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Energy Saving in Pick and Place Operations using Parallel Robots and their Natural Motion

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Abstract

The European Union has set a target for 2020 of "saving 20% of its primary energy consumption compared to projections […] as a key step towards achieving long-term energy and climate goals" [1]. According to the Energy Efficiency Plan, "about 20% of the EU's energy consumption is accounted for by industry" [1]. Although this sector has made most of the progress in energy efficiency, energy saving opportunities still remain. Moreover, the plan explains that expertise in energy efficient processes, technologies, and services "can also be turned into a new export business, giving a competitive edge to European industries" [1]. Various strategies for saving energy in robots have been proposed [2, 3], such as using lower consumption modes, recovering kinetic energy in capacitors or implementing optimal trajectories. This is especially important in the light of the result of other studies that show the potential of robots in terms of energy savings. For example, in [2] it is reported that 15% to 28% of an automobile energy consumption during its life cycle occurs within the production phase, and 8% of the energy consumed on the assembly lines is due to robots. In general, the search for energy- efficient robots is still under development.

One of the most common tasks of industrial robots are pick and place operations, being the SCARA and the DELTA two of the most commonly used manipulators for this task. According to [4], "in pick and place operations, a robotic manipulator is meant to take a workpiece from a given initial pose, specified by the position of one of its points and its orientation with respect to a certain coordinate frame, to a final pose, specified likewise". This task involves a high speed oscillatory motion between the pick and the place position and reusing the energy that the mechanism can return in parts of the cycle could significantly increase the energy efficiency and reduce the load on the actuators.

Elastic elements (i.e. springs) can be attached to the robot, so that the natural motion (free response to initial conditions) of the system is such that the end-effector matches the required final point in the required time after starting from the pick position [5]. Another way of looking at this is in terms of energy. When the elastic elements are added, "most part of the required energy to carry out the task can be supplied by the elastic elements instead of the actuator" [6]. This happens because the elastic elements store energy in part of the cycle as potential elastic energy and then release it to the rigid bodies, increasing their kinetic energy. Then they return the energy to the springs, and so on. In the absence of dissipative forces, the robot would continue oscillating indefinitely, but in real systems energy is dissipated via friction forces in the joints and the structure. Consequently, the actuators need to compensate the dissipated energy [6]. However, if the actuator only must counteract the effect of dissipative forces and guide the mechanism through the desired trajectory, instead of introducing all the necessary energy for every cycle, then the energy expenditure will be reduced.

Only a few works have analyzed the impact of natural motion on the performance of an industrial robot. Goya et al [7] proposed in 2012 to exploit the natural motion of a SCARA robot for pick and place operations, finding an energy saving of 72% in a pick and place operation with two different sinusoidal trajectories. However, the use of natural motion in parallel robots can be much more complicated, because of the complexity of the kinematics and the control. For example, while in a SCARA robot the motion of the links occurs in a single plane and is controlled by two independent motors, the DELTA is a three-dimensional robot with more complex kinematics and it requires the simultaneous control of three different motors. This background has motivated a project with the following research question: Is it possible to add elastic elements to a DELTA robot and implement a control strategy, in such a way that the performance of the robot with this configuration is better than the performance of the original robot?

Some of the key aspects of the project include: finding the required characteristics of the elastic elements that yield to a desired natural motion of the system, finding the optimal trajectory that the system should follow, and designing a controller that guarantee the execution of the optimal trajectory and the optimal torque.

The first part of the project has been focused on solving these questions for a five-bar linkage, with the idea of being able to apply the same principles to the DELTA or other parallel robots. In [5] a methodology for finding the optimal springs which take the end-effector of a five-bar mechanism without friction from the pick to the place position in the desired time without using any energy or torque from the motors was presented. Another result derived from this analysis was the optimal trajectory followed by the end-effector.

Based on this motivation and background, a new methodology for finding the optimal trajectory (and optimal torque) for a general pick and place task using a Five-Bar Linkage and a simple friction model will be presented. In addition, a study on how the energy consumption varies taking into account the variation on the task requirements will be included as well as a procedure to determine the optimal combination of springs considering this variations. Finally a discussion on possible controllers will be carried out. The controller should guarantee that the optimal trajectory is followed by the end-effector during the real operation of the system, where the task characteristics (pick position, place position and time) vary, the behavior of the system is not perfectly predictable and the time for calculations is very short.

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