A COBOTIC AND FLEXIBLE SOLUTION FOR HANDLING OF HEAVY LOADS

Vigen ARAKELIAN[1, 2]

[1]*INSA-Rennes / Mecaproce, 20 av. des Buttes de Coësmes, CS 70839, F-35708 Rennes, France*
[2]*LS2N / ECN UMR 6004, 1 rue de la Noë, BP 92101, F-44321 Nantes, France*

Abstract
The aim of the work is to describe the Cobot++ project solution to develop a modular system that combines a cobot and a balancer. Such a system to be able to co-manipulate heavy loads by increasing the capacity of a classic cobot, often limited to loads of less than 10 kg. In the paper, the advantages of the coupled cobot and balancer are disclosed, as well as the optimal design of the cooperative workspace is discussed. The behavior of the coupled system in the static mode under the limitation of the speeds of the cobot does not present any special problems. In this case, the inertial forces are much less than the gravitational ones. The payload is fully compensated by the balancer and the cobot assumes the prescribed displacements. However, in dynamic mode, massive links of the balancer creates additional loads on the cobot, which can be significant. This study considers a method for determining the inertial impact of the balancer on the cobot. Numerical simulations show a significant increase in input torques due to inertia forces of the balancer. It should be noted that the study carried out in the framework of the Cobot++ project took into account safety and ergonomics issues to arrive at a solution compatible with industrial constraints.

Key words: *handling of heavy payloads; balancer; gravity compensation; cobot; dynamic behaviour.*

INTRODUCTION

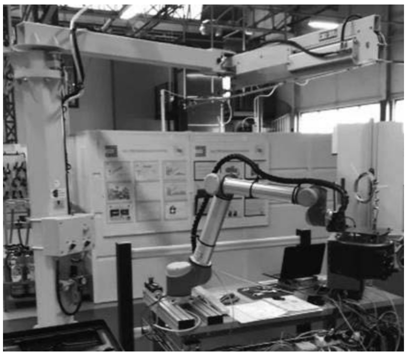
Workers in industries such as manufacturing and assembly often handle heavy objects. However, manual handling is often repetitive and tedious, reduces efficiency, and leads to back pain and musculoskeletal disorders. It is obvious that industrial robot applications can have a number of advantages over manual control: improved repeatability, increased accuracy and speed. However, industrial robots still have many disadvantages compared to humans. For example, industrial robots currently have a limited ability to perceive their surroundings requiring costly safety measures to avoid serious injury. These safety measures are especially important and expensive when working with large and powerful industrial robots. Obviously, serial robots have a poor payload-to-weight ratio (*Taghirad, 2017*). For example, a manipulator working with a payload of 50 kg must have a weight of at least 400 kg. The purchase, installation and operation of such a robot is quite expensive. In addition, the heaviness of the robot and load leads to rather complex system dynamics, which makes it difficult to move accurately and quickly. This becomes especially noticeable during the assembly process, when heavy parts must be installed on the surface using guide pins. In this case, the manipulator should move smoothly, without significant vibrations, and any sudden movement can damage the mechanical surface of the part. Such a task is not easy to accomplish. Thus, autonomous manipulation does not always provide the expected reliability and flexibility. The aim of the study is to describe the Cobot++ project, which is a new design solution combining a cobot and a balancer.

ADVANTAGES AND FEATURES OF THE COUPLED COBOT AND BALANCER

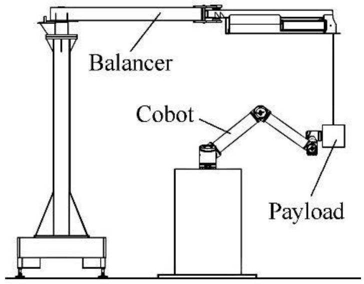
In all likelihood, balanced robotic systems, such as cobots coupled with balancers, can be effectively used to handle heavy objects. The combination of motion programming for a cobot and the simplicity of a balancer arm can make a system much better than using an industrial robot arm.

Design and application of balancers is a well-known problem. Different approaches and solutions devoted to these systems have been developed and documented (*Matsumoto, 1975; Patarinski, Markov, Konstantinov, 1985; Bittenbinder, 1995; Moor, Akouna, 2003; Arakelian, 2004; Arakelian, Briot, 2015; Arakelian, 2016; Arakelian, 2022*). They have found wide application in several fields of industries, where it is necessary to mechanize heavy manual labor. Now consider the collaboration of a cobot and a balancer for handling of heavy parts. In other words, consider a new-coupled system in which the operator is replaced by the cobot (Fig. 1).

a) Balancer controled by the opertator.



b) Coupled system in which the operator is replaced by the cobot.



c) Schematic representation of the coupled system.

Fig. 1 Coupled system consisting of a cobot and a balancer.

At present, given the great capabilities of cobots that allow human intervention to control the payload, such a cooperation becomes much more effective, since it does not exclude the possibility of human presence in the cobot's workspace. Note that this is optional purpose. However, in some circumstances this may be the most optimal solution. Thus, it can reduce security measures compared to the use of industrial robots, since the space can be shared.
When designing coupled systems, it is necessary to keep in mind that they consist of two units with different characteristics. However, some of their parameters can be modified during the interaction of these units. One of the first is the consideration of constructive conformity, i.e. the balancer must accompany any payload movement performed by the cobot. If there is a discrepancy between the movements of these two units, the coupled system will be blocked. From this point of view, it is of particular importance to take into account the singular configurations of both the cobot and the balancer.
Figure 2 shows an example when the balancer is in the singular configuration.

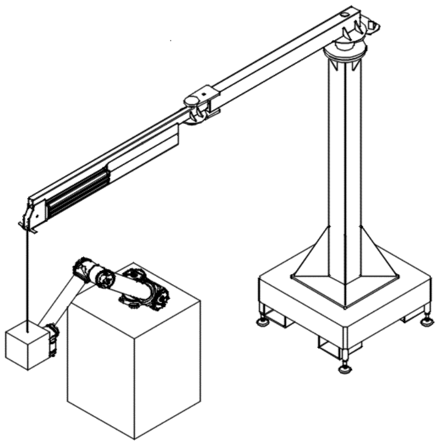
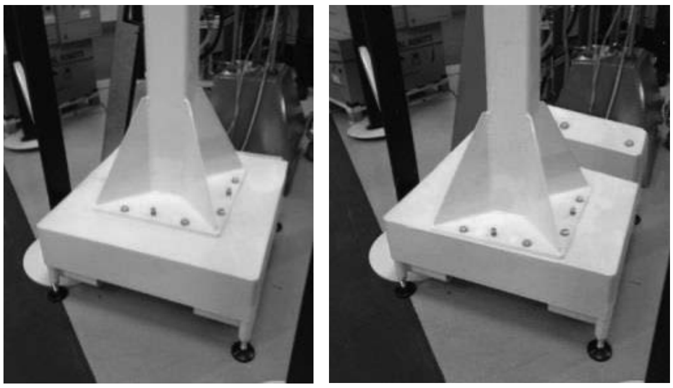


Fig. 2 Coupled system in which the balancer is in the singular configuration.



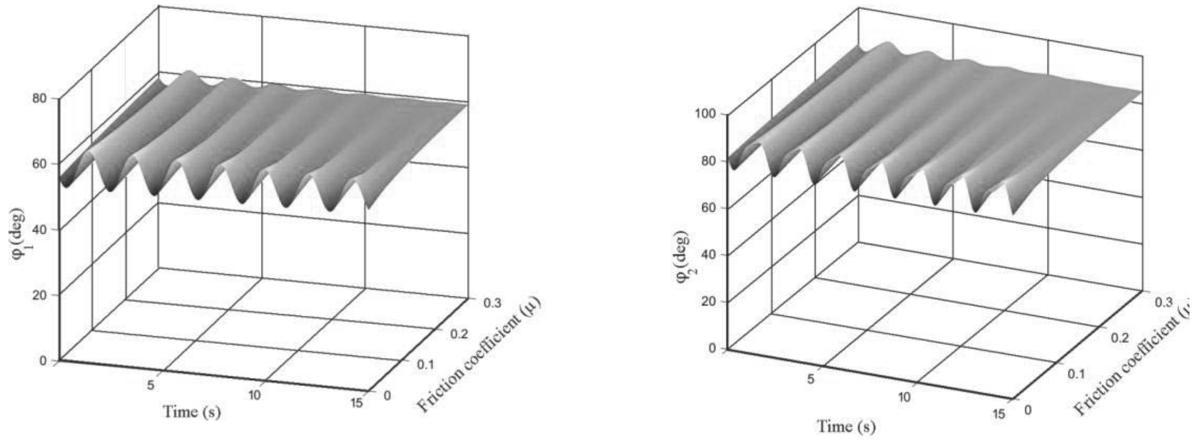
(a) (b)

Fig. 3 Frame of the balancer (a) and its modified version (b) for cobot - balancer cooperation.

In the case of a traditional use of the balancer, this configuration is not inconvenient, since the operator will not move the payload in the radial direction. He will move the payload in such a direction that allows the balancer to come out of the singular position. Then, the operator will perform the necessary movements. However, in a coupled system, it is imperative to consider this when planning the path of the cobot, because one can impose such movements of the cobot, which cannot be carried out by the balancer. Thus, it is necessary to avoid not only singular configurations of the cobot, but also the balancer. The design of the units can also be changed. In the coupled system with common workspace, the balancer uses only a small part of its accessible space due to the workspace of the cobot, which is generally limits the common volume. Thus, the design of the balancer can be modified to adapt to new conditions. The vertical axis of the balancer can be moved closer to the cobot, and the gravity balancing can be adjusted by a counterweight as shown in figure 3. Such an arrangement is more optimal in terms of cooperative workspace.

STATIC AND DYNAMIC BEHAVIORS OF THE COUPLED COBOT AND BALANCER

The behavior of the coupled system in static mode when the speeds of the links of the balancer are limited does not present any particular problems. In this mode, the inertial forces are much lower than the gravitational forces. The payload is completely compensated by the balancer and the cobot supports low loads. However, when the accelerations increase, the inertial forces also increase and, respectively, the efficiency of gravitational balancing decreases. Therefore, the balancer with massive links creates additional loads on the cobot. Our observations have shown that the behavior of the coupled system in dynamic mode is completely different for the balancer, assuming gravity compensation of the payload. In this case, dynamic loads on the cobot occur in the form of the balancer's oscillations at the end of the working cycle when the cobot is stopped. These oscillations essentially depend on the friction in the joints of the balancer. Such dependence is shown in figure 4. One of the ways to reduce these unwanted vibrations is to increase the friction on the balancer's joints.



a) Oscillations of the first link of the balancer with cable lift after stopping the cobot.

b) Oscillations of the second link of the balancer with cable lift after stopping the cobot.

Fig. 4 Oscillations of the rotating links of the balancer with cable lift after stopping the cobot.

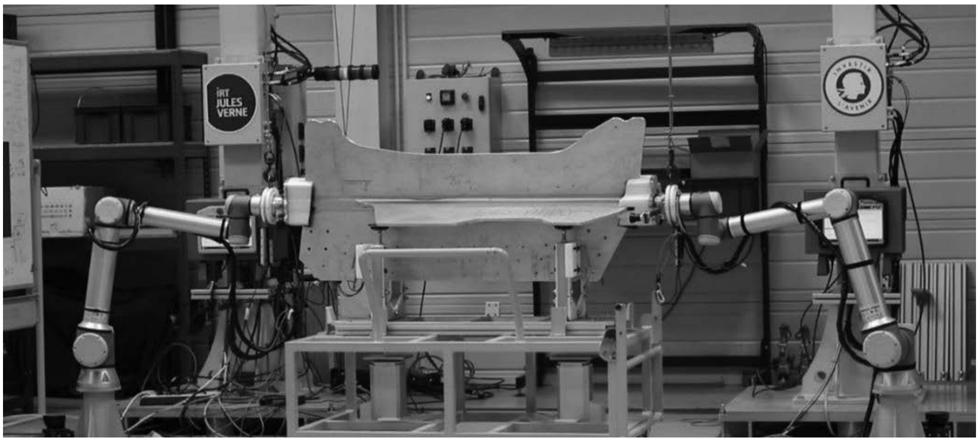


Fig. 5 Two coupled cobot/balancer systems developped for AIRBUS Nantes.

Unfortunately, the increase in friction in the balancer's joints creates a drag force that the cobot has to overcome in any movement. Then two efforts compete: 1) the inertial force due to the oscillations of the balancer, and 2) the drag effort created by the friction. A decrease in the first means an increase in the second. Thus, it is necessary to find the optimal friction so that the drag force will be minimized and the vibration reduction remains effective. Such an optimization highly depends on the application for the coupled system. Indeed, the efforts will mainly depend on the friction, of course, but they will also depend on the accelerations and trajectories imposed by the cobot and the payload. A more detailed discussion of this issue can be found in (*Zhang et al., 2019*).
The application of the described above solution to move a payload of 30 kg was tested on an assembly line at the SAUNIER DUVAL site in Nantes (*https://www.youtube.com/watch?v=vWx53wem_zo*). A demonstrator for heavy and long payloads consisting of two coupled cobot/balancer systems (Fig. 5) for a part turning application during adjustment operations for AIRBUS Nantes has also been developed (*https://www.youtube.com/watch?v=0YiIAFwk3zk*).

CONCLUSIONS

This study deals with the main characteristics of coupled balancers and cobots. It is disclosed the particularities of design of the cooperative workspace, the need to consider singular configurations of the balancer and the cobot. It is revealed that in dynamic mode, the massive-link balancer creates additional loads on the cobot, which can be significant. Observations and tests, as well as numerical simulations have shown the significant increase in input torques of the cobot due to the inertial forces of the balancer. Behavior of the balancer with cable lift and the cobot has been also examined. It is disclosed that there are significant oscillations of the rotating links of the balancer with cable lift after stopping the cobot. It is proposed to eliminate these unwanted oscillations by controlling friction in the joints of the balancer. The author believes that the proposed solution is promising because it is not expensive taking into account the coasts of a balancer and a cobot. It can be easily applied to solve various problems related with the moving of heavy payloads. The coupled balancer/cobot systems can be widely used in various engineering projects.

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Corresponding author:
Prof. Vigen Arakelian, Department of Mechanical and Control Systems Engineering, INSA Rennes, 20 av. des Buttes de Coësmes, CS 70839, F-35708 Rennes Cedex 7, France, phone: +33223238492, e-mail: vigen.arakelyan@insa-rennes.fr