Variable Structure Slip Control for Grasping Objects

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Abstract: A variable structure slip control strategy is developed for grasping objects by a robot end-effector. A hybrid controller comprised of a fuzzy controller and a PI controller is designed to perform the strategy. When a grasped object is slipped by an external force as a disturbance, the applied fingertip force is rapidly increased to stop sliding and then decreased to a reliable limit to hold the object. The control structure is automatically changed from PI control to fuzzy control if the slip is higher than the predetermined limit. The control system is simulated for a two fingered robot hand driven by permanent magnet dc motors.

Key-Words: variable structure, slip control, grasping objects.

1 Introduction

Sensing technology and intelligent controllers have been developed to perform robotic tasks such as grasping objects and manipulation with dexterous end-effectors. When performing grasping fragile objects, it is necessary to control the inserted force in order to protect object from damages and also to avoid object sliding. The hybrid position/force control strategy can be used to track a desired force trajectory [1]. The measured forces and positions are compared with desired positions and forces to provide a suitable command by controller to compensate errors in feedback control loops. The control system selects the direction in which the end-point position is controlled or the direction in which the end-point force is controlled [2]. When an external force is inserted to object, slip may occur. The slip control is then operated to stop sliding. The fingertip force is increased in response to the detected slip until stop sliding. The combined linear and rotational slippage can be detected using tactile and force sensors [3]. It is possible to detect slip at pre-slip, start and post-slip conditions [4]. There are several techniques that can be used for slip detection during the period of sliding [5], [6].

A comprehensive review on robotic grasping and contact was presented [7]. It involves friction problem significantly in several aspects. Friction in joints is a nonlinear function of joint velocity and is modeled by dry, stick, viscose and negative terms of friction [8], [9]. Each contact point can be modeled as a frictionless point contact, a frictional point contact, or a soft contact [10]. However, it is particularly difficult to model the relation between small object/finger displacements and changes in contact forces arising from these displacements. To increase friction and compliance at the contact, the fingertips can be covered with soft rubbers [11]. The Coulomb friction model works well for contacts between materials like metals, but is not accurate for viscoelastic materials such as the rubbers with which most fingertips are covered [12]. Friction is well considered to the design of hands for manufacturing tasks [13].

It is very important that the slip control is designed as it can handle the friction effects due to uncertainties. Fuzzy controller is used to overcome the uncertainties [14]. Numerous reports show that intelligent controllers based on fuzzy logic, neural networks, and hybrid methods have been designed to perform force control for robot manipulators [15-20].

First of all, in this paper a variable structure slip control approach is developed for grasping objects. When slip is detected, the controller commands to increase fingertip force until stop sliding. The slip control strategy is then described and a hybrid controller is designed. After that the simulation results are presented and finally conclusion is provided.

2 Control Strategy

When slippage is detected, the controller produces suitable control inputs for the actuators to drive the finger. A required normal force on the fingertip is then produced in order to avoid slipping object. The fingertip force is increased until stops object slipping. Fig.1 shows the slip control system.

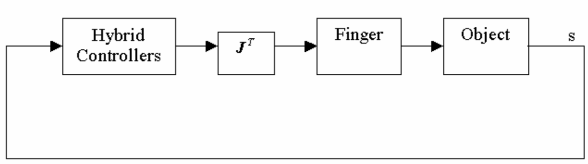

Fig.1 The slip control system

A hybrid controller comprised a fuzzy controller and a PI controller is designed to impellent the control strategy. Whenever the slip goes out of predetermined limit, the fuzzy controller is automatically operated. The fuzzy rules are defined in order that the slip is decreased back under the predetermined limit and also errors subjected to disturbances are reduced by an ability of disturbance rejection. When the slip is located under the limited value then the fuzzy controller is automatically exited. At the same time, the PI controller operates to reduce the slip. If by any reason the error goes out of the limited value, this procedure is repeated again to reduce the slip. Based on the slip value, the structure of control system is automatically varied.

3 Fuzzy Controller

Fuzzy controller can handle the system output by controlling the system input based on the defined fuzzy rules. However, the number of fuzzy rules always causes conflict between accuracy and complexity. Reducing the number of rules makes a reduction in calculating time and causes simplicity in the controller design. On the other hand, it may increase error. Moreover, there is not always a guarantee to cancel errors using a large number of rules.

As illustrated in Fig.1, the reaction force on the fingertip is transformed from the task space to the joint space. When the end-effector is in contact with the environment, the load torque is approximately equal to the motor torque. The load torque can be measured from either the motor shaft or the motor current. It is proportional to motor torque as well.

A fuzzy controller is designed for each joint. The inputs and output for fuzzy controller of each joint are arranged as:

$$\begin{aligned}&\text{input1}: \text{ slip}\\&\text{input2}: \text{ derivative of slip}\\&\text{output}: \text{ voltage}\end{aligned}$$

The 15 fuzzy rules are written as

If input1 is MF_m and input2 is MF_n then output is $MF_{m,n}$

For m=1,…,5 and n=1,…,3

Table 1 shows the fuzzy rules and fuzzy sets arranged for two input variables, and the output variable.

Table 1. Fuzzy rules

Voltage		Derivative of slip		
		n	z	p
Slip	h	z	nl	ph
	m	z	pl	pm
	z	z	z	pl

Fig.2 shows three membership functions (MFs) that are used for slip named as positive (p), zero (z), and negative (n). Fig.3 shows three MFs named as positive (p), zero (z), and negative (n) that are used for derivative of slip. Fig.4 shows five MFs positive high (ph), positive medium (pm), positive low (pl), zero (z), negative low (nl) that are arranged for voltage. Mamdani type of fuzzy inference method is chosen to calculate the fuzzy controller and center of gravity defuzzification method is applied.

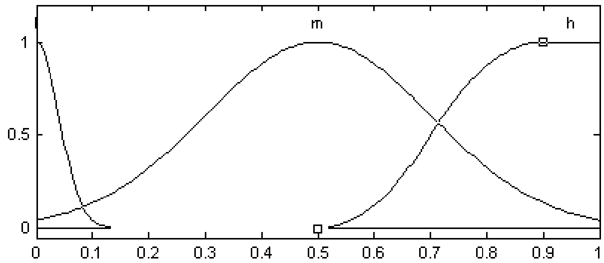

Fig.2 MFs of slip.

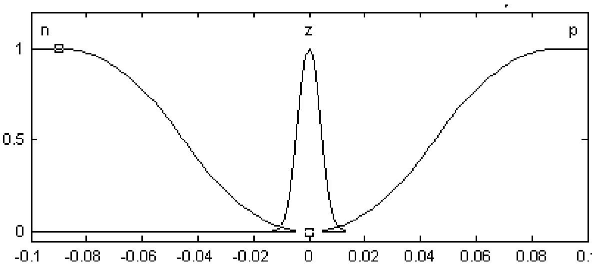

Fig.3 MFs of derivative of slip.

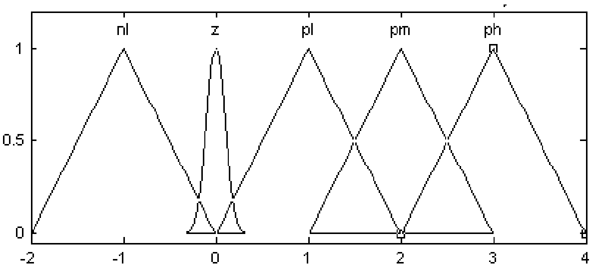

Fig.4 MFs of voltage.

4 Simulation

The control system is simulated for a two fingered end effector driven by permanent dc motors. The first simulation is carried out for a given disturbance of 20N applied on an object with a mass of 1kg. The fuzzy controller designed in section 3 and a PI controller with a proportional gain of $k_p = 0.25$, and a integral gain of $k_i = 5$ are used to perform the control strategy. A friction gain of $\mu = 0.5$ is given. Fig.5 shows the slip which is stopped after about 0.02sec. The displacement of object is about 2.3mm as shown in Fig.6. The normal force is rapidly increased to avoid slipping and is then decreased to the reliable limit of 60N to hold the object (Fig.7).

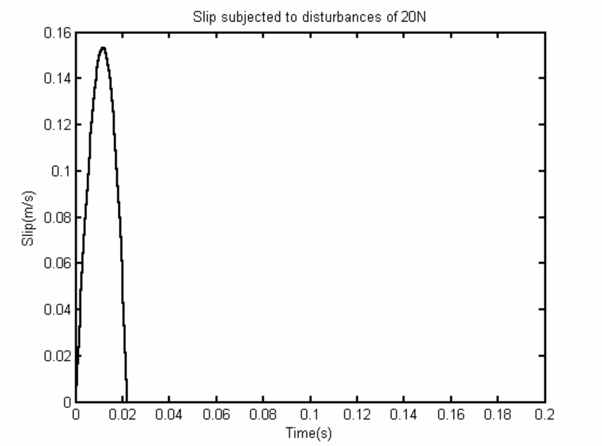

Fig.5 the slip.

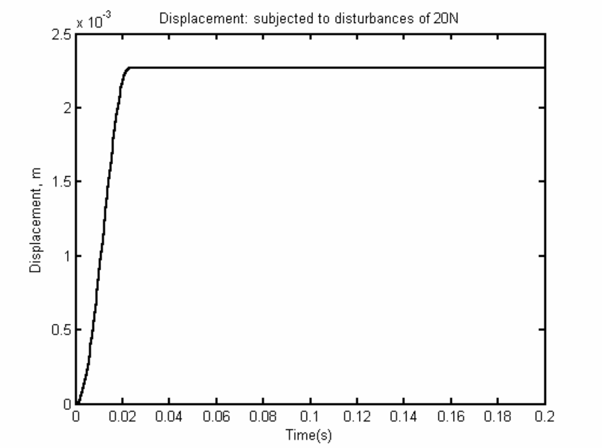

Fig.6 displacement.

In the next simulation, we increase the disturbance to about 40N and the other parameters are given the same as the first simulation. The slip is shown in Fig.8 which shows the same behavior but is longer than before. The normal force is rapidly increased to avoid slipping and is then decreased to the reliable limit of 90N to hold the object (Fig.9).

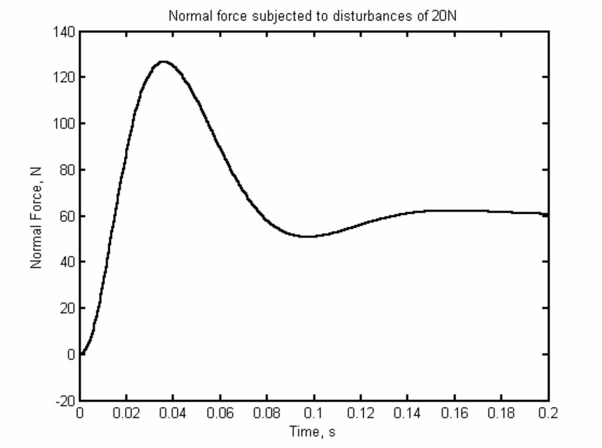

Fig7. the fingertip force.

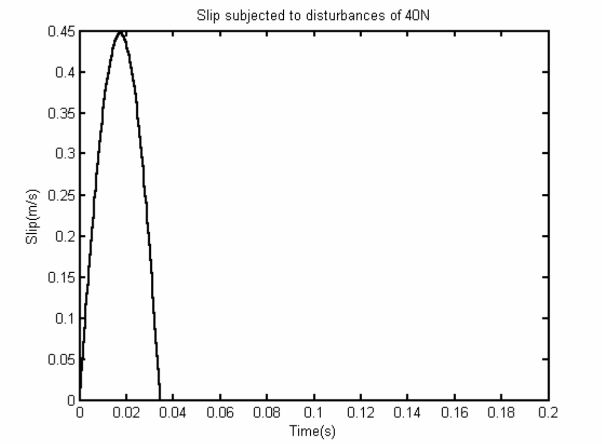

Fig.8 the slip.

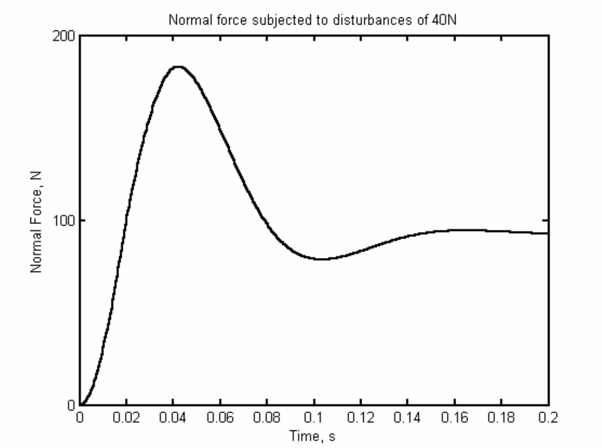

Fig.9 the fingertip force.

6 Conclusion

A variable structure slip control strategy has been developed for grasping object by a two fingered robot end-effector. The control structure has been automatically changed from PI control to fuzzy control based on a predetermined value of slip. When slip is located under the limited value then the fuzzy controller is automatically exited and, at the same time, the PI controller operates to reduce the tracking error. If by any reason slip goes out of the limited value, this procedure is repeated again to reduce slip. The control system can overcome the uncertainties using the fuzzy controller and also can hold the object by a reliable force limit using the PI controller. When a grasped object is slipped subjected to an external force as a disturbance, the applied fingertip force is rapidly increased to stop sliding and then decreased to a reliable limit to hold the object. The control system has been simulated and the controller has been considered to perform the strategy.

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