International Conference on Control, Engineering & Information Technology (CEIT'13)
Proceedings Engineering & Technology - Vol.2, pp. 116-119, 2013

Fuzzy Logic Control for Grasping 3D Objects with Sliding Contacts

Rim Boughdiri[#1], Hela Bezine[#2], Adel M. Alimi[#3]

[#] *REGIM: REsearch Group on Intelligent Machines, University of Sfax*
National Engineering School of Sfax (ENIS), BP 1173, Sfax, 3038, Tunisia
[1] `rimboughdiri@gmail.com`
[2] `hala.bezine@ieee.org`
[3] `adel.alimi@ieee.org`

***Abstract*— The overwhelming complexity of the grasping process and imprecise knowledge about articulated robot hand systems leads to a certain control problem. In order to solve these problems, the paper proposes a new design of fuzzy control approach for two fingered robot hand, which is able to control simultaneously grasping and slipping of 3D fragile objects in unstructured environment. In this context, the unstructured environment means that we consider objects of different mass and shape whose physical properties such as mass, rigidity and friction are unknown. The control scheme consists of a combination of two fuzzy logic controllers. The first controller is used for insuring object stable grasping and the second for controlling object slipping motion. Hence, by adding the slippage information, we achieved a grasping task with minimum fingertip force which reduces the risk of deforming or crushing the gripped object. The proposed control architecture allows a safe and stable grasping without needing to measure the fingertip force, so the noise introduced by the force sensors does not exist. Several simulation results are presented to demonstrate the effectiveness of the developed work.**

***Keywords*— Robot grasping, Slip control, 3D unknown object, fuzzy logic control.**

I. INTRODUCTION

Human dexterity is an amazing skill. Human can grasp a wide variety of size and shape of objects, carry out complex tasks, and switch between grasps according to changing task requirements. Indeed, these abilities are due in part to the physical structure of our hand (multiple fingers with many degrees of freedom), and in part to our sophisticated control capabilities. Therefore, the grasping and manipulating of objects in an unstructured environment, in particular where the physical properties of the object are not previously known are one of the main challenges of robotics. Especially, the control of the multi-fingered robot hand is very complicated [1] since they have too many degrees of freedom (DOF) and their dynamics are highly nonlinear and coupled. Moreover, if the tactile sensors are introduced, it becomes a much more complex control problem that deals with both position and force.

In literature, various approaches have been applied to solve this problem. The model based decoupling [2-5] control and adaptive control approaches are analytic and cannot be easily implemented in real time applications due to the computational burden and dynamic uncertainty. Furthermore, the analytic methods cannot be used if variables such as the object's weight and end-effector acceleration are unknown. To overcome these limitations, other approaches using fuzzy controllers [6-13] have been developed as this kind of controllers is readily applied to higher order nonlinear multiple input/multiple output (MIMO) systems. Also, it does not need precise mathematical models with known inputs but rather describes system dynamics through membership functions and rules. Control rules are established based on human experience. The fuzzy logic is the ideal choice for our system controller since much heuristic knowledge is available on hand movements to carry out grasps. Hence, this paper investigates the application of fuzzy logic to control articulated two fingered robot hand grasping of 3D object unknown a priori.

The remainder of the article is organized as follows: Firstly, Section II describes the grasping experience of human being studied by Neuroscientists. Section III expounds on the control scheme of Fig. 1 by carefully defining each control bloc. Hence, this Section presents two controllers design for controlling the fingertip force and controlling the slip phenomenon. In Section IV, simulation results are presented to confirm the effectiveness and applicability of the proposed approach. Finally, Section V draws some conclusions and directions for future work.

II. HUMAN GRASPING

Understanding how humans execute grasps is needed to generalize human grasping control movements. Humans perform grasping and manipulation actions naturally without precise planning but using learning and sensory feedback. Hence, the human talent for grasping and manipulating objects has been carefully studied by many Neuroscientists. Recently, Johansson and Flanagan in [9,16] demonstrated that the human grasping and manipulation involve a great use of tactile signals from several different types of mechanoreceptors in the glabrous (non-hairy) skin of the hand, with vision and proprioception providing information which is less essential. Also, in the same paper, the authors divide the apparently easy task of picking up an object and setting it back down into seven different phases: reach, load, lift, hold, replace, unload, and release.

In the reach phase, humans close their fingers to establish the contact with the object. Specifically, the passage from the reach to load phase is known to be detected by the FA-I (Meissner) and FA-II (Pacinian) afferents that are stimulated by the initial fingertip contact. The abbreviation FA means that these mechanoreceptors are fast-adapting because they respond primarily to changes in mechanical stimuli, having small and large receptive fields respectively. Once contact has been occurred, human beings increase their grasp force to the desired level by using both pre-existing knowledge about the object and tactile information gathered during the interaction. The response of the SA-I (Merkel) afferents, which are slowly-adapting with small receptive fields, is used largely to regulate this loading process. When the desired grasp force is achieved with a stable hand posture, the load phase terminates. Then, once the object is securely grasped, humans can lift up the object, hold it in the air, and possibly transport it to a new location using their arm muscles.

Humans can apply corrective actions, typically increases in grasp force, during the lifting and holding phases if the tactile feedback does not match the expected result. As mentioned in the work [15], the FA-I and FA-II signals are the principal sources of information to detect both fingertip slip and new object contact. Srinivasan et al. [15] demonstrate that, in the lifting and holding phases, the detection of slip is essential to reject disturbances, while object contact must be detected during the replace stage to successfully transition to unloading. Also, in order to set properly the object down before full release, the SA-I afferents have again an important role during unload phase. These tactile sensing abilities and corrective reactions allow humans to adeptly grasp a very wide set of objects without crushing or dropping them. Typically, humans apply a grasp force which is only 10–40% more than the minimum amount required to avoid slippage [14], so achieving both safety and efficiency goals.

III. ROBOTIC GRASPING

To build the proposed control scheme, it is required to get information about the system characteristics for use in simulation work. Hence, we define first the input/output variables of the system. The input variable to the system is the position error between the desired and the actual fingertip position expressed in 3D space since in this work we considered 3D objects whose physical proprieties are previously unknown. The output variable of the system is the required motor voltage which is proportional to the joint torque. Also, in this work we take into account relative motions between fingers and the object, in particular sliding phenomenon.

To facilitate the formulation and implementation, the analysis of the control problem considered in this paper is based on some assumptions that are as follows:

- We assume that only the fingertips are making contact with the object i.e. a precision type grasp.
- The constraint at each contact point between fingertips and object is described by the sliding contact.
- We suppose that the direction of the applied fingertips force is along the z-axis.
- The object is expressed in 3D space and has unknown physical proprieties a priori.

By investigating the human hand behaviour presented in the previous section, we conclude that the stable grasping of the object in the hand needs accurate control of the forces applied to the object and effective slip control algorithm. Hence, we propose the control scheme presented in Fig. 1 that is applied for each finger of the multi-fingered robot hand.

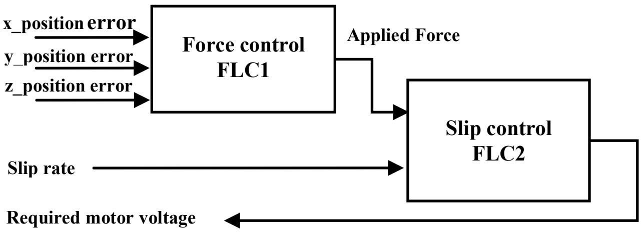

Fig. 1 Proposed control architecture for one finger

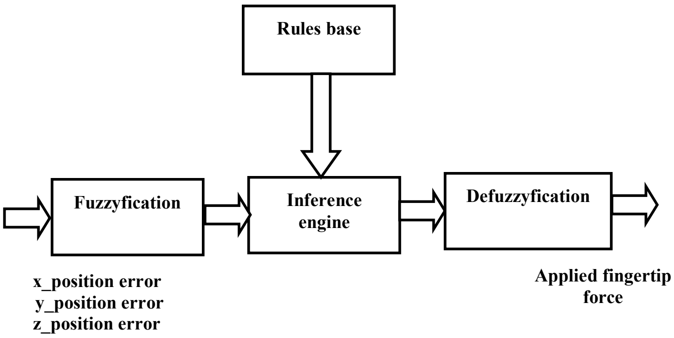

Fig. 2 Structure of the force fuzzy logic controller for one finger

A. Force Controller Design

We describe a typical fuzzy inference process with reference to our FLC implemented on each finger although the same procedure is applied for the FLC1 and FLC2 as well.

As shown in Fig. 2, the fuzzy controller FLC1 consist of the four units for fuzzification, rule base, inference mechanism and defuzzification, as well as FLC2. The initial design of the fuzzy logic controllers was accomplished heuristically. First, inputs and outputs are defined. The FLC1 has three inputs: x, y and z position errors between the desired fingertip position and the actual set point. Then, the set of crisp inputs are fuzzified via membership functions which are fuzzy sets giving the degree of membership in each set. The membership functions for the x_position error and the y_position error are selected as negative (neg), zero (zero) and positive (pos). However, for the z_position error the membership functions are large negative (ln), negative (neg), zero (zero), positive (pos) and large positive (lp).

For the controller, we used triangular and trapezoidal membership functions. The reasons for using triangular membership functions is that they simplify the calculations since they are linear, they also enable the overlap between neighboring fuzzy sets, and finally they include a smaller steady-state error than other functions. On the output side, trapezoidal functions can represent the actuator saturation.

Next, instead of using mathematical formulas, a set of IF-THEN rules is generated and evaluated for each combination of fuzzified inputs to provide fuzzy output sets of appropriate control actions. The proposed finger controller for the force control consists of 11 rules that consider the three inputs and determine the fuzzy output. The Rule Base for the Finger fuzzy controller FC1 is determined from both analysis of heuristics and kinematic of the finger object interaction. The rules are constructed as showed in Table 1.

The FLC1 has one output which is the applied fingertip force. Its membership functions are defined by four fuzzy variables that are zero (zero), small positive (sp), positive (pos), and large positive (lp). The fuzzy output sets are then added to establish an aggregated output set that is defuzzified though the center of gravity method. The expression of this method is as follows:

$$h = \frac{\sum_{i=1}^{n} h_i \cdot \mu_i(h_i)}{\sum_{i=1}^{n} \mu_i(h_i)}$$

Where h is the output value from defuzzification, μ is the degree of membership, and n is the number of output partitions.

TABLE I
RULE BASE FOR THE FINGER FUZZY FORCE CONTROLLER FLC1

Applied Force	**x_position error**	neg	zero	pos	none
	y_position error	neg	zero	pos	none
z_position error	ln				zero
	neg	zero	zero	sp	
	zero	sp	sp	zero	
	pos	pos	lp	lp	
	lp				lp
	none				

B. *Slip Controller Design*

There are several factors that can induce slipping situation on the grasped object, in particular, external forces acting on the object and the pull of gravity. Appling more force to the object can reduce this slippage. Nevertheless, there is a limit to the force that the finger can apply to the object because if we apply a large force, the object can be crushed, also, the object can slip if the finger cannot apply more force due to the mechanical limits. Hence, the slippage information is added to the controller to solve this problem. The majority of existents controllers used only information given from a force sensor to perform the slip controller but the developed slip controller ensures stable grasping with minimum fingertip force without need to get information from force sensors which reduce the noise introduced by these sensors. The fuzzy slip control FLC2 has two inputs and one output. The inputs are the partial output of FLC1 the Applied Force and the slip rate given by slip sensor. The output is the required motor voltage which is directly proportional to the motor torque.

The membership functions for the Applied Force are selected as zero (zero), small positive (sp), positive (pos), and large positive (lp) and for the Slip rate are zero (zero), Almost Nil (AN), small (S), Medium (M) and large (L). The membership functions for the required motor voltage are selected as zero (zero), very small (VS), small (S), medium (M), large (L), very large (VL), very very large (VVL), and negative very small (NVS). The required motor voltage set has more set members so as to have a smoother output. Triangular membership functions were chosen for all signals because of their simplicity and economy. The rules base is depicted in Table 2.

TABLE III
RULE BASE FOR THE FINGER FUZZY SLIP CONTROLLER FLC2

Required motor voltage		**Applied fingertip force**			
		zero	sp	pos	lp
Slip rate	zero	VVL	M	zero	NVS
	AN	VL	M	VS	zero
	S	L	L	M	S
	M	VL	VL	L	M
	L	VVL	VL	L	M

IV. SIMULATION RESULTS

In order to evaluate the proposed controller, computer simulations are performed with the model implemented in the Simulink MATLAB shown in Fig. 3. The inputs are fuzzified from step input signals.

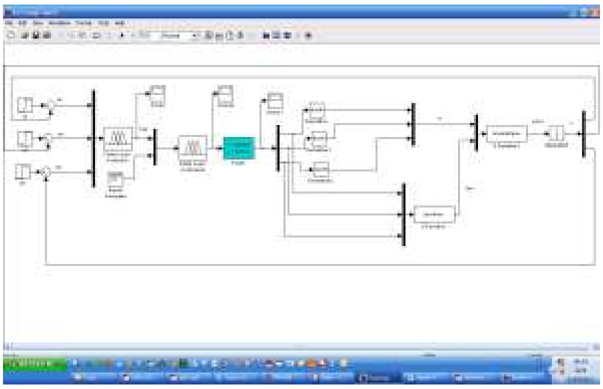

Fig. 3 Simulin Model of the Fuzzy control architecture for one finger

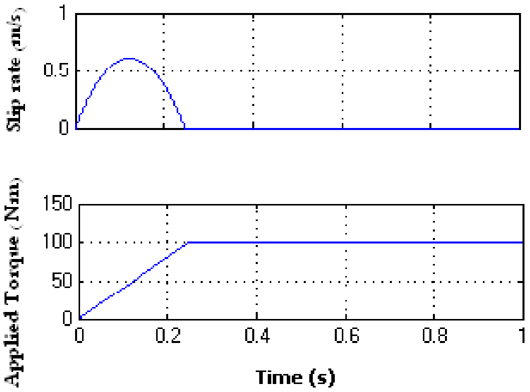

Fig. 4 Applied Torque for a given Slip rate on one finger

The Fig. 4 shows that if the slip rate increases, the applied motor torque increases also in order to regulate the fingertip force. However, if the slip rate is equal to zero the applied motor torque also is equal to zero. Hence, the effectiveness of the fuzzy controller architecture is proved.

V. CONCLUSIONS

In this study, a fuzzy control scheme suitable to allow stable precision grasping of 3D objects with controlling of the slip condition. The proposed architecture emulates the highly sophisticated behaviour of a human finger trying to achieve a grasping with minimum fingertip force can be achieved which reduce the risk of deforming or crushing the gripped object. We assumed that the fingers can be separately controlled. Therefore, the control algorithm was implemented and tested on one finger since the other fingers would have a similar control structure and response.

The main advantage of the proposed controller is that it is robust since knowledge concerning the physical proprieties of objects is not required, but not adaptive. Moreover, the fuzzy logic controller is easy to implement and can operate in real time as it require low computation time.

Satisfactory results were illustrated using the proposed fuzzy controller.

The future work will propose a hierarchical architecture for controlling the whole hand as it arranges the computation load and allows having a more complex system (i.e. more inputs) but keeping its transparency (i.e. small rule base).

ACKNOWLEDGMENT

The authors would like to acknowledge the financial support of this work by grants from General Direction of Scientific Research (DGRST), Tunisia, under the ARUB program.

REFERENCES

[1] A. Bicchi, “Hand for dexterous manipulation and robust grasping: A difficult road toward simplicity,” *IEEE Transactions on Robotics and Automation*, 2000, pp. 652–662.

[2] T. Wimboeck, C. Ott, G. Hirzinger, “Passivity-based object-level impedance control for a multifingered hand,” *IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*, 2006, pp. 4621–4627.

[3] T. Yoshikawa, “Multifingered Robot Hands: Control for Grasping and Manipulation,” (Review Paper), *Annual Reviews in Control*, vol.34, 2010, pp.199-208.

[4] R. Boughdiri , H. Nasser , H. Bezine, N. K. M’Sirdi, A. M. Alimi, A. Naamane, “Dynamic Modeling and Control of a Multi-Fingered Robot Hand for Grasping Task,” *Procedia Engineering*, vol. 41, 2012, pp. 923 – 931.

[5] S. Ueki, H. Kawasaki, T. Mouri, “Adaptive coordinated control of multi-fingered robot hand,” *Journal of Robotics and Mechatronics*, vol. 21, no. 1, 2009, pp. 36–43.

[6] J. A. Dominguez-Lopez, D. N .Vila-Rosado, “Hierarchical fuzzy control to ensure stable grasping,” *Seventh Mexican International Conference on Computer Science (ENC'06)*, 2006, pp. 37 – 43.

[7] N. Petroff, K.D. Reisinger, P. Mason, “Fuzzy-Control of a Hand Orthosis for Restoring Tip Pinch, Lateral Pinch, and Cylindrical Prehensions to Patients with Elbow Flexion Intact,” *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 9, no. 2, June 2001.

[8] N.I. Glossas, N.A. Aspragathos, ‘‘Fuzzy logic grasp control using tactile sensors,” *Mechatronics*, vol. 11, 2001, pp. 899-920.

[9] S. Arimoto, ‘‘Intelligent control of multi-fingered hands,” *Annual Reviews in Control*, vol. 28, 2004, pp. 75-85.

[10] E.A. Al-Gallaf, ‘‘Multi-fingered robot hand optimal task force distribution Neural inverse kinematics approach,” *Robotics and Autonomous Systems*, vol. 54, 2006, pp. 34-51.

[11] E. Zio, P. Baraldi, I. Popescou, ‘‘From Fuzzy Clustering to a Fuzzy Rule-Based Fault Classification Model,’’ *International Journal of Computational Intelligence Systems*, vol. 1, no. 1, 2008, pp. 60-76.

[12] N.I. Glossas, N.A. Aspragathos, “A Cluster Based Fuzzy Controller for Grasp and Lift Fragile Objects,” *18th Mediterranean Conference on Control & Automation Congress*, Marrakech, Morocco, June 23-25, 2010.

[13] A. M. Zaki , A. M. Soliman, O. A. Mahgoub , A.M. EI-Shafei, “Design and Implementation of Efficient Intelligent Robotic Gripper,” *Proceedings of the 2010 International Conference on Modelling, Identification and Control*, Okayama, Japan, July 17-19, 2010, pp. 710-716.

[14] R. S. Johansson and J. R. Flanagan, “Coding and use of tactile signals from the fingertips in object manipulation tasks,” *Nat. Rev. Neurosci.*, vol. 10, May 2009, pp. 345–359.

[15] M. A. Srinivasan, J. M. Whitehouse and R. H. LaMotte, “Tactile detection of slip: Surface microgeometry and peripheral neural codes,” *J. Neurophysiol*., vol. 63, 1990, pp. 1323–1332.

[16] R. Flanagan, M. Bowman, R.Johansson, ‘‘Control strategies in object manipulation tasks,” *Current Opinions Neurobiology*, vol. 16, no. 6, 2006, pp. 650-657.