Position and Force Control for Active Compliance

There are two simplest and opposite manipulator models used for the *active compliance control*: *position control* model and *force control* model.

In pure position control the user is allowed to specify the end-effector's position trajectory p(t) completely. In pure force control the user provides a vector function f(t) which specifies the forces to be exerted by the end-effector.

The *distinction between force control and position control* may be illustrated by considering the conceptual extremes:
(i) If the manipulator tip is buried in an immobile stiff solid substance, then there is no positional freedom at all, and pure position control is meaningless. However, the manipulator will have complete force freedom, since any force it wishes to expert will be "accepted" by the solid substance. In this instance, pure force control of the manipulator is appropriate.
(ii) If at the manipulator is in free space, there is no degree of freedom for force, because there is no possible source of the required reactive force. Since there is no constraint on manipulator position, pure position control is now indicated.

It appears that pure *position and pure force control are dual concepts*, and that the historical emphasis on position control is the natural result of applications which involve very little physical contact.

C-surfaces and the position/force control of manipulators

Intermediate between the extremes of solid space and free space are surfaces in the *configuration space,* called *C-surfaces.* Loosely speaking, a C-surface is a task configuration which allows only partial positional freedom [Mason, 1981]. Freedom of motion occurs along C-surface tangents, while freedom of force occurs along C-surface normals.

Neither pure position nor pure force control is appropriate in this case, but rather a hybrid mode of control, which gives control of end-effector force along the C-surface normal and control, end-effector position along the C-surface tangent.

Every manipulation task can be broken down into elemental components that are defined by a particular set of contacting surfaces. With each elemental component is associated a set of constraints, called the ***natural constraints***, *that result from the particular mechanical and geometric characteristics of the task configuration*. For instance, a hand in contract with a stationary rigid surface is not free to move through that surface (position constraint), and, if the surface is frictionless, it is not free to apply arbitrary forces tangent to the surface (force constraint). *In general, for each task configuration a generalized surface can be defined in a constraint space* [C], *with position constraints* *along the normals to this surface and force constraints along the tangents*. These two types of constraints, force and position, partition the degrees of freedom of possible hand motions into two orthogonal sets that must be controlled according to different criteria.

Additional constraints, called ***artificial constraints***, *are defined by the desired motions or force patterns in the task configuration*. These constraints also occur along the tangents and normals to the generalized surface, but, unlike natural constraints, artificial force constraints are specified along surface normals, and artificial position constraints along tangents.

Once the natural constraints are used to partition the degrees of freedom into a position-controlled subset and a force-controlled subset, and desired position and force trajectories are specified through artificial constraints, it remains to control the manipulator. The **basic hybrid control idea** is an architectural concept that links the constraints of a task requiring force feedback to the controller design. The controller may be described by:

$$T_i = \sum_{j=1}^{N} \{\Gamma_{ij}[s_j \Delta f_j] + \psi_{ij}[(1 - s_j)\Delta x_j]\}$$

where:

T_i = torque applied by the i^{th} actuator;

Δf_j = force error in j^{th} degree of freedom of [C];

Δx_j = position error in j^{th} degree of freedom of [C];

Γ_{ij} and Ψ_{ij} = force and position compensation functions, respectively, for the j^{th} input and the i^{th} output;

s_j = component of compliance selection vector.

The ***compliance selection vector*** S is a binary N-tuple that specifies which degrees of freedom in [C] are under force control (indicated by $s_j = 1$) and which are under position control ($s_j = 0$).

The transformation from [C] to the joints is for the general case:

$q_i = \Omega_i (x_1, x_2, \ldots, x_n)$

where:

q_i = position of i^{th} joint;

Ω_I = inverse kinematic function;

x_j = position of j^{th} degree of freedom in {C}.