A New Concept of Actuation for Robotic Manipulators

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A large number of practical applications involve robotic manipulators having a spatial kinematics as to be suitable to accomplish some design tasks. For instance, often robots are characterized by an anthropomorphic kinematics in order to be able to replicate human movements. It is not uncommon that such systems have to generate constant forces for relatively long times. Active robotic systems offer the advantage of an unconstrained choice of kinematics, but they may imply significant energy consumptions (motors actuating joints), and in general their architecture is not intrinsically safe (the failure of a sensor could lead to instability etc.). On the other hand, passive systems do not entail any energy consumption and they are intrinsically safe, but their kinematics cannot be arbitrary and they need a manual tuning.

In this work we present a new concept of actuation for robotic manipulators, aiming at creating a hybrid system with the advantages of active and passive systems, without their drawbacks. The idea is inspired by gravity balancing techniques using passive elements (e.g. springs): the physical concept is that the total potential energy of a system is made to be constant, regardless of its kinematic configuration. This means that the system is always in indifferent equilibrium and it does not need any external force/torque to be kept in equilibrium in any configuration. As an example, see Fig. 1 where a 1-dof link is gravity balanced using a properly installed zero-free length spring. Although such kind of spring does not exist in the real world, the same behaviour can be obtained, for instance, using a real spring and a system of cable and pulleys.

The idea of gravity balancing is not new and there are several works about it. However, often they are limited to planar kinematics. Some tentatives for extending such idea to spatial kinematics are generally complicated and bulky.

We reformulated a simple gravity balancing approach for a general serial spatial manipulator, using \( n \) springs for a \( n \)-dof manipulator (Fig. 2).

The idea of balancing can be extended to the more general idea of actuating: indeed, with suitable changes in the design, it is possible to maintain the principle of constant total potential energy of a system even when exerting a desired force. The new actuation concept developed allows to exert a force of variable intensity and spatial orientation at the level of the end effector of a generic spatial serial manipulator without any motor torque required during any movement. A motor torque is necessary only when a change of the exerted force’s intensity and/or orientation is requested, implying the change of some of the springs’ attachment points. This results in reduced energy consumptions and highly simplified controller (only a position control), making the manipulator intrinsically safe for users interacting with it.

The design of a wearable anthropomorphic arm actuated with this technique is being finalized at Percro, SSSA. In the opinion of authors, the intrinsic safety and the low energy consumption of this kind of devices make them very promising for future robotic applications.

REFERENCES


Fig. 1. Balanced 1-dof link (a) and possible real implementation (b).

Fig. 2. Part of a generic spatial manipulator (a) and its generic link \( i \) (b).