Motion Control of a Flexible Underactuated Manipulator by Using High-Frequency Excitation

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Summary. We proposed a motion control method for a flexible 2-link underactuated manipulator which has flexibility in the first and second links and can be regarded as a thin beam. The first joint possesses an actuator and a sensor. The second joint connecting the first link with the second does not have an actuator or a sensor, i.e. the second joint is a free joint. We periodically excite the first joint with high-frequency and vary the configuration of the first joint continuously. At this time, the second link undergoes various pitchfork bifurcations and can move the stable-equilibrium point continuously. It is experimentally confirmed for the 2-link underactuated manipulator that the bifurcation control carries out swinging up the top of the second link in the opposite direction of gravity without state feedback from the second link.

Introduction

Manipulators are expected a realization of the reduction of the weight and energy consumption, cost, or performance improvement by replacing an active joint with a free or passive joint. A manipulator whose number of generalized coordinates is larger than the number of actuators is called a underactuated manipulator .
There has been much study on the control of underactuated manipulators in recent years. Ichida et al. proposed a control method for the 3-link underactuated manipulator using a fuzzy energy region method based on a logic based switching method [1]. By swithcing the active joint's controller, Aoustin et al. showed a method to control the swing-up of the 2-link underactuated manipulator under gravity affection[2]. These control strategies were constructed on the premise that information of all joint's state can be obtained. On the other hand, Yabuno et al. proposed a control method without state feedback of the free joint. Nonlinear phenomena in the free link under high-frequency excitation to the active link are utilized and validity is experimentally confirmed [3]. This method has an advantage in the situation where the actuator and sensor of a joint fail.
These studies and control methods assumed all links to be rigid body. However, in order to reduce transportation cost, weight reduction by thinning down of component is necessary. Yabuno investigated a position control method for a 2-link underactuated manipulator with a thin elastic second link by applying high-frequency excitation on the active joint [4].
By expanding this control strategy, we experimentally achieve motion control for a flexible 2-link underactuated manipulator in which both links are elastic and there is no feedback from the free joint.

Analytical Model of Flexible Underactuated Manipulator and Control Strategy

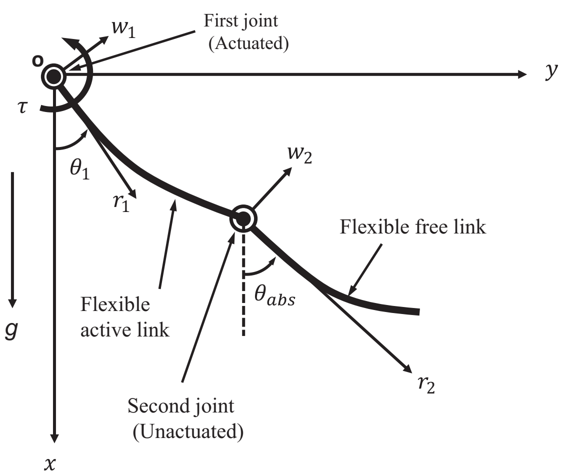

Figure 1: Model of flexible underactuated manipulator.

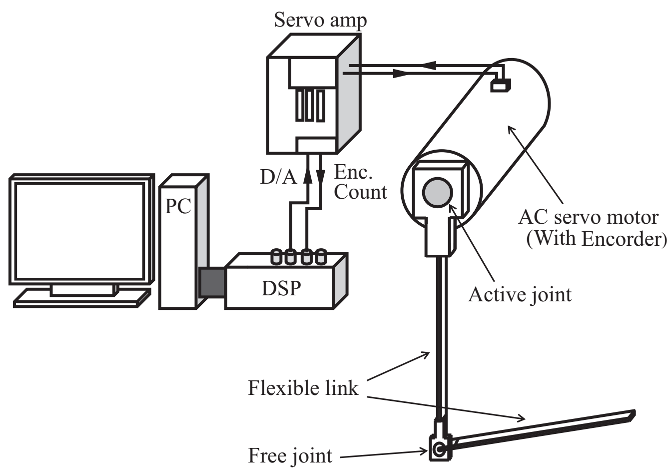

Figure 2: Experimental apparatus of flexible underactuated manipulator.

The model of a flexible 2-link underactuated manipulator is shown in Fig. 1. The first and second links have elasticity and they behave like a beam. A servo motor equipped to the first joint can apply the driving torque τ which is utilized to control of the first link θ_1. The second joint is free and does not have any angular sensors or actuators. Therefore, we consider the situation without using the information of configuration of the second link. Furthermore, the manipulator is

affected by the gravity effect g in the positive direction of x axis.
We apply high-frequency excitation on the first joint as follows:

$$\theta_1 = \theta_{1off} + a_\theta \cos \omega t, \tag{1}$$

Here, θ_{1off}, a_{θ_1}, and ω are the configuration of the first link, the excitation amplitude and the excitation frequency, respectively. In our previous study of rigid links [3], it is clarified that high-frequency excitation with large amplitude is required to control the motion without state feedback in the free link. To apply a similar strategy, we set the first link to resonate at ω close to it's first natural frequency of bending. Then, the second link undergoes pitchfork bifurcation, which is perturbed depending on the magnitude of θ_{1off}. We change θ_{1off} from 0 to $\pi/2$ continuously and achieve the swing-up of the second link in the opposite direction of gravity without state feedback from the free joint.

Experiment and Result

The experimental system of the flexible 2-link underactuated manipulator is shown in Fig. 2. The servo motor was controlled by DSP [digital signal processor: dSPACE corp., DS1104 R&D Controller Board (sampling-time 40ns)] through the servo amp. The joints are made from aluminum alloy, and the second link is connected to radial-bearings with low friction. The approximate dimensions of the first link and second link made from phosphor bronze is 140mm in length, 10mm in width, 1.0 mm in thickness, and the first natural frequency of bending vibration of the first link is 12Hz.
First, we set the first link under the high-frequency excitation (13 Hz) in $\theta_{1off} = 0$. After the convergence of the second link in the equilibrium point, we increase θ_{1off} to $\pi/2$ continuously. Then, swing-up of the second link in the opposite direction of gravity and stabilization of this state are achieved as Fig. 3.

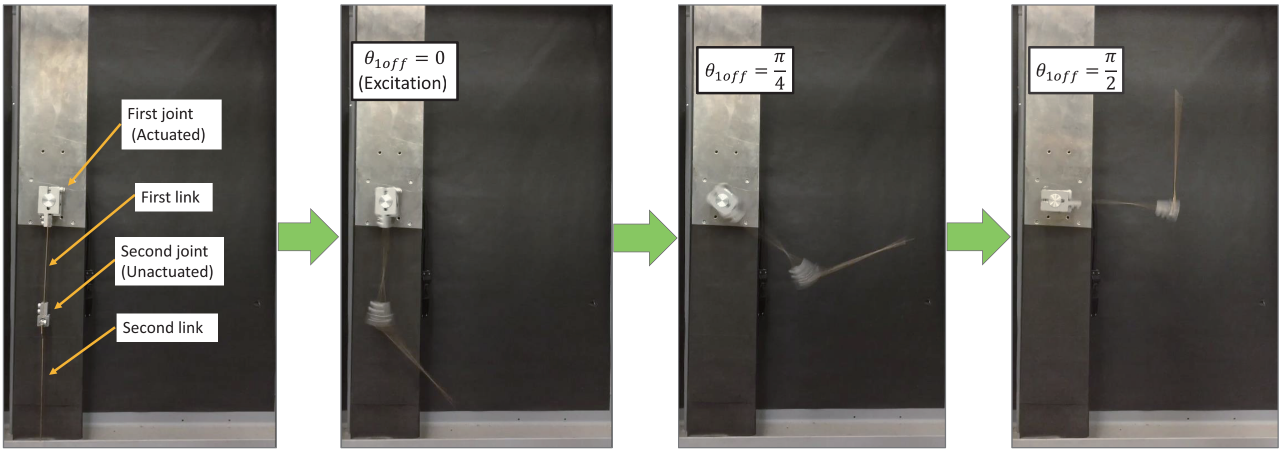

Figure 3: Swing-up of the flexible underactuated manipulator by bifurcation control under high-frequency excitation.

Conclusions

We proposed a strategy based on the bifurcation control under a high-frequency excitation, which can control a flexible 2-link underactuated manipulator with a flexible first active link and flexible second free link which can be regarded as a thin beam. The swing-up of the free link to the upright position and the stabilization are experimentally achieved in an underactuated flexible manipulator.

References

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