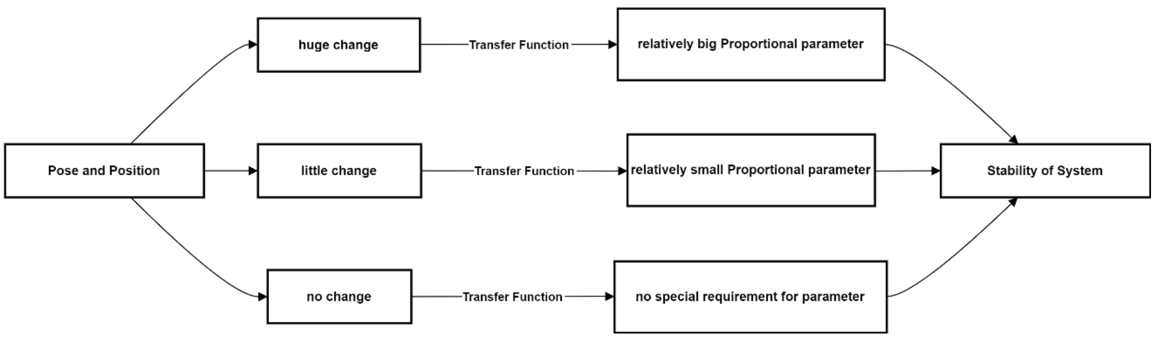

Figure 3. Possible influence of the change of the pose parameters of the robot arm on the p algorithm.

Takeaway-delivery drones are only a simple application of robotic drones, and this study mainly focuses on drones with single joint robotic arms. When the UAV is equipped with more joint and more degrees of freedom of robotic arms, which is more complex, then it can undertake more complicated tasks, and in this case, the conversion relationship mentioned above should be harder to be defined.

5. Conclusion

This study focuses on a possible design method for the UAV with a single joint robotic arm to complete the stable and accurate hover task, the combination of PID algorithm and Newton-Euler dynamic equation, and gives a brief introduction to both of them. PID algorithm consists of three parts, Proportional, Integral, Derivative, while Newton-Euler dynamic equation is applied to gain objects' information of attitude and so on. After analyzing the real example, it tells that the conversion relationship between them could be absolutely important, which could be carried out by accurate theorical calculation and a huge number of experiments. The process is difficult, so it can be seen that the research has certain limitations. The UAV with robotic arm undoubtedly has promising future. Except takeaway drone mentioned above, it can also take part in kinds of sorting work and so on. When the robotic arm is not limited to a single joint and has a higher degree of freedom, it can even participate in more complex work, such as some high-altitude operations originally needed to be artificial. Under this circumstance, the so-called conversion relationship is surely more complex and also one of the very promising research directions in the field of UAV and robotic arm in the future.

About the author

Zehui Zhou, male Research direction: Mechanical engineering topic: Research on the transmission system design, modeling, simulation and control algorithm of "Eye in the Sky" aerial robot manipulator- -take DJI UAV as an example.

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