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Research paper

An engineering-oriented motion accuracy fluctuation suppression method of a hybrid spray-painting robot considering dynamics

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ABSTRACT

Due to the complex dynamic characteristics of a hybrid spray-painting robot, the motion accuracy fluctuates in the workspace. In order to reduce the accuracy fluctuation of the hybrid robot, this paper proposes an engineering-oriented motion accuracy assurance method by considering dynamic characteristics, including workspace optimization and control parameters design. First, the dynamic model of the hybrid spray-painting robot is derived based on the virtual work principle, and a dynamic evaluation index is investigated to describe the possible maximum dynamic load. Then, based on the evaluation index, the relative location of the task workspace for painting an aircraft wing in the whole workspace is optimized. Then, a control parameters design approach is presented to ensure that the robot always has desired accuracy in the optimized task workspace. Finally, some experiments are performed, and the results show that the robot has better performance in the optimized task workspace with the designed control parameters, which proves the effectiveness of the proposed method.

1. Introduction

In the field of automatic spray-painting, serial mechanisms are widely used in different spray-painting systems due to their simple structure. Compared with conventional serial mechanisms, parallel mechanisms have larger load capacity, higher stiffness to weight ratio, and better dynamic performance potential [1–4]. However, parallel mechanisms have smaller workspace [5–7]. For the application of spray-painting, the parallel mechanism and the serial mechanism can be combined to construct a hybrid spray-painting robot.

Although the hybrid robot possesses both advantages of serial and parallel mechanisms in theory, there still exists the problem of motion accuracy fluctuation [8] in the workspace, which is caused by many complicated reasons. One of the main reasons is the performance mismatching between the mechanical subsystem and the control subsystem. The hybrid robot has the complex time-varying dynamic characteristics [9,10] in its large workspace, and the inertia of each driving joint changes with the configuration of the robot [11–13]. The time-varying dynamic characteristics make the control of hybrid robot more challenging. The mature industrial controller has stable performance but simple structure, and the traditional

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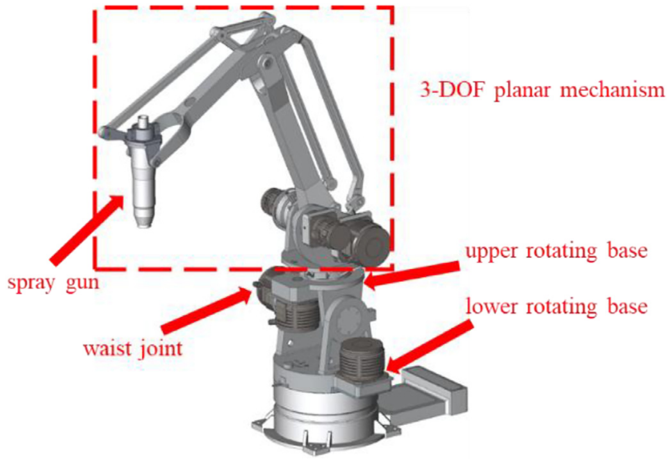

Fig. 1. A hybrid spray-painting robot.

control parameters design approach generally does not consider the time-varying dynamic load. So the motion accuracy fluctuates since the performance of two subsystems may not be always matched. In order to reduce the fluctuation of motion accuracy from the viewpoint of performance matching, the dynamic load variation in the task workspace should be suppressed and the control parameters should be appropriately designed. Thus, the workspace optimization and control parameters design by taking dynamics into account are two important issues related to the accuracy assurance of a robot.

For workspace optimization, the performance index of the robot is important and previous studies mostly concentrated on the kinematic performance of robot [14–18]. However, the dynamic performance of the robot is also worthy of attention since the dynamic load changes in the workspace. Some researchers have proposed some dynamic indices, such as the local and global dynamic conditioning indices proposed by Huang [19–21], and the torque index proposed by Zhao [22,23]. In addition, Liu [24,25] proposed performance indices from the viewpoint of force transmissibility. These performance indices are valuable in practical mechanical design and performance evaluation. However, the work on workspace optimization considering dynamics is still not enough, especially how to select the task workspace for better dynamic performance when the whole workspace is given.

For the control of hybrid robot [26,27], the PID closed-loop feedback controller are still the most widely used in industrial applications [28]. The conventional PID control parameters design approach is to adjust the control parameters repeatedly by using a small noise signal in one position until the servo system gets a satisfactory response, and the set of control parameters keeps unchanged during the motion process. The complex dynamic characteristics of the hybrid robot have not been taken into account. The robot can have a good motion performance in a limited region, while the motion accuracy will have quite strong fluctuations in the whole workspace since the robot inertia changes obviously. Considering the effect of dynamic characteristics, some researchers gave time-varying control parameters for different regions in the whole workspace, and the parameter update laws have been derived [29,30]. However, the time-varying control parameters may lead to the instability of mechatronic system.

This paper investigates the engineering-oriented motion accuracy fluctuation suppression method, which is a two-step method including the workspace optimization and control parameter design. For a specific spray-painting robot with an industrial control system, the task workspace is optimized to reduce the actual load fluctuation and facilitate the control system performance matching. Then, the control parameters are designed based on dynamic characteristics.

This paper is organized as following: Section 2 establishes the dynamic model of the hybrid spray-painting robot. Then the dynamic evaluation index is derived in Section 3. Section 4 obtains the optimized task workspace with lowest dynamic load. Section 5 gives the designed control parameters considering dynamics. The conclusion is drawn in Section 6.

2. Kinematic and dynamic modeling

2.1. Kinematics

As shown in Fig. 1, a 6-degree of freedom (DOF) hybrid spray-painting robot which consists of a 3-DOF planar mechanism, two rotating bases and a waist joint is designed. The 3-DOF planar mechanism with three parallelograms is mounted at the upper rotating base, which is connected to the waist joint and the lower rotating base, so the planar mechanism can rotate around the vertical axis and the horizontal axis. Considering that the 3-DOF planar mechanism has a more serious change of inertia in the whole workspace than the other structures, the dynamic characteristics of the 3-DOF planar mechanism is mainly considered in this paper.