

Design of Balanced Mechanisms Based on Reconfiguration for Space Applications

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Abstract. Often, one achieves the dynamic balancing condition by resorting to counter-devices approach, however, by doing this, one adds extra weight and therefore the inertia are increased inside the whole system, which is not cost-effective when the system is sent into space and later used in space. In this study, it is suggested one is able to achieve the reactionless condition through combining the self-balanced system. For example, the dynamic balancing condition can be realized via the reconfiguration concept. Extra counter-mass is not employed but through reconfiguring the whole structure, in this way, the system will not get to be heavy and therefore, reduce the energy costs and make the system more applicable and flexible for space applications. Based on this concept, first and foremost, one needs to balance a single component through the reconfiguration approach (i.e. decomposition process) and after that integrate the above balanced components to build the entire system (i.e. integration process). Finally, with the mechanical reconfiguration, the control laws governing the operation of the mechanism also need to be changed, so as to make whole systems more flexible when they are used in space.

1. Introduction

When mechanisms move, because the center of mass (CoM) of the system also moves and the angular momentum is not constant, vibration is therefore exist, which greatly affect the accuracy performance when the system is employed in space, especially for those are conducting high speed tasks in space applications. How to reduce those vibrations and therefore to have a flexible system used in space has become a common desire. The space flexible system concept has been widely advocated by many industries and scholars. In the space applications and its arena, the space flexible system can be simple put as this way, increase productivity and flexibility without comprising other conditions. Take the delta robot as an example, when the robot is used in space or operates in other applications, because the whole system is not dynamic balanced, the whole system will vibrate and therefore will significant affect the accuracy performance and sometimes can delay the productions.

1.1. Approach 1 - Prior to Structural Synthesis

A Dutch scholar thoroughly investigated this approach in his work [1]. Other approaches can be referred to [2-4].

1.2 Approach 2 - After Structural Design

In [5], the CRCM-based approaches were put forward. The first is the low inertia pattern approach, the second is the CRCM approach and the last is the ground CRCM balancing principle. The merit of the first approach is that the system has low inertia. The merit of the second approach is that only a single



CRCM is essential for the moment balancing. The merit of the third approach is that the system has compact construction. The single CRCM structure is not a wise approach due to a pair of gears being added to the top movable linkage instead of the ground. However, the downside of the CRCM that is close to the base structure can be concluded as follows: the CRCM gears to moment balance the top movable linkage is on the ground linkage, which causes the mechanism to be heavier. Other approaches can be referred to [6-11].

2. Dynamic balancing via reconfiguration concept

Two masses are put in the bottom, as shown in Fig. 1, and the whole system is force balanced. When we spin this system, it is also dynamically balanced. When we move one mass slightly up, and we spin the system again, it will not be dynamically balanced anymore. So how can one rearrange this system to regain the dynamic balanced condition?

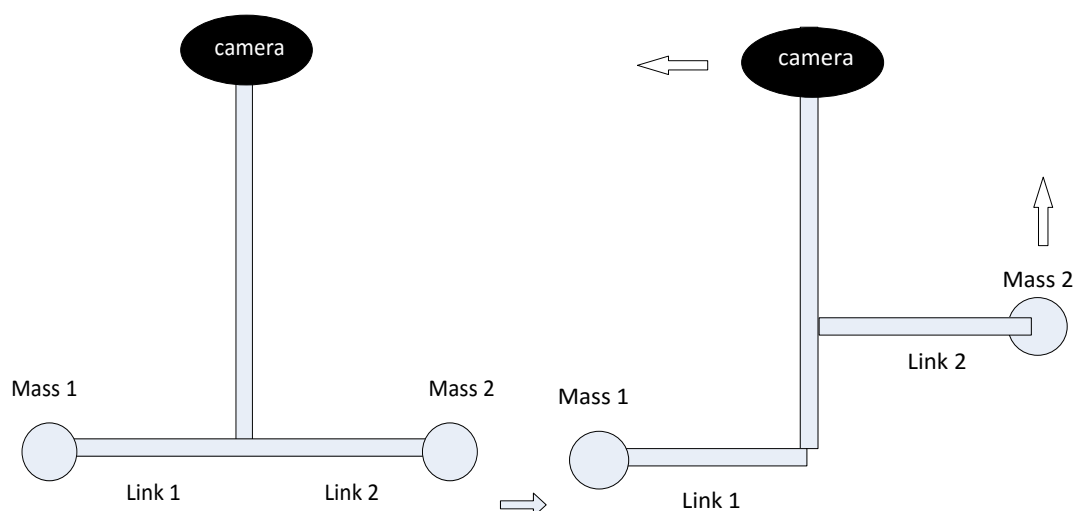


Figure 1. Simplified version of SteadiCam

Consider that one shifts the linkage 2 to a different position all the way to the top, in order to regain the balancing condition, the only way we can do is that to move the camera in a same fashion direction all the way to the left, same goes to the mass 1 but move it to the bottom. In the end, we have the same situation, it is just that there are two masses in the top and one mass in the bottom instead of two masses in the bottom and one mass in the top. From the above, it is observed that when we have the same mass relations, we can keep the system balanced.

Inspired by the above, dynamic balancing via reconfiguration is therefore put forward, which will not increase the weight of the whole system, i.e. to have a more flexible condition, so as to further improve its accuracy performance.

The purpose of using counter-weight is to make the CoM move to a fixed position. Now is it possible to achieve this by using another approach? We can re-position the linkage to make its CoM to move to a fixed position, for example, to make it move to the joint position. In this way, one does not use any extra counter-devices, and therefore the system will not get to be heavy. Based on this concept, first and foremost, one needs to balance a single component through the reconfiguration approach (i.e. decomposition process) and after that integrate the above balanced components to build the entire system (i.e. integration process).

By applying this concept to multi-DOF serial manipulator systems and other kinds of systems, new dynamic balanced multi-DOF and other systems are able to be generated, which will be presented in the following section. It is observed that the above approach will not make the system heavier or make the system have more inertia. Whereas by using the old adding counter-devices approach, one potentially puts a negative effect onto the system in terms of mass and inertia.

3. Decomposition and integration for space flexible system

Regarding the crank-slider system, it can be considered as three-linkage open chain, the end linkage is a slider which does not rotate and it only translates. Due to the fact that the end linkage does not rotate, the CoM of this linkage is in any point on this linkage. Using similar approach, one can achieve the balancing condition through reconfiguration. The crank-slider that is balanced via reconfiguration can be employed to be functioned as a Scott-Russell system to replace the traditional Scott-Russell system [8], and we integrate it into the linkage of the 3-RPR robotic mechanism to re-synthesize the whole system, as illustrated in Figure 2, which can be potentially used in space.

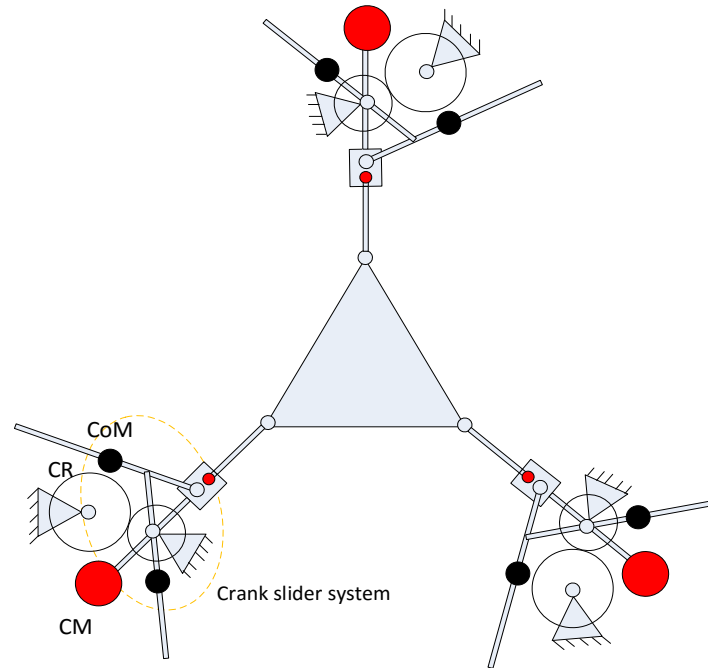


Figure 2. Dynamic balanced 3RPR planar parallel manipulator

4. Reconfiguration Control

In [12], a model reference adaptive fuzzy control system was designed for the multi-input and multi-output plant model to control an uncertain flexible joint manipulator, and the control system was approved stable by resorting to the Lyapunov approach. The novelty of the above study is that by introducing the fuzzy modelling and fuzzy model based control system into the MRAC, the new control system design can achieve the trajectory tracking effectively in spite of parameter perturbation and manipulator model uncertainty. In [13, 14], a new type adaptive control system was developed by combining an intelligent supervisory loop and the MRAC, and based on this, four different control strategies were derived, and it was applied to a single link flexible robotic manipulator. The feasibility of the design approach was verified. In [15], the control issue for an uncertain robotic manipulator with input saturations and unknown input scaling was studied by resorting to the MRAC. The MRAC was used to handle the input saturations, the unknown input scaling was rejected by the non-regressor procedure, and the robotic manipulator's uncertain dynamics were managed by the known function regressor. In [16], A MRAC algorithm using fuzzy logic adjustment of reference model parameters was designed and used in robotic manipulators. The algorithm was designed in a way in order to deal with complex environment conditions that the robotic manipulator could possibly go through. The intention of the designed control system was to ensure automatic change of the controller parameters so that they match with the current robotic manipulator environment.

There are many other types and forms of model reference adaptive control systems that are in the same family category of the above MRAC. The main strategy inside the MRAC system is that the dynamic parameters of the plant model (e.g. a space robot) are constantly being adapted and adjusted by the adaptation algorithm, and this adaptation algorithm is mainly formed by the output of the plant

model and the reference model. The main purpose of adaptation is to compensate the parameters change effect in the plant due to outside disturbances. The main difficulty that one faces during the reconfiguration or adaptive control system design is the development of the adaptation algorithm. There are mainly two approaches to design the adaptation algorithm, one is based on the Lyapunov stability theorem, and the other is based on the hyper-stability theorem. In space applications, accuracy is critical for a task. For pure mechanical systems, how to have a control system that has strong adjustability and reconfigurable capability to cope with the unexpected disturbances in space is the common desire. Control reconfiguration mainly refers to adjust/change the control system structure or add an extra control component inside the whole control system in a way that the control system can handle the mechanical change. There are many articles that are dealing with hybrid control design by combining the adaptive control and other control systems, the purpose of which is to make the control system have more adaptability and move the robotic system move more smoothly.

The control system's stability performance is crucial because it is hard to develop a stable adaptation rule. Usually, for a given plant model, we can develop a stable adaptation rule, but when the plant model slight changes, for example, to cope with outside disturbances in space, the stable condition can be easily broken. This issue is worth further to be further addressed in the future, and to develop a general stable adaptation algorithm for a general type of system that are used in space and other areas. The other issue one faces is that MRAC system depends on cancelling the non-linear segments via the reference model.

5. Conclusion

In this paper, the authors presented the methodology of dynamic balancing via reconfiguration for space flexible systems, and therefore the robotic system is not getting to be heavy, which is very important when the system is sent into space and therefore, reduce the energy costs and also to make the system more flexible when used in space. After dynamically balancing a component via the reconfiguration approach, one then integrates the balanced components to build the entire system. New reactionless mechanisms can be obtained via the methodology of decomposition and integration and via resorting to reactionless structures. The mechanism and control system interconnect with one another. When one conducts the mechanism reconfiguration, the corresponding controller needs to be adapted as well. The reconfigured system is briefly discussed. Future research will focus on new model reference adaptive control system design for space flexible mechanisms and also connect the mechanism system safety issue with new model reference adaptive control, i.e. through controlling to achieve system safety when they are used in space.

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