

Hybrid fuzzy-sliding grasp control for underactuated robotic hand

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Abstract

A major part of the success of human-robots integration requires the development of robotic platforms capable of interacting in human environments. Human beings have an environment designed for their physical and morphological capacity, robots must adapt to these conditions. This paper presents a fuzzy-sliding hybrid grasp control for a five-finger robotic hand. As a design principle, the scheme takes into account the minimum force required on the object to prevent the object from slipping. The robotic hand uses force sensors on each finger to determine the grasp state. The control is designed with two control surfaces, one when there is slippage, the other when there is no slippage. For each surface, control rules are defined and unified by means of a fuzzy inference block. The proposed scheme is evaluated in the laboratory for different objects, which include spherical and cylindrical elements. In all cases, an excellent grasp was observed without producing deformations in the fragile objects.

Keywords: fuzzy sliding, grasp control, hybrid control, robotic hand

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1. Introduction

The human hand possesses a total of 23 degrees of freedom (DOF). This great capacity of movement is fundamental in the processes of human interaction, particularly in cases of grasp. The equipment, tools and in general all mechanical systems designed by man are strongly influenced by the design of the human hand, this ergonomics has facilitated the development of man. In its daily use, the human hand makes many different types of grasps (opening doors, screwing a screw or lifting a soda can), particularly with the right or dexterous hand [1]. Considering that one of the basic purposes of robotics is that robots work together with human beings, it is normal to think that they should be properly integrated into human environments, and therefore also require this type of grasping [2]. One of the interesting schemes for its duplication by an artificial hand is the cylindrical grasps [3].

This type of grasp is very common in objects that interact with humans [4]. They are found in tools (hammer, screwdriver, etc.), machines (vehicles, drills, etc.), and even in everyday items such as glasses and bottles. A robot that interacts with these tools, machines, and elements must have a hand design similar to that of the human hand, and a control scheme that allows safe and reliable operation. This safe operation includes, on the one side, not dropping the object, and on the other side, controlling the force applied so as not to damage it. The control schemes for these prototypes usually contain real-time response schemes with PID, fuzzy or hybrid control blocks. The problem in the design lies in its non-linear characteristic, largely due to the requirement of precision and the delay and hysteresis behavior of the mechanical actuators [5].

An important aspect of the control scheme is the mechanical design of the hand. According to the configuration of the actuators, there are two topologies of robotic hands: the underactuated robotic hands (have more DOF than actuators) and those that have the same number of DOFs as actuators [6]. The first case is the one of greatest interest at the moment since it is very attractive the idea of a mechanical design of high performance but less expensive. Control of the underactuated robotic hands is also easier as it involves fewer variables [7]. In many cases, the control schemes involve motion planning systems by means of state feedback through artificial vision, which often reduces the need for calibration of the robot's kinetic model [8]. Sometimes this processing is simplified by using geometrical

shape recognition, which allows it to be implemented on embedded platforms directly on the robot [9].

On the other side, this type of research is also of great importance in the development of prostheses that functionally replace organs with artificial devices, and therefore have a great impact on improving the quality of life of disabled communities [10-12]. Beyond facilitating a certain task, this last field of action has a strong impact on social inclusion of people who have lost one of their arms, even more, when the solution is highly functional and low cost.

We propose a hybrid control scheme that mixes two control surfaces using a fuzzy inference scheme [13, 14]. We want the hand grasp to be secure, i.e., the object does not slide out of the hand [15, 16]. However, we do not want the hand to exert much pressure on the object, because if the object is fragile (a cup for example) it can break. For this reason we define two different control surfaces with the intention of determining correctly the level of pressure to be applied with each finger [17, 18]. The following part of the paper is arranged in this way. Section 2 presents preliminary concepts and problem formulation. Section 3 illustrates the design profile and development methodology. Section 4 we present the preliminary results. And finally, in Section 5, we present our conclusions.

2. Problem Formulation

The ARMOS research group possesses the prototype of a robotic hand, underactuated with five fingers, and morphologically structured to replicate human hand functionality (anthropomorphic robotic hand equivalent in size and motion) [19]. For this hand, we are looking to design a control scheme for a cylindrical grasp. As design conditions we look for:

- a) A secure cylindrical grasp (no slipping of the object).
- b) A good cylindrical grasp (without deforming or destroying the object).
- c) A control system with real-time response.
- d) Control scheme embedded in the robotic hand.
- e) Minimalist and low-cost general scheme.

This control scheme must take into account different operating states of the hand, in particular:

- a) The slipping of the object in the hand.
- b) The non-slipness of the object in the hand.
- c) No objects in the hand during the grasp.

3. Methodology

The control strategy designed for the robotic hand is inspired by the behavior of the human hand (human brain). It consists of considering the system as composed by two general states of operation [20], these states are: (1) When applying the grasp the control system detects slipping of the object in the hand, and (2) When applying the grasp the control system does not detect slipping in the hand [21, 22, 23]. In the first case, it could be said that the control is close to its ideal value, but it is necessary to increase the grasp force gently to avoid slipping. In the second case, the system has exceeded its equilibrium point, and the force must be reduced in order not to affect the structure of the object. These two control surfaces define two models of systems whose meeting point is the ideal output of the system. This strategy requires switching between two control surfaces (sliding control), which is why the overall control scheme is hybrid.

3.1. Control Architecture

To achieve a global smooth control surface (without sudden jumps between control actions), we proposed a fuzzy inference system, with fuzzy rules for each surface [24, 25]. The final control action is interpreted as a force applied by the motor that produces the movement in the finger (the control scheme works independently for each finger). This force is inferred by the control unit according to the rules defined in the control surfaces as shown in Figure 1.

3.2. Estimate of Object Slippage

To detect the slipping of the object during grasping we use force sensors on each finger. The calibration of the force sensors was done with a glove. The glove emulated the grasp under different conditions, and we were able to record data for analysis and characterization. We make many grasps of the object in order to characterize the different states that occur in the grasp, especially when slipping occurs. With the information, we can clearly differentiate three states: when the object is grabbed, when the object is sliding and when the object is not grabbed. The transition between the different states can be seen in Figure 2.

Sensor signals were analyzed in MatLab. Figure 2 shows five states in the detected signals. State 0 when the object is absent, states 1 and 3 when the object is firmly grasped and states 2 and 4 when the object is sliding. Once each zone is identified, we perform a frequency domain analysis for each signal state using the Fast Fourier Transform (FFT). This analysis allowed to find particular frequency characteristics in each one. We observe that for non-slip events the signal is formed by frequencies lower than 10 Hz, and for slip signals, higher frequency peaks appear, which are between 40 and 60 Hz. This checks that the signal frequency varies when the object is sliding and allows us to use this feature to make control decisions. The signals are filtered to remove noise and high-frequency components. Then we use a bandpass filter from 10 Hz to 50 Hz as shown in Figure 3.

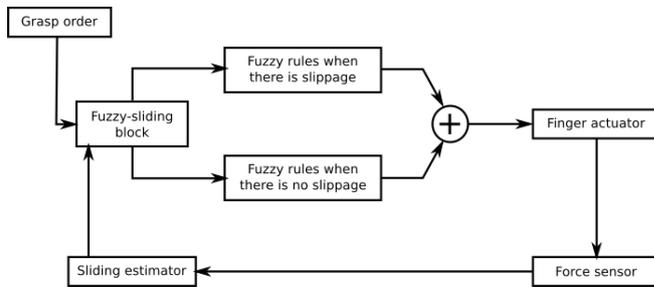


Figure 1. Scheme of hybrid fuzzy-sliding grasp control

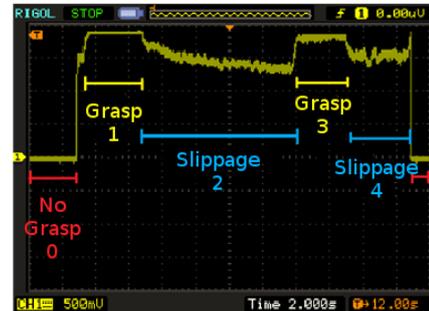


Figure 2. Different states of the grasping process

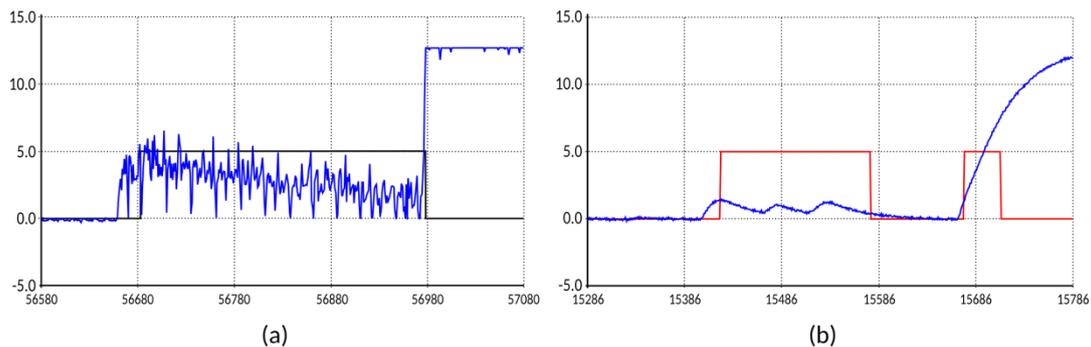


Figure 3. (a) Unfiltered signal with presence of slippage, (b) Filtered signal with presence of slippage

3.3. Fuzzy Rules

The reference value for the slip is zero. We selected the slip error as the fuzzy input variable. This variable is the same for each control block of each finger. For the fuzzy output variable, we select the angular position of each servomotor (increasing the angle we increase the force on the object). We use MatLab for the design and adjustment of the fuzzy control. We use the same universe for the five inputs selected according to the full-scale reading of the

sensor (when the object is slipping into the closed hand). The membership functions are also the same for each input. We use two triangular membership functions for medium and high error values, and for low values, we use a trapezoidal one as shown in Figure 4(a). For the output, we also use three fuzzy sets as shown in Figure 4(b). The rule base considered the sliding of the bottle, as well as the need for a secure grip but without deforming the object. These rules are summarized in Table 1. For inference, we use Mandani and center of gravity.

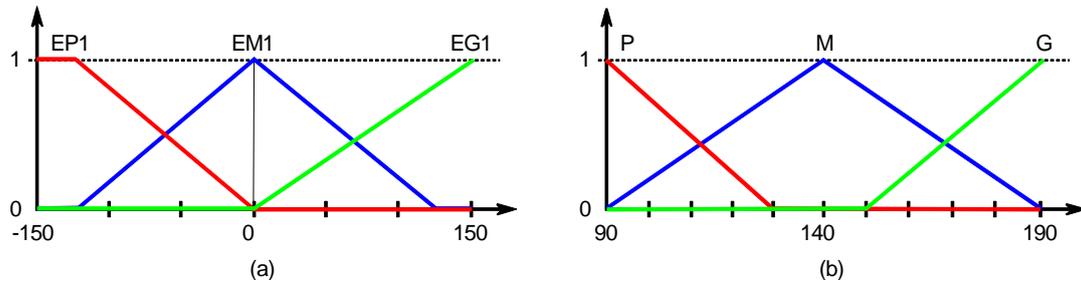


Figure 4. (a) Fuzzy sets of input variables, (b) Fuzzy sets of output variables

Table 1. Basis of Fuzzy Rules

Rule base											
Sensor 1			Condition	Sensor 2			Condition	Sensor 3			
EP1	EM1	EG1		EP2	EM2	EG2		EP3	EM3	EG3	
X			AND	X			AND	X			
	X		OR		X		OR		X		
		X	OR			X	OR			X	

Condition	Sensor 4			Condition	Sensor 5			Implication	Output (Deg)		
	EP4	EM4	EG4		EP5	EM5	EG5		PG	MG	GG
AND	X			AND	X			Then	X		
OR		X		OR		X		Then		X	
OR			X	OR			X	Then			X

4. Findings

The hand has force sensors on each finger for individual feedback. The actuators are servomotors, one for each finger, which will force a nylon ligament in response to the behavior of the object in the hand. The servos used are TowerPRO SG-5010 with three kilograms of force. FSR sensors (10 kg resistive force sensors) were used as sensors, which are read with an adjustable voltage tracker. Servo motors used as actuators have a position range between 0 and 180 degrees. These parameters were used for the definition of fuzzy variables, universes, and membership functions. As interface hardware with sensors and actuators, we use a communication card based on the Atmel ATmega328P microcontroller (20 MIPS, on-chip 2-cycle multiplier, six PWM channels, 6-channel 10-bit ADC and 28 programmable I/O lines).

The fuzzy control system runs in real time on the microcontroller. The sensed signals are discretized at 10 bits, and the operations are carried out inside the microcontroller in fixed point. The output to actuators is filtered to an analog value with the PWM. The performance of the control scheme was evaluated during several operation tests with various cylindrical objects, most of them with plastic bottles with different liquid levels. During the tests, we verify the grip of the object and the response to slippage by trying to remove the object from the robotic hand. The sensor on each finger detects the presence or absence of the object according to the pressure level on the sensor. Safe grip tests were performed with different strategies to remove the bottle from the hand. Some tests were carried out at low speed, others at medium speed and others at very high speed. In all cases the control reacts correctly, trying to avoid the loss of the object as shown in Figure 5. The operation of the control scheme can be seen here: <https://youtu.be/6JgKlj6Pqes>.

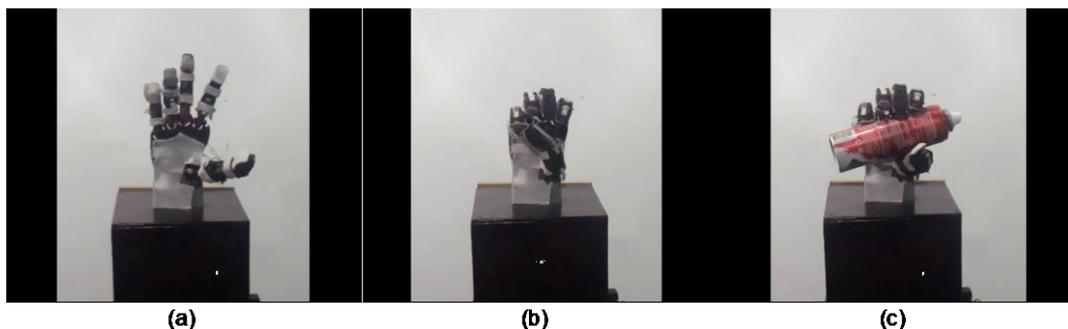


Figure 5. Robotic hand with different operating states. (a) open hand, (b) closed hand without object detection, (c) hand with a cylindrical grasp

5. Conclusion

In this paper, we describe the development of a fuzzy-sliding hybrid control scheme for an anthropomorphic robotic hand, specifically for cylindrical grasping processes. The design principle of the control scheme considers two different control surfaces: When the grasped object slides out of the hand and when the grasped object does not slide out of the hand. In each of the two cases, we define specific control rules to reduce slippage without damaging the object. The two control surfaces are joined together in a single fuzzy inference system, which provides the output parameter for each finger's motor. The slip level is estimated from the frequency analysis of the force sensor signals located on each of the fingers of the hand. Laboratory tests have shown that when slipping occurs, vibration occurs at a characteristic frequency detectable by the sensor. The performance of the control system was verified on a real robotic platform, demonstrating the validity of the approach.

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