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Evaluation of the dynamic performance variation of a serial manipulator after eliminating the self-weight influence

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ABSTRACT

Manipulators used in the industrial field usually have a very stiff structure but without an equivalent payload on their end-effectors. This is because the stiff structure is used to prevent excessive deformation which will negatively impact the positioning accuracy of the manipulator, especially when the manipulator is fully extended. However, the stiff structure increases the weight of the manipulator and consumes much of the output of the constituent joint actuators in order to overcome the gravitational force resulting from the heavy structure. To cope with this problem, the concept of gravity balance was proposed decades ago, and there have been several approaches suggested to eliminate the influence of the self-weight of the structure. With the help of gravity balance, the output of the constituent joint actuators can fully be used to drive the manipulator and save considerable energy when the manipulator is in static or low-speed applications.

For decades, many papers have discussed how to make a manipulator in gravity balance or how to design and apply a gravity balance mechanism to satisfy a certain application. However, none of them discuss what the influence on the dynamic performance of a manipulator is after it is equipped with a gravity balance mechanism or how to evaluate that influence. To rectify this insufficiency, this article utilizes acceleration radius to be the index of measuring the dynamic performance before and after a manipulator is equipped with a gravity balance mechanism and proposes a new index, the maneuverability ratio, to provide quantitative information to measure whether the dynamic performance of the manipulator increases or not after the gravity balance mechanism is applied.

1. Introduction

In the industrial field, many kinds of manipulators are designed to do assembly jobs on production lines. One common characteristic of these manipulators is that the weight of their arms is much greater than the payload at their end-effectors. This heavy weight results from the stiff structure which is used to prevent excessive deformation from negatively impacting positioning accuracy, especially when the manipulator is fully extended. The heavy structure increases the demand of the output of the constituent joint actuators which are used to counterbalance the influence of the heavy self-weight. For many applications, manipulators spend most of their work time on static or low-speed jobs and consume considerable amounts of energy to counterbalance their self-weight [1], thus increasing the operational cost.

To cope with this problem, the concept of gravity balance is proposed and successfully counteracts the adverse effects of self-weight. For decades, the gravity balance model and theory have been studied in a large volume of literature [2–22], and many special designs have been developed to successfully satisfy the requirements of different applications [1,23–31]. Meanwhile, the required actuator output which is used to perform a specific task before and after a manipulator has been equipped with a gravity balance mechanism has also been investigated in some studies [32]. However, as far as the author knows, none of the literature discusses what the variation in dynamic performance is before and after a manipulator is equipped with a gravity balance mechanism, and they all focus on how to eliminate the influence of the self-weight or the required actuator output used to perform a specific task after a gravity balance mechanism is applied. Because manipulators are not just designed for or dedicated to static or low-speed applications and certainly not just designed for a specific task, this will lead to insufficient conclusions. How the gravity balance mechanism influences the dynamic performance of a manipulator needs to be considered. To rectify this insufficiency, this article utilizes acceleration radius to evaluate the dynamic performance before and after a manipulator is equipped with a gravity balance mechanism, and this article also proposes a new index, the maneuverability ratio, to provide quantitative informa-

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