On the Trajectory Planning for the Control of All State Variables for Torque-unit Manipulator

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Summary. Torque-unit Manipulator (TUM) is a design concept of (space) manipulator. Each joint of TUM is free and a device which is called "torque unit" is equipped on each link. The "torque unit" can be made easily of a rotary actuator such as DC-servo motor and a disc. TUM is a Multibody system. The paper presents the trajectory planning of the links for the control of positions of the links and angular velocities of the discs for 2-dimensional N d.o.f. TUM.

Introduction

"Torque-unit Manipulator (TUM)" is a new design concept of (Space) manipulator[1]. Figure 1 shows a schematic picture of TUM. TUM has an open-loop kinematic chain as the traditional types of manipulators, however the differences are as follows.

(i) Each joint of TUM is free joint which is 1 degree-of-freedom.

(ii) Each link has a "torque-unit" on an arbitrary position. The "torque-unit" applies torque to the link on the position. The "torque-unit" can be made of a rotary actuator such as DC-servo motor and a disc which is connected to the rotating shaft of the actuator.

Packing the actuator and the disc into one "unit", we can make a torque-unit and attach it on an arbitrary position of each link of a kinematic chain whose joints are all free. (See Fig.2) Thereby, we would be able to construct a Torque-unit Manipulator very easily. The TUM would have merits, for example,

- Easy maintenance since all joints are free,
- Possibility of construction of redundant actuator system since we could attach a few torque-units on each link.

The merits would give TUM high-reliability. The high-reliability is very important if we utilize manipulators in remote and hazardous environments such as the space. Also, TUM would have merit of alterability of dynamical feature. See Ref.[2] in detail. TUM is an interesting sample of Multibody Systems.

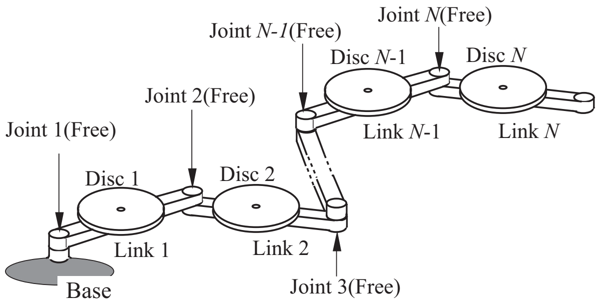

Figure 1: TUM:A Design Concept of Manipulator

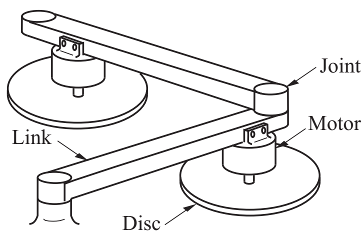

Figure 2: Torque-unit

A problem in the control of TUM

We have shown the position-controllability of the links for general type of N d.o.f. TUM by using a conventional control law for manipulators[2]. However there arises a problem. When we use such conventional control laws, we only focus on the behavior of links and ignore the behavior of the discs in torque-units. Hence, we only ensure that positions of the links approach desired positions and that the angular velocities of the discs never go to infinity even asymptotically. The angular velocities of the discs usually do not approach zero and result to be constant when the links approach desired positions. The residual angular velocity might give bad influence to the actuator. The problem arose because we ignored the behavior of the disc. For the purpose to represent the dynamic behavior of TUM, rotation angles of the discs in torque-units have no meaning; we need joint angles, angular velocities of the links, angular accelerations of the links, angular velocities of the discs , and angular accelerations of the discs. Hence, taking the all variables to represent the state of TUM into account, i.e., taking also the behavior of the discs into account, we have found that TUM is a system with non-holonomic constraints: a Non-holonomic system[3]. Hence the angular velocity of each disc at each time depends on the trajectory of the links: how the links moved until the time from the beginning.

A control scheme for TUM

Based on the property, by planning the trajectory of the links, we have considered the possibility to control the position of each link to desired position and the angular velocity of each disc to desired constant value which may be not zero. (When the all discs have constant angular velocities, the links stay in the same positions.) As the results, we have given the followings[4]:

- We can control the angular velocities of only $N-1$ discs because TUM has a first integral which represents constraint condition on the behavior of the discs; angular velocity of one disc is dependent on the angular velocities of the other discs.
- There exist a trajectory of the links which joins an initial configuration and a desired configuration of the links and that drives the angular velocities of $N-1$ discs to approach desired constant values.

The state variables of the TUM are not controllable. However the first integral implies that angular momentum of all discs is conserved while the motion of the TUM, hence, the first integral allows us to control the TUM from a zero-velocity initial state:$\boldsymbol{q}(0) = \boldsymbol{q}_i$, $\dot{\boldsymbol{q}}(0) = \boldsymbol{0}$, $\dot{\boldsymbol{\varphi}}(0) = \boldsymbol{0}$ to a zero-velocity final state:$\boldsymbol{q}(T) = \boldsymbol{q}_f$, $\dot{\boldsymbol{q}}(T) = \boldsymbol{0}$, $\dot{\boldsymbol{\varphi}}(T) = \boldsymbol{0}$, where $\boldsymbol{q}(t)$, $\dot{\boldsymbol{\varphi}}(t)$ denote joint angle vector of the links, angular velocity vector of the discs, respectively. $\boldsymbol{q}_i$, $\boldsymbol{q}_f$ denote arbitrary joint angle vectors. Then, we have given a trajectory which joins an initial configuration of the links and a final desired configuration to control the TUM from a zero-velocity initial state to a zero-velocity final desired state. In planning the trajectory we need the exact values of some physical parameters of the TUM, e.g., mass, mass center, inertial moment of the discs. It is difficult to obtain exact values of such physical parameters. By using the uncertain parameter values we cannot plan the trajectory of the links good enough for control performance. Then, we have given a control scheme for the TUM from zero-velocity initial state to zero-velocity final state[5] to get around the difficulty; even if the values of physical parameter are obtained by roughly approximate calculations, we can drive the residual angular velocities of the discs to approach zero.

Other trajectory of the links to make the residual angular velocities of the disacs zero

We have used a sinusoidal function in planning the trajectory described in the previous section, then, this paper presents followings:

- a proposition which allows us to use wider class of functions for planning trajectory of the links than that shown in the proposition in ref.[5, 6] and which is more convenient in practical use.
- a trajectory planned according to the proposition above for the control of all state variables for 2-dimensional 3 d.o.f TUM as an example.

Conclusions

Torque-unit Manipulator (TUM) is a design concept of (space) manipulator. Each joint of TUM is free and a device which is called “torque unit" is equipped on each link. The “torque unit" can be made easily of a rotary actuator such as DC-servo motor and a disc. If we control the links of TUM with conventional control laws, there remain residual angular velocities of the discs in the torque unit. The problem arose because we ignored the behavior of the discs. Considering the all state variables, we have found TUM is a Non-holonomic system. By taking the advantage of the feature in the dynamics of TUM, we have given a control scheme from a zero-velocity initial state to a zero-velocity final state. Then, in this paper we have shown a proposition to plan other trajectory for the control of all state variables for 2-dimensional N d.o.f TUM. We have also shown a trajectory planned according to the proposition above for the control of all state variables for 3 d.o.f TUM.

References

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