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LOCAL POSITION CONTROL:

A NEW CONCEPT FOR CONTROL OF MANIPULATORS

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ABSTRACT

Resolved motion rate control is currently one of the most frequently used methods of manipulator control. It is currently used in the Space Shuttle remote manipulator system (RMS) and in prosthetic devices. Position control is predominately used in locating the end-effector of an industrial manipulator along a path with prescribed timing.

In industrial applications, resolved motion rate control is inappropriate since position error accumulates. This is due to velocity being the control variable. In some applications this property is an advantage rather than a disadvantage. It may be more important for motion to end as soon as the input command is removed rather than reduce the position error to zero.

Local position control is a new concept for manipulator control which retains the important properties of resolved motion rate control, but reduces the drift. Local position control can be considered to be a generalization of resolved position and resolved rate control. It places both control schemes on a common mathematical basis.

INTRODUCTION

Space presents a uniquely promising work environment for operations associated with research, manufacturing, and services in a number of fields of commercial importance [1]. Semiconductor, superconductor, and biological technologies and satellite servicing being some of the more promising areas of commercial uses of space.

Space also presents a uniquely unfamiliar and hazardous work environment for people. The micro-gravity and ultra-vacuum of low earth orbit, which is so promising in its technological uses, exposes astronauts to potentially dangerous situations. The use of advanced automation and robotics in space is seen as a way of reducing both the risks and the costs of space operations [2].

Astronauts excel at integrating sensory information, interpreting sensory information, and then using his judgment to make decisions as to how best to complete a task, even in the event of some unforeseen circumstance. An astronaut, however, can become overwhelmed by sensory information and not be able to perform effectively. Teleoperated manipulators, like the Shuttle remote manipulator system (RMS), are an extension of a person's sensing and manipulating capability to a location remote from him.

Automation and robotics will not lessen the importance of the astronaut, since fully autonomous operation in space is not possible in the foreseeable future. Rather, astronauts and automation need to be utilized each to their best advantage. Automation excels in quickly storing and recalling large amounts of data, computing, responding to signals, and in continuously monitoring many different tasks without being distracted. Sharing controlling between astronauts and automation can result in a system with greater capability than either operating alone.

The problem of sharing control of a manipulator between man and machine is of crucial importance for space and other remote applications of automation. Some directions in which automation and robotics research should evolve from this technology into more advanced telerobots are described by Sheridan [3]. Sheridan distinguishes between efferent (motor) and afferent (sensory) computer extensions to the human operator. This paper describes a new concept for control of manipulators, local position control. It is an efferent extension in that it unifies position and resolved rate control techniques and is also an afferent extension in that in some implementations it would reduce the sensory burden.

CONTROL OF MANIPULATORS

A common characteristic of manipulator control systems is that they must generate a trajectory for one or more appendages. A trajectory consists of two parts, a path and a displacement along that path. A teleoperator control system [4] is shown in Figure 1.

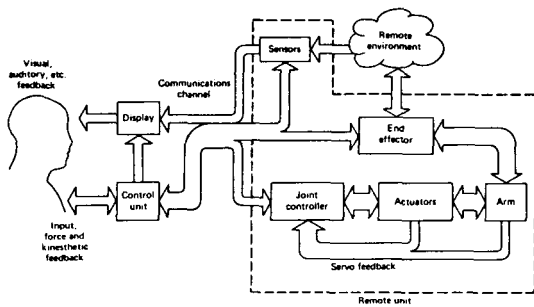


Figure 1 - Teleoperator Control System

Resolved motion rate control allows the operator to specify the velocity of the end-effector in directions resolved into a Cartesian coordinate system. It is one of the most frequently used methods of manipulator control and is used in the RMS and prosthetic devices. Here, the path generated and the path commanded diverge since rate is control variable. At any instant the input is commanding a velocity on the path generated without regard to the path commanded.

Resolved position control allows the operator to specify the position of the end-effector in directions resolved into a Cartesian coordinate system. It is commonly used in locating the end-effector of an industrial manipulator along a path with prescribed timing.

In industrial applications, resolved motion rate control is inappropriate since position error accumulates. In some applications, however, this property is an advantage rather than a disadvantage. It may be more important for motion to end as soon as the input command is removed rather than reduce the position error to zero.

LOCAL POSITION CONTROL

Local position control can be thought of as consisting of position control in a plane normal to the path and rate control along the path. The concept is shown graphically in Figure 2. For a path P between two points A and B, the actual position is point C at a particular instant in time t. Point C is in error since it is not on the path P. Under the local position control paradigm, the commanded position at time t + Δt can be found by projecting C in a plane normal to the path to point D on the path and then advancing along the path to point E according to the desired time rate of change of displacement along the path. The next position can be expressed as

$$\underline{r}(t + \Delta t) = \underline{r}_{E/C} + \underline{r}(t) \quad (1)$$

where

$$\underline{r}(t) = \underline{r}_{C/O} \quad \text{and} \quad \underline{r}(t + \Delta t) = \underline{r}_{E/O}$$

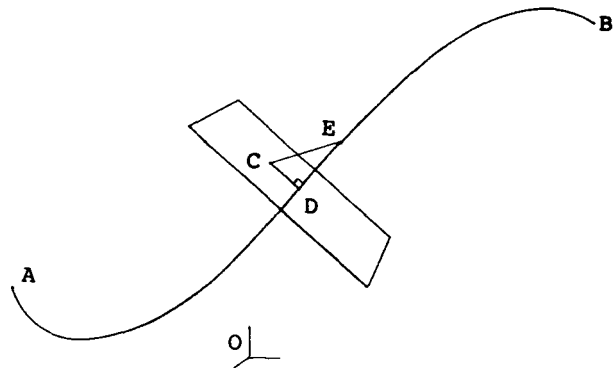


Figure 2 - Local Position Control of Translation

Similarly, the orientation trajectory may be thought of as a displacement along a path on a hypersphere as shown in Figure 3. For a path P on the hypersphere between two orientations A and B, the actual orientation at a particular instant in time t is in error at point C. As before, the next commanded orientation at time t + Δt can be found by projecting C normal to the path to point D and then advancing along the path to point E according to the desired time rate of change of orientation. The next orientation can be expressed as [5]

$$\underline{q}(t + \Delta t) = \underline{q}_{E/C} \underline{q}(t) \quad (2)$$

where $\underline{q}(t)$ is the quaternion for orientation C, $\underline{q}(t + \Delta t)$ is the quaternion for orientation E and $\underline{q}_{E/C}$ is the quaternion of the orientation change between E and C.

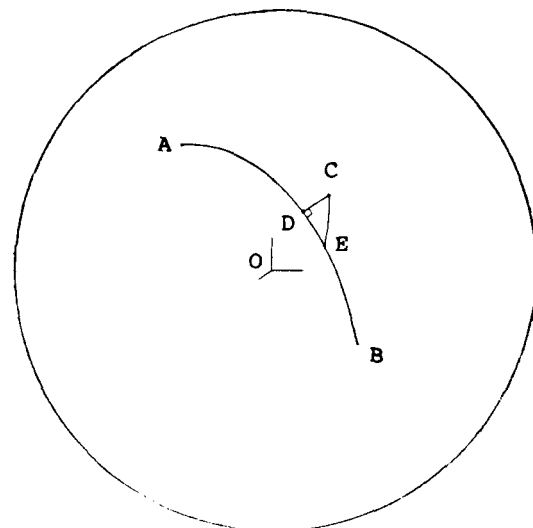


Figure 3 - Local Position Control of Orientation

SOME POSSIBLE REALIZATIONS

The range of possible realizations of local position control encompasses all modes currently described in the literature. Local position control also suggests some new modes not described before. A few of the possible modes are

1. Handcontroller with rate inputs and
 - a) Normal and tangential position errors ignored. Equivalent to resolved rate control
 - b) Tangential position error ignored.
 - c) Neither normal nor tangential errors ignored. Equivalent to resolved rate control with position servo [6].
2. Computer generated path with
 - a) One handcontroller rate input for displacement along the path in Δt .
 - b) Displacement along the path in Δt is a programmed function of time.
3. Computer generated surface with
 - a) Two handcontroller rate inputs for displacement along a path in Δt constrained to the surface.
 - b) Displacement along a path in Δt constrained to the surface is programmed function of time.
4. Path generated by a master manipulator driving a slave manipulator
 - a) Kinematic control of slave. Unilateral control.
 - b) Forces and torques sensed by slave are reflected back to the operator of the master. Bilateral control.
 - c) Forces and torques are not sensed by slave but synthesized as a function of the position and orientation difference between master and slave. Synthetic bilateral control.
5. Path generated by a master manipulator driving a slave is constrained to a computer-generated path. Results in the same three cases as mode 4.
6. Path generated by a master manipulator driving a slave is constrained to a computer-generated surface. Results in the same three cases as mode 4.
7. Supervisory level computer generates a path or surface and an operational level computer generates the displacement and orientation rates.

SHUTTLE RMS AS AN APPLICATION

Local position control of the Shuttle RMS would be practical if a means of determining the relative position and orientation of objects in space can be found. Recent work on the Laser Docking Sensor [7] indicates that this may soon be possible with a high degree of accuracy at ranges from 0.1 to 22,000 feet.

One might envision using mode 2 a) with a smooth computer-generated curve superimposed on the TV monitor as a visual aid to the operator. The curve might be heuristically chosen for a particular task like docking or berthing and have perhaps a parametric adjustment. The operator would have to input only a single rate, the rate of displacement along the path, and visually verify that it is following the superimposed curve.

CONCLUSION

Local position control can be considered to be a generalization of the resolved position and rate control concepts. All previously described control modes can be described in the context of local position control and many new ones can be thought of as well. Local position control may well be a big step in the right direction in the evolution of telerobots.

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