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Impedance control

Impedance control is an approach to the control of dynamic interaction between a manipulator and its environment. This type of control is suitable for environment interaction and object manipulation.

We are interested in controlling the mechanical impedance of a mechanism. Using the analogy to electrical impedance where impedance is the ratio of voltage output to current input (e.g. resistance is voltage divided by current), mechanical impedance is the ratio of force output to motion input. A "spring constant" defines the force output for a tension or compression of the spring. A "damping constant" defines the force output for a velocity input. If we control the impedance of a mechanism, we are controlling the force of resistance to external motions that are imposed by the environment.

Mechanical admittance is the inverse of impedance - it defines the motions that result from a force input. If a mechanism applies a force to the environment, the environment will move, or not move, depending on its properties and the force applied. For example, a marble sitting on a table will react much differently to a given force than will a log floating in a lake.

The key theory behind the method is to treat the environment as an admittance and the manipulator as an impedance. It assumes the postulate that "no controller can make the manipulator appear to the environment as anything other than a physical system." Hogan's rule can also be stated as: "in the most common case in which the environment is an admittance (e.g. a mass, possibly kinematically constrained) that relation should be an impedance, a function, possibly nonlinear, dynamic, or even discontinuous, specifying the force produced in response to a motion imposed by the environment.[1]

Principle

Impedance control doesn't simply regulate force or position of a mechanism. Instead it regulates the relationship between force on the one hand and position, velocity and acceleration on the other hand, i.e. the impedance of the mechanism. It requires a position (velocity or acceleration) as input and has a resulting force as output. The inverse of impedance is admittance. It imposes position. So actually the controller imposes a spring-mass-damper behavior on the mechanism by maintaining a dynamic relationship between force and position, velocity and acceleration: F = Ma + Cv + Kx + friction + static force.

Mass and spring (stiffness) are energy storing elements, while a damper is an energy dissipating element. So if we can control impedance, we are able to control energy exchange during interaction, i.e. the work being done. So impedance control is interaction control.[2]

Note that mechanical systems are inherently multi-dimensional - a typical robot arm can place an object in three dimensions (x, y, z coordinates) and in three orientations (e.g. roll, pitch, yaw). In theory, an impedance controller can cause the mechanism to exhibit a multi-dimensional mechanical impedance. For example, the mechanism might act very stiff along one axis and very compliant along another. By compensating for the kinematics and inertias of the mechanism, we can orient those axes arbitrarily and in various coordinate systems. For example, we might cause a robotic part holder to be very stiff tangentially to a grinding wheel, while being very compliant (controlling force with little concern for position) in the radial axis of the wheel.

Applications

Impedance control is used in applications such as robotics as a general strategy to send commands to a robotics arm and end effector that takes into account the non-linear kinematics and dynamics of the object being manipulated.[3]

References

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