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# Are Parallel Manipulators More Energy Efficient?

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## Abstract

The energy efficiency of a robotic manipulator is important, particularly when that manipulator is used in conjunction with a mobile robot with limited battery life. In this paper the energy efficiency (in terms of the electrical energy usage) of a spatial three DOF parallel manipulator is compared to a serial manipulator with the same drive motors and a similar workspace. The effects of end-effector position, velocity and acceleration, and static loading due to gravity are examined. Over a range of conditions, the average energy usage of the parallel manipulator was determined to be 26% of the serial manipulator's. This benefit is not due simply to the reduction in moving mass achieved by the parallel design since its moving mass is 70% of the serial manipulator's. Static loading due to gravity was found to roughly double the power usage of both manipulators without significantly affecting their relative energy efficiency.

## 1. Introduction

As pointed out by Carlisle [1] at ICRA 2000, today's industrial robots are far less efficient than human beings, and any improvements in manipulator energy efficiency would be both economically and environmentally beneficial. Also, when a robotic manipulator is used in conjunction with an untethered mobile robot (either to interact with the environment or to assist in locomotion) its energy efficiency is crucial to extending battery life.

Previous work related to the energy efficiency of robots has focused on either path planning of conventional manipulators or gait planning for walking machines. Mayorga, Wong and Ma [5] describe an efficient local path generation approach for redundant or nonredundant manipulators which minimizes energy while avoiding both obstacles and singularities. Lee and Yamakawa [3] present a method for planning a minumum-energy collision free path which also maximizes the available dexterity. Marhefka and Orin [4] and Silva and Machado [7] analyze the problem of energy efficiency in walking machines and optimal parameter selection, while Gregorio, Ahmadi and Buehler [2] describe the design and control of an energy efficient monopod.

To our knowledge no researchers have studied the influence of the mechanism type used for a manipulator on its energy efficiency. The objective of this paper is to compare the energy efficiency (in terms of the electrical energy usage) of a parallel manipulator to a serial manipulator with the same drive motors and a similar workspace. The effects of end-effector position, velocity and acceleration, and static loading due to gravity, will be investigated.

## 2. D.C. Motor Efficiency

Before studying the manipulators' power usage it is useful to examine the efficiency of the D.C. motors which are used with most robots. With a D.C. motor, the armature current is proportional to the motor torque:

$$i_a = \frac{\Gamma}{K_m} \tag{1}$$

Where $\Gamma$ is the motor torque and $K_m$ is the torque constant. The motor armature voltage is:

$$V_a = K_b\dot{\theta}_m + L_a\frac{di_a}{dt} + R_a i_a \tag{2}$$

Where $\dot{\theta}_m$ is the motor velocity, $K_b$ is the back e.m.f constant, $L_a$ is the armature inductance and $R_a$ is the armature resistance. The instantaneous motor power usage can be calculated using:

$$P_{elect} = V_a \times i_a \tag{3}$$

The mechanical power output is:

$$P_{mech} = \Gamma \times \dot{\theta}_m \tag{4}$$

The efficiency of the motor can be defined as the ratio of the power output to the power input, i.e. $P_{mech}/P_{elect}$. Efficiency curves for a D.C. brushless motor are plotted in Figure 1. Each curve is for a constant value of $i_a$ and $\Gamma$. The parameters for this particular motor are: $K_b$=7.5 V/krpm, $K_m$=0.06 Nm/A, $L_a$=0.8 mH and $R_a$=1.0 ohm.