ACTIVE COMPLIANCE CONTROL STRATEGIES FOR MULTIFINGERED
ROBOT HAND

AMIRUL SYAFIQ BIN SADUN

A thesis submitted in
fulfilment of the requirement for the award of the
Doctor of Philosophy of Engineering Technology

Faculty of Engineering Technology
Universiti Tun Hussein Onn Malaysia

AUGUST 2018

Dedicated to my beloved parents

and family

ACKNOWLEDGEMENT

First and foremost, I praise and thank Allah, the Almighty, for His Showers of blessings throughout my research work to complete this study successfully.

I would like to express my deep and sincere gratitude to my supervisor Associate Professor Dr Jamaludin bin Jalani, for the invaluable guidance and encouragement that he has provided me throughout my time doing this research. I have been so privileged to have a supervisor who cares and whose vision, sincerity and motivation have deeply inspired me.

I would also extend my gratitude to all members of the Faculty of Engineering Technology who have helped me in one way or another.

Finally, I wish to express my gratitude to my parents and family members for their endless love and prayers. Their continuous support and encouragement have given me the strength to complete this study. They make this study so meaningful to me.

ABSTRACT

Safety issues have to be enhanced when the robot hand is grasping objects of different shapes, sizes and stiffness. The inability to control the grasping force and finger stiffness can lead to unsafe grasping environment. Although many researches have been conducted to resolve the grasping issues, particularly for the object with different shape, size and stiffness, the grasping control still requires further improvement. Hence, the primary aim of this work is to assess and improve the safety of the robot hand. One of the methods that allows a safe grasping is by employing an active compliance control via the force and impedance control. The implementation of force control considers the proportional–integral–derivative (PID) controller. Meanwhile, the implementation of impedance control employs the integral sliding-mode controller (ISMC) and adaptive controller. A series of experiments and simulations is used to demonstrate the fundamental principles of robot grasping. Objects with different shape, size and stiffness are tested using a 3-Finger Adaptive Robot Gripper. The work introduces the Modbus remote terminal unit [RTU] protocol, a low-cost force sensor and the Arduino IO Package for a real-time hardware setup. It is found that, the results of the force control via PID controller are feasible to maintain the grasped object at certain positions, depending on the desired grasping force (i.e., 1N and 8N). Meanwhile, the implementation of impedance control via ISMC and adaptive controller yields multiple stiffness levels for the robot fingers and able to reduce collision between the fingers and the object. However, it was found that the adaptive controller produces better impedance control results as compared to the ISMC, with a 33% efficiency improvement. This work lays important foundations for long-term related research, particularly in the field of active compliance control that can be beneficial to human–robot interaction (HRI).

ABSTRAK

Aspek keselamatan perlu dipertingkatkan ketika robot tangan mengendalikan objek yang mempunyai kepelbagaian bentuk, struktur dan kekerasan. Ketidakupayaan untuk mengawal daya memegang dan kekakuan jari boleh menimbulkan isu ketika robot tangan mengendalikan objek. Meskipun telah banyak kajian dijalankan bagi menyelesaikan isu memegang objek terutamanya bagi objek yang mempunyai pelbagai saiz, struktur dan kekerasan, kawalan daya memegang masih memerlukan penambahbaikan. Oleh itu, sasaran utama kajian ini adalah untuk menilai dan menambah baik aspek keselamatan robot tangan. Salah satu kaedah yang membenarkan proses genggaman yang selamat adalah dengan mengaplikasikan kawalan patuh aktif menerusi kawalan daya dan kawalan impedans. Implementasi kawalan daya dilaksanakan dengan menggunakan kawalan perkadaran-kamiran-derivatif (PID). Manakala, perlaksanaan kawalan impedans adalah dengan menggunakan kawalan mod kamiran gelongsor (ISMC) dan kawalan penyesuaian. Satu siri eksperimen dan simulasi dijalankan bagi menjelaskan prinsip asas proses menggenggam oleh robot. Objek dengan pelbagai bentuk, saiz dan kekerasan diuji dengan menggunakan robot-3-jari-penyesuai-penggenggam. Kajian ini turut memperkenalkan protokol unit terminal kawalan jauh Modbus [RTU], sensor daya kos rendah dan Pakej Arduino IO bagi penyediaan perkakasan masa-sebenar. Hasil kajian mendapati kawalan perkadaran-kamiran-derivatif (PID) menunjukkan keupayaan jari-jari robot untuk mengekalkan sentuhan dengan objek pada posisi tertentu, bergantung kepada daya yang dikehendaki (1N dan 8N). Sementara itu, perlaksanaan kawalan impedans melalui kawalan mod kamiran gelongsor (ISMC) dan kawalan penyesuaian menghasilkan pelbagai tahap kekakuan pada jari robot serta mampu mengurangkan pertembungan antara jari robot dan objek. Walaubagaimanapun, kawalan penyesuaian didapati mendapat hasil yang lebih baik berbanding kawalan mod kamiran gelongsor (ISMC), dengan penambahbaikan kecekapan sebanyak 33%. Kajian ini meletakkan asas yang penting untuk penyelidikan jangka masa panjang, terutamanya dalam bidang

kawalan patuh aktif yang boleh memberi manfaat kepada interaksi manusia-robot (HRI).

.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

ACT	-	Anatomically-correct testbed
ADC	-	Analog to digital converter
Anthrobot	-	Anthropomorphic robot hand
BERUL	-	Bristol elumotion robot hand
BRL	-	Bristol robotics laboratory
Cybhand	-	Cybernetics robot hand
DART	-	Dexterous anthropomorphic robotic typing
DH	-	Denavit hartenberg
DOF	-	Degree of freedom
FBG	-	Fiber bragg grating
ISMC	-	Integral sliding mode control
LMEE	-	Local minimum of elastic potential energy
MRAC		Model reference adaptive controller
PID	-	Proportional integral derivative
PISMC	-	Proportional-integral sliding mode control
RL	-	Reinforcement learning
SEAs	-	Series elastic actuators
SMC	-	Sliding mode control
SPTS	-	Single pressure tactile sensor
ST ARM AC	-	Stanford testbed of an autonomous rotorcraft for multi-agent control
VSSs	-	Variable-structure systems
Z	-	Impedance
k	-	Stiffness
b	-	Viscous damping coeeficient
I_i	-	Inertia
T_{gen}	-	Generated torque
ω	-	Actual speed
α	-	Actual acceleration
τ	-	Joint torque vector for modelling contact
M	-	Mass matrix for modelling robot finger
V	-	Resulting coriolis matrix for modelling robot finger
G	-	Gravitational force vector for modelling robot finger
F_r	-	Friction force vector
q	-	Joint position vector
qf	-	Coordinate vector describing the combined configuration of the system consisting of one or more parts and robot fingers
W	-	Grasp matrix that maps the individual fingertip contact wrenches

f_{all}	-	Vector obtained by stacking the wrench at an active contact
c_i	-	An active contact
M_f	-	Mass matrix for modeling constant
C	-	Resulting coriolis matrix for modelling contact
g	-	Gravitational force vector for modelling contact
T_f	-	Control forces for modelling contact
T_f	-	Joint torque vector for modelling contact
F	-	Force
N^T	-	Null space operation
I	-	Identity matrix
U	-	Cost function
K_a	-	Actuator activation matrix
f_u	-	Unknown but bounded some known functions of the states
s	-	Sliding mode surface
c	-	Constant
x	-	Position error
M_i	-	Constant
sgn	-	Signum
$\dot{x}$	-	Velocity error
q_e	-	Tracking error
Θ_1	-	Angular data of joint 1
Θ_2	-	Angular data of joint 2
Θ_3	-	Angular data of joint 3
X_0	-	Reference frame
Y_0	-	Reference frame
Z_0	-	Reference frame
VG_1	-	Lumped expressions of coriolis/centrifugal force and gravity
VG_2	-	Lumped expressions of coriolis/centrifugal force and gravity
VG_3	-	Lumped expressions of coriolis/centrifugal force and gravity
T_1	-	Actual torque joint 1
T_2	-	Actual torque joint 2
T_3	-	Actual torque joint 3
T_D	-	Driving torque joint 1
T_{L21}	-	Load torque joint 1
T_{L22}	-	Driving torque joint 2
T_{L31}	-	Load torque joint 2
T_{L32}	-	Driving torque joint 3
r_1	-	Radius of the first pulley
r_{21}	-	Radius of the second pulley
k_{12}	-	Constant to take into account offset
r_{22}	-	Radius of the second pulley
r_3	-	Radius of the third pulley
k_{22}	-	Constant to take into account offset
f	-	Lumped expression for the major nonlinearities
q_d	-	Desired trajectory
$\dot{q}_d$	-	Desired trajectory velocity

$\ddot{q}_d$	-	Desired trajectory acceleration
r	-	Filtered control error
$\dot{q}_r$	-	Reference trajectory velocity
$\ddot{q}_r$	-	Reference trajectory acceleration
λ	-	Constant
k_1	-	Constant
k_i	-	Integral Constant
$\hat{f}$	-	An estimate of the friction force
$\hat{M}$	-	An estimate of the mass
S	-	Basis functions used for friction identification
P	-	A vector of parameters
ε	-	A small remaining error
$\tilde{f}$	-	Actual of the friction force - estimate of the friction force
$\tilde{M}$	-	Actual of the mass - estimate of the mass
u_r	-	Compensate for any remaining modeling uncertainty ε
k_2	-	Constant
$\dot{\hat{\Theta}}$	-	Adapting law
Γ	-	Adapting law
ψ	-	Adapting law
σ	-	A forgetting factor
τ_0	-	Computed torque component
τ_1	-	Discontinuous torque control
M_0	-	Nominal value
f_0	-	A discontinuous torque control
k_p	-	Proportional constant
k_d	-	Derivative constant
Γ_0	-	Gain to drive $s = 0$
K_s	-	Gain for sliding surface/damping constant
K_{is}	-	Integral gain for sliding mode control/spring constant
y_{di}	-	Demand signals
y_i	-	Output signals
N_s	-	Number of samples
u_i	-	Control signal
γ	-	Gain to suppress chattering
H	-	External force measurement signal
G_f	-	Input distribution gain
q_r	-	Virtual demand
m_v	-	Virtual mass of the spring
K_{ss}	-	Virtual damping constant
K_{ii}	-	Virtual spring constant
ω_n	-	Natural frequency
ζ	-	Damping ratio coefficient
R_d	-	Desired radial
$\dot{R}_d$	-	Desired radial velocity
$\ddot{R}_d$	-	Desired radial acceleration
R_e	-	Radial error
F_0	-	PD controller
F_1	-	Integral sliding mode controller

B	-	Projection matrix
$\hat{s}$	-	Sliding mode variable for the posture control
δ_{SL}	-	Gain to suppress chattering for the posture control
K_{dp}	-	Constant
K_{SL}	-	Constant
K_v	-	Constant
w_1	-	Constant
w_2	-	Constant
ϕ_1	-	Constant
ϕ_2	-	Constant
R_r	-	Virtual demand
H	-	External force
G_f	-	Positive scalar
K_s	-	Damping coefficient
K_i	-	Stiffness coefficient

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Research Background

Robots are commonly used in highly structured and pre-defined environments, such as factories. Tasks such as painting, deburring, polishing and welding require robots to move from initial positions to goal positions efficiently, without colliding with obstacles or other robots [1]. The unstructured robot environment (i.e., an environment in which the robot has no prior knowledge of the environment) has been a subject of interest for many researchers, particularly when the robots are sharing the same workspace as humans or other robots [2]. This scenario requires researchers to focus on safety issues during interactions between the robot and its surroundings. For example, the safety of an object being grasped by a robot hand relies on several aspects, such as the provision of reliable mechanical structures or mechanisms in the robot, the presence of adequate motion control and the feasibility of compliance control [3], [4], [5], [6].

In general, compliance control can be divided into two categories: active compliance control and passive compliance control. Active compliance control uses the force feedback method, while passive compliance control applies elements of elasticity and mechanical structure to specifically generate compliance tasks at the robot endpoint [7]. Over the last ten years, work on active and passive compliance control in robot hands has been performed extensively in the effort to imitate human hand capability. Figure 1.1 summarises the general concepts of passive and active compliance control.
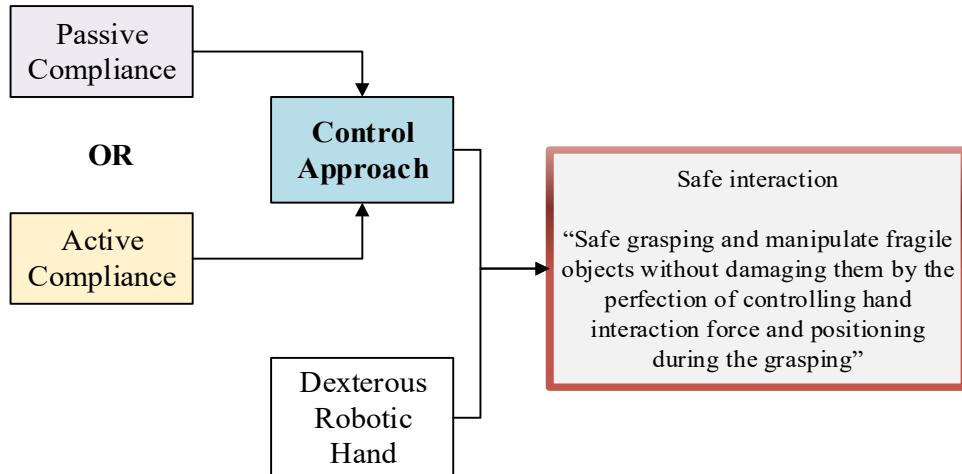
Figure 1.1: General Concept of Passive and Active Compliance Control

Past research on compliance control strategy has shown that position control has been used more commonly than force control to produce fast, accurate and repeatable robot motion. Moreover, position control works best in a well-organised and controlled work space because the controlled robots operate repeatedly in the same working area, such as in the automation manufacturing industry. However, position control is not enough when extending the application of robots outside of the controlled working environment to tasks that involve contact with objects when position data are not entirely known. The use of pure position control can result in fluctuations in contact force that ultimately lead to dangerous behaviours such as breakage or instability. Therefore, many compliance controls strategy for robot movement, and specifically for robot hands, have been introduced by researchers to replicate safe human grasping and object contact. This work focuses on compliance control strategy, particularly in relation to a robot hand.

1.2   Research Context

This research focuses on the active compliance control approach for a robot hand grasping operation. Generally, an active compliance control can be divided into two categories: force control and impedance control [8]. This is depicted in Figure 1.2.
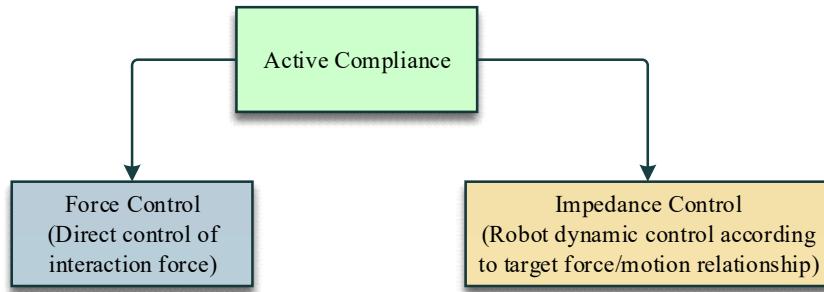
Figure 1.2: Active Compliance Control Categories

Force control is defined as a control technique in which the desired interactions between force and robot position are controlled. In force control, the desired force trajectory is commanded, and force is measured in real time to enable feedback control. Conversely, impedance control is based on position control, and it requires positioning commands and measurements to close the feedback loop. In addition, force measurements are also required to realise the target impedance characteristic. It uses the different relationships between the acting forces and manipulator position to adjust the mechanical impedance of the end-effector to the external forces.

The most common types of impedance control are stiffness (position proportional), damping (velocity proportional) and general impedance (position, velocity and acceleration proportional) [8]. The impedance causality implementation is more robust in terms of rigid contact, but the admittance control scheme is more widely applicable and has better nominal performance in free motion.

The context of this research includes both force and impedance control approaches. The proposed force control utilises proportional–integral–derivative (PID) controller, while the impedance control uses two different controllers, namely, integral sliding-mode controller (ISMC) and adaptive controller (friction compensation–based).

REFERENCES

1. Oliver, C. S. and Dolan, J. M. Multi-robot Path Planning by Predicting Structure in a Dynamic Environment. *Proceedings of the First IFAC Conference on Mechatronic Systems*. 2000. 2: pp. 593–598.

2. Herrmann, G. and Melhuish, C. Towards safety in human robot interaction. *Int. J. Soc. Robot.* 2010. 2(3): pp. 217–219.

3. Kyriakopoulos, K. J., Van Riper, J., Zink, A., & Stephanou, H. E. Kinematic analysis and position/force control of the anthrobot dextrous Hand. *IEEE Trans. Syst. Man, Cybern. Part B Cybern.* 1997. 27(1): pp. 95–104.

4. Albu-Schäffer, A., Ott, C., & Hirzinger, G. A Unified Passivity-based Control Framework for Position, Torque and Impedance Control of Flexible Joint Robots. *Int. J. Rob. Res.* 2007. 26(1): pp. 23–39.

5. de Montigny, M. and Sicard, P. Adaptive force/position control of a robot hand. *IEEE Canadian Conference on Electrical and Computer Engineering*. 1999. 3: pp. 1392–1397.

6. Yoshikawa, T. Dynamic Hybrid Position/Force Control. *IEEE J. Robot. Autom.* 1987. 11(8715798): pp. 386–392.

7. Lefebvre, T., Xiao, J., Bruyninckx, H. & G. De Gersem. Active compliant motion : a survey. *Adv. Robot.* 2015. 19(5): pp. 479–499.

8. Ekalo, Y., Surdilovic, D., & Vukobratovic, M. Dynamics and Robust Control of Robot-environment Interaction. *World Sci. Publ. Co. Pte. Ltd.* 2009. 2: pp. 1–629.

9. Regoli, M., Pattacini, U., Metta, G., & Natale, L. Hierarchical grasp controller using tactile feedback *2016 IEEE-RAS 16th Int. Conf. Humanoid Robot.* 2016. pp. 387–394.

10. Romeo R. A. et al. Development and preliminary testing of an instrumented object for force analysis during grasping. *Proc. Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. EMBS*. 2015. 2015–Novem: pp. 6720–6723.

11. Hristu, D., Babb, J., Singh, H., & Gottschlich, S. Position and Force Control of a Multifingered Hand: A Comparison of Fuzzy Logic to Traditional PID Control. 1994. 2.

12. Cheung, N. C. and Chan, K. K.-C. PID control of a novel variable reluctance gripper. *The 27th Annual Conference of the IEEE Industrial Electronics Society PID.* 2001. 1: pp. 456–461.

13. Nakamura, T., Shimamura, K., and Andou, T. A Magnetic Parallel Motion Hand for Micro Grasping and Processes. *Proceedings of the 2001 IEEE International Conference on Robotics & Automation.* May 21-26, 2001. Seoul, Korea: IEEE, 2001. 3920–3925.

14. Jalani, J., Mahyuddin, N., Herrmann, G., & Melhuish, C. Active robot hand compliance using operational space and Integral Sliding Mode Control. *2013 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM).* July 9-12, 2013. Wollongong, Australia: 2013: pp. 1749–1754.

15. Visioli, A., Adamini, R., and Legnani, G. Adaptive friction compensation for industrial robot control. *2001 IEEE/ASME International Conference on Advanced Intelligent Mechatronics Proceedings.* 8-12 July, 2001. Como, Italy: 1(July): 577.

16. Verbert, K. A. J., Toth, R., and Babuska, R. Adaptive Friction Compensation: A Globally Stable Approach. *IEEE/ASME Transactions on Mechatronics.* 2016. 21(1): pp. 351–363.

17. Rafan, N. A., Jamaludin, Z. and Heng, C. T. Investigation on tracking performance of adaptive friction compensation using Cascade P / PI controller at low velocity. *2016 International Conference on Computer & Communication Engineering.* 2016: pp. 149–154.

18. Huang, L., Wang, W. and Huang, Y. Design of dynamic model with adaptive nonlinear friction compensation for vacuum parallel manipulator. *The 6th Annual IEEE International Conference on Cyber Technology in Automation, Control and Intelligent Systems.* June 19-22, 2016. Chengdu, China: pp. 33–38, 2016.

19. Jalani, J., Herrmann, G. and Melhuish, C. Robust active compliance control for practical grasping of a cylindrical object via a multifingered robot hand. *IEEE Conf. Robot. Autom. Mechatronics, RAM - Proc.* 2011. pp. 316–321.

20. Allen, K. S. R., Peter K., Michelman, P. System for Programming and Controlling a Multisensor Robotic Hand. 1990. 20(6): pp. 1450–1456.

21. Mouri, T., Kawasaki, H., Kigaku, K. and Ohtsuka, Y. Novel Control Methods for Multi-fingered Haptic Interface Robot. *Proceedings of the 2006 IEEE/RSJ International Conference on Intelligent Robots and Systems.* October 9 - 15, 2006. Beijing, China. 2006. (Hiro Ii): pp. 1576–1581.

22. Dollar, A. M., and Howe, R. D. Simple, robust autonomous grasping in unstructured environments. *2007 IEEE International Conference on Robotics and Automation.* April 10-14 2007. Roma, Italy. 2007. pp. 4693–4700.

23. Fukui W. et al. Development of multi-fingered universal robot hand with torque limiter mechanism. *IECON Proc. (Industrial Electron. Conf.* 2009. pp. 2205–2210.

24. Herrmann, G., Jalani,J., Mahyuddin, M. N., Khan, S. G. and Melhuish, C. Robotic hand posture and compliant grasping control using operational space and integral sliding mode control. *Robotica.* 2016. 34(10): pp. 2163–2185.

25. Krut, S., Bégoc, V., Dombre, E. and Pierrot, F. Extension of the form-closure property to underactuated hands. *IEEE Trans. Robot.* 2010. 26(5): pp. 853–866.

26. Deimel, R. and Brock, O. A novel type of compliant and underactuated robotic hand for dexterous grasping. *Int. J. Rob. Res.* 2016. 35(1–3): pp. 161–185.

27. Massa, B., Roccella, S., Carrozza, M.C. and Dario, P. Design and development of an underactuated prosthetic hand. *Proceedings of the 2002 IEEE International Conference on Robotics & Automation.* May 2002. Washington, DC. 2002. 4: pp. 3374–3379.

28. Plooij, M., Mathijssen, G., Cherelle, P., Lefeber, D. and Vanderborght, B. Review of locking devices used in robotics. *IEEE Robot. Autom. Mag.* 2010. 22(337596): pp. 106–117.

29. Hirose, S. and Umetani, Y. The development of soft gripper for the versatile robot hand. *Mechanism and Machine Theory*. 1978. 13(3), pp.351–359.

30. Crowder, R.M., An anthropomorphic robotic end effector. *Robotics and Autonomous Systems*. 1991. 7(4), pp.253–268

31. Dechev,N., Cleghorn, W.L. and Naumann, S. Multiple finger, passive adaptive grasp prosthetic hand. *Mechanism and Machine Theory*. 2001. 36(10), pp.1157–1173.

32. Laliberté, T., Birglen, L. and Gosselin, M.C. Underactuation in robotic grasping hands. *Machine Intelligence & Robotic Control*. 2003. 4(3), pp.1–11.

33. Carrozza M.C. et al., The SPRING Hand: Development of a Self-Adaptive Prosthesis for Restoring Natural Grasping. *Autonomous Robots*. 2004. 16(2), pp.125–141.

34. Carrozza M.C. et al. A cosmetic prosthetic hand with tendon driven under-actuated mechanism and compliant joints: Ongoing research and preliminary results. *Proceedings - IEEE International Conference on Robotics and Automation*. April 2005. Barcelona, Spain. 2005. pp.2661–2666.

35. Nasser, S., Rincon, D. and Rodriguez, M. Design of an anthropomorphic underactuated hand prosthesis with passive-adaptive grasping capabilities. *Florida Conf. Recent Adv. Robot. Robot Showc* .2006. pp. 25–26.

36. Cipriani C. et al. Closed-loop controller for a bio-inspired multi-fingered underactuated prosthesis. *Proceedings - IEEE International Conference on Robotics and Automation*. May 2006. Orlando, Florida. 2006. pp.2111–2116.

37. Birglen, L. and Gosselin, C.M.,. Force Analysis of Connected Differential Mechanisms: Application to Grasping. *The International Journal of Robotics Research*, 25(10), 2006. pp.1033–1046.
   Available at: http://journals.sagepub.com/doi/10.1177/0278364906068942.

38. Tincani, V. and Catalano, M. Velvet fingers: a dexterous gripper with active surfaces. *IEEE International Conference on Intelligent Robots and Systems*, 2012. pp.1257–1263.
   Available at: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6385939.

39. Member, S., Odhner, L.U. and Dollar, A.M. A Modular Open-Source 3D Printed U nderactuated Hand Raymond. 2013. pp.2737–2743.

40. Ahrary, A. A new approach to flexible multi-joint robot finger. *Proceedings - 2014 IEEE 10th International Colloquium on Signal Processing and Its Applications, CSPA 2014*. 2014. pp.1–4.

41. Wiste, T. and Goldfarb, M. Design of a simplified compliant anthropomorphic robot hand. *Proceedings - IEEE International Conference on Robotics and Automation*. 2017. pp.3433–3438.

42. Reis, M.F., Leite, A.C., Lizarralde, F. and Liu Hsu. Kinematic modeling and control design of a multifingered robot hand. *2015 IEEE 24th International Symposium on Industrial Electronics (ISIE)*. 2015. pp.638–643.

Available at: http://ieeexplore.ieee.org/document/7281543/.

43. Sahoo, S., Korrapati, M., Hota, R.K. and Kumar, C.S. Bond graph modelling of a tendon driven prosthetic hand finger for motion and impedance control. *International Conference on Robotics and Automation for Humanitarian Applications, RAHA 2016 - Conference Proceedings*. 2017. pp.1–6.

44. Giinver, H. and Erhen, A.M. Optimal Robot Hand Preshaping Control Using Genetic Algorithms. 1997. pp.137–142.

45. Kaneko, M., Higashimori, M. and Tsuji, T. Transition Stability of Enveloped Objects. 1998. (0). pp.3040–3046.

46. Muscio, G., Pierri, F. and Trinkle, J. A hand / arm controller that simultaneously regulates internal grasp. *IEEE International COnference on Robotics and Automation*. 2014. pp.895–900.

47. Cutkosk, M.R. and Wright, K. Modeling manufacturing grips and correlations with the design of robotic hands. *IEEE Transactions on Robotics and Automation*. 1986. pp.1533–1539.

48. Johnson, Johnson, K.L., 1985. *Contact Mechanics*

49. Shimoga, K.B. and Goldenberg, A.A. Soft materials for robotic fingers. *The International Journal of Robotics Research*. 1996. 15: pp.335–350.

50. Albu-Schaffer, A., Ott, C. and Hirzinger, G. A Unified Passivity-based Control Framework for Position, Torque and Impedance Control of Flexible Joint Robots. *The International Journal of Robotics Research*. 2007. 26(1): pp.23–39.

51. Wimböck, T. et al. Impedance control for variable stiffness mechanisms with nonlinear joint coupling. *2008 IEEE/RSJ International Conference on Intelligent Robots and Systems, IROS. 2008*. 2008. pp. 3796–3803.

52. Khan, S.G. et al. Reinforcement learning and optimal adaptive control: An overview and implementation examples. *Annual Reviews in Control*. 2012. 36(1): pp.42–59.
Available at: http://dx.doi.org/10.1016/j.arcontrol.2012.03.004.

53. Lii, N.Y., Wimboeck, T. and Borst, C.H. Experimental study on impedance control for the five-finger dexterous robot hand DLR-HIT II. *2010 IEEE/RSJ International Conference on Intelligent Robots and Systems*. 2010. pp.5867–5874.

54. Chan, K.K. and Cheung, N.C. Grasping of Delicate Objects by a Novel Two-Finger Variable Reluctance Gripper. 2001. 0(C), pp.1969–1974.

55. Grammatikopoulou, M., Psomopolou, E., Droukas, L. and Doulgeri, Z. A controller for stable grasping and desired finger shaping without contact sensing. *IEEE International Conference on Robotics & Automation*. 2014. pp.3662–3668.

56. Starr, G.P., Experiments in Assembly Using a Dexterous Hand. IEEE *Transactions On Robotics And Automation*. 1990. 6(3), pp.342–347.

57. Kawasaki, H., Komatsu, T. and Uchiyama, K. Dexterous Anthropomorphic Robot Hand With Distributed Tactile Sensor : Gifu Hand II. *IEEE/ASME Transactions On Mechatronics.* 2002. 7(3). pp.296–303.

58. Yamasaki, Y., Tsumugiwa, T. and Yokogawa, R., Grasp and Transport Control for a Chopsticks-type Robot Using Work Done on an Object. *Proceedings of the 2010 International Conference on Modelling, Identification and Control*, July 17-19,2010. Okayama, Japan. 2010. 2. pp.269–275

59. Saen, M., Ito, K. and Osada, K., Action-Intention-Based Grasp Control With Fine Finger-Force Adjustment Using Combined Optical-Mechanical Tactile Sensor. 2014. 14(11), pp.4026–4033.

60. Lei, L., The Intelligent Grasping Tactics of Dexterous Hand. *2014 13th International Conference on Control, Automation, Robotics & Vision.* 10-12th December 2014. Marina Bay Sands, Singapore. 2014. pp.10–12.

61. Zhang, T. et al. Fingertip Three-Axis Tactile Sensor for Multifingered Grasping. *IEEE/ASME TRANSACTIONS ON MECHATRONICS*. 2015. 20(4). pp.1875–1885

62. Shaw, J., Design of servo actuated robotic gripper using force control for range of objects. *Proceedings of 2016 International Conference on Advanced Robotics and Intelligent Systems*. 2016. pp.1–6

63. Tamamoto, T., Nomura, S. and Koganezawa, K. Dexterous gripping of a hand with multi-joint fingers. *IEEE/ASME International Conference on Advanced Intelligent Mechatronics, AIM*, 2016–Sept, 2016. pp.19–24

64. Zhang, Y., Chu, L., Zhuo, W. and Deng, H. Grasping force control preventing excessive deformation for underactuated prosthetic hands. *Proceedings of 2016 IEEE Advanced Information Management, Communicates, Electronic and Automation Control Conference, IMCEC 2016*. 2017. pp.1747–1751.

65. Ekalo, Y., Surdilovic, D., & Vukobratovic, M. Dynamics and Robust Control of Robot-environment Interaction. *World Sci. Publ. Co. Pte. Ltd.* 2009. 2: pp. 1–629.

66. Nakashima, A., Yoshimastsu, Y. and Hayakawa, Y. Analysis and Synthesis of Stable Grasp by Multi-Fingered Robot Hand. *IEEE International Conference on Control Application.* 2010. pp.1582–1589

67. Jo, J., Kim, S., Oh, Y. and Oh, S., Compliance control of a position controlled robotic hand using F/T sensors. *2011 8th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI).* 2011. pp.446–450.

68. Elbrechter, C., Haschke, R. and Ritter, H. Folding paper with anthropomorphic robot hands using real-time physics-based modeling. *IEEE-RAS International Conference on Humanoid Robots.* 2012. pp.210–215.

69. Kazemi, M., Valois, J.S., Bagnell, J.A. and Pollard, N. Human-inspired force compliant grasping primitives. *Autonomous Robots*, 37(2). 2014. pp.209–225

70. Zisimatos, A.G., Liarokapis, M. V, Mavrogiannis, C.I. and Kyriakopoulos, K.J. Underactuated Robot Hands. 2014 . (Iros), pp.3207–3212

71. Xu, Y., Jiang, C. and Jie, Y. Compliance control for grasping with a bionic robot hand. *28th Chinese Control and Decision Conference (CCDC).* 2016. pp.5280–5285.

72. Chen, Z., Lii, N.Y., et al. Experimental study on impedance control for the five-finger dexterous robot hand {DLR-HIT II}. *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS).* October 2010. 2010. pp. 5867–5874.

73. Prattichizzo, D., Malvezzi, M., Aggravi, M. and Wimböck, T., Object motion – decoupled internal force control for a compliant multifingered hand. *IEEE International COnference on Robotics and Automation*, May 14-18. 2012. pp.1508–1513.

74. Grebenstein, M. et al. The {DLR} hand arm system. *IEEE International Conference on Robotics and Automation (ICRA).* May 2011. 2011. pp. 3175–3182

75. Ajoudani, A. et al. Exploring Teleimpedance and Tactile Feedback for Intuitive Control of the Pisa/IIT SoftHand. *IEEE Transactions on Haptics.* 2014. 7. pp.203–215.

76. Wang, K.J. Fuzzy Sliding Mode Joint Impedance Control for a tendon-driven robot hand performing peg-in-hole assembly. *2016 IEEE International Conference on Robotics and Biomimetics, ROBIO 2016*. 2017. pp.2087–2092.

77. Martineau, T. and Vaidyanathan, R.,. Studying the implementation of iterative impedance control for assistive hand rehabilitation using an exoskeleton. *2017 International Conference on Rehabilitation Robotics (ICORR)*. 2017. pp.1500–1505.
    Available at: http://ieeexplore.ieee.org/document/8009460/.

78. Khan, S.G. et al. Safe adaptive compliance control of a humanoid robotic arm with anti-windup compensation and posture control. *International Journal of Social Robotics*. 2010. 2(3), pp.305–319.

79. Teshigawara, S. et al. Highly sensitive sensor for detection of initial slip and its application in a multi-fingered robot hand. *Proceedings - IEEE International Conference on Robotics and Automation*. 2011. pp.1097–1102.

80. Javier, A., Collahuazo, P., Esteban, A. and Ordoñez, F. Design and Construction of a Robot Hand Activated by Electromyographic Signals. *IEEE* 2012.

81. Chen, C.H. Virtual model for a multi-finger robot hand design. *Proceedings - 2012 4th International Conference on Computational Intelligence, Communication Systems and Networks, CICSyN 2012*. 2012. pp.176–180.

82. Song, X. et al. A novel dynamic slip prediction and compensation approach based on haptic surface exploration. *IEEE International Conference on Intelligent Robots and Systems*. 2012. pp.4511–4516.

83. Talib, M.A.A. et al. PID position control for 2-DOF robotic finger. *IEEE 4th Control and System Graduate Research Colloquium*. 2013. pp.152–157.

84. Palli, G. and Pirozzi, S. An optical joint position sensor for anthropomorphic robot hands. *Proceedings - IEEE International Conference on Robotics and Automation*. 2013. pp.2765–2770.

85. Ramli, M.S. and Azlan, N.Z. Design and Development of an Anthropomorphic Shoe-Tying Robot. *Mecatronics*, (November). 2014. pp.377–382.

86. Zhang, T. et al. Multifingered robot hand dynamic grasping control based on fingertip three-axis tactile sensor feedback. *Proceedings of the World Congress on Intelligent Control and Automation (WCICA)*, 2015–March(March). 2015. pp.3321–3326.

87. P Dhepekar, P. and Adhav, Y.G. Wireless robotic hand for remote operations using flex sensor. *International Conference on Automatic Control and Dynamic Optimization Techniques, ICACDOT 2016*. 2017. pp.114–118.

88. Suárez-Ruiz, F. et al. Grasp mapping between a 3-finger haptic device and a robotic hand. *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*. 2014. 8618. pp.275–283.

89. Skovsgaard, L. Accredited Universal Robots support Centre and Forum . Authorized Robotiq and MiR distributor . Robotiq grippers. 2016. pp.1–2. Available at: http://www.zacobria.com/robotiq-zacobria-universal-robot-grippers.html.

90. Reis, M.F., Leite, A.C. and Lizarralde, F. Modeling and Control of a Multifingered Robot Hand for Object Grasping and Manipulation Tasks. *IEEE 54th Annual Conference on Decision and Control (CDC)*. 2015. pp.159–164.

91. Dabling, J.G., Filatov, A. and Wheeler, J.W. Static and cyclic performance evaluation of sensors for human interface pressure measurement. *Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS*. 2012. pp.162–165

92. Kim, T.K. et al. 2-DOF torque sensor for precise force control of robot hand. *IEEE International Conference on Automation Science and Engineering*. 2012. pp.892–895..

93. Liarokapis, M. V., Calli, B., Spiers, A.J. and Dollar, A.M. Unplanned, model-free, single grasp object classification with underactuated hands and force sensors. *IEEE International Conference on Intelligent Robots and Systems (IROS)*. 2015. pp.5073–5080.

94. Greiner, H. Passive and Active Grasping with a Prehensile Robot End-Effector. 1990. Available at: http://dspace.mit.edu/handle/1721.1/7032

95. Albu-Schäffer, A., Haddadin, S., Ott, Ch. A.S., Wimböck, T. and Hirzinger, G., The DLR lightweight robot: design and control concepts for robots in human environments. *Industrial Robot: An International Journal*. 2007. 34(5). pp.376–385.

96. Z Chen, Z., Lii, N.Y. et al. Cartesian Impedance Control on Five-Finger Dexterous Robot Hand DLR-HIT II with Flexible Joint. *Hand, The*. 2010. pp.1–12.

97. Wang, X., Zhao, Y., Fan, X. and Wu, H.,. Active gripping impedance force control with dual fingers hand. *Proceedings of 2011 International Conference on Electronic and Mechanical Engineering and Information Technology, EMEIT 2011*. 2011. 9. pp.4531–4534.

98. Tsutsui, H., Murashima, Y., Honma, N. and Akazawa, K., 2013. Robot hand with soft tactile sensors and underactuated control. *Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS*, pp.4148–4151.

99. Hasan, M.R., Vepa, R., Shaheed, H. and Huijberts, H.,. Modelling and control of the barrett hand for grasping. *Proceedings - UKSim 15th International Conference on Computer Modelling and Simulation, UKSim 2013*. 2013. pp.230–235.

100. Junaid, A. Bin et al.,. Design and Control of Artificial Robotic Hand. *International Journal of Mechanical and Mechanics Engineering*. 2014. 11(4). pp.26–33.

101. Or, K. et al. Position-force combination control with passive flexibility for versatile in-hand manipulation based on posture interpolation. *IEEE International Conference on Intelligent Robots and Systems*, November, 2016. 2016. pp.2542–2547.

102. Dalli, D. and Saliba, M.A., The university of Malta minimal anthropomorphic robot (UM-MAR) Hand II. *IEEE/ASME International Conference on Advanced Intelligent Mechatronics, AIM*, September 2016. 2016. pp.371–376.

103. Pablo, S., Pliego-jim, J. and Arteaga-p, M. A centralized hybrid position / force controller for cooperative robots with bounded torque inputs. *13th IEEE International Conference on Control & Automation (ICCA)*. 2017. pp.839–844.

104. Sadun, A.S., Jalani, J. and Sukor, J.A. An Overview of Active Compliance Control for a Robotic Hand. , 11(20). 2013. pp.2–5.

105. Adnan, R., Rahiman, M.H.F. and Samad, A.M. Model identification and controller design for real-time control of hydraulic cylinder. *Signal Processing and Its Applications (CSPA), 2010 6th International Colloquium on*. 2010. (1). pp.1–4.

106. Faudzi, A.A.M. et al. Controller design for simulation control of Intelligent Pneumatic Actuators (IPA) system. *Procedia Engineering* 2012. 41(Iris). pp.593–599. Available at: http://dx.doi.org/10.1016/j.proeng.2012.07.217.

107. Elya, M.N., Loqman, M., Aqilah, M. and Murniati, S. Development of simple setup for model identification using Matlab Data Acquisition. *Control System, Computing and Engineering (ICCSCE), 2013 IEEE International Conference on*. 2013. pp.52–57.

108. Yao, S. et al. Analysis and grasp strategy modeling for underactuated multi-fingered robot hand. *2009 IEEE International Conference on Mechatronics and Automation, ICMA 2009*. 2009. pp.2817–2822.

109. Nguyen, T.N. and Stephanou, H.E., 1989. A continuous model of robot hand preshaping. *Conference Proceedings., IEEE International Conference on Systems, Man and Cybernetics*, pp.798–803.

110. Zaidi, L., Bouzgarrou, B., Sabourin, L. and Mezouar, Y., Interaction modeling in the grasping and manipulation of 3 D deformable objects. *Proceedings of the IEEE Int. Conf. on Advanced Robotics*. 2015. pp.504–509.

111. Chen, D., Dietrich, V. and Von Wichert, G. Precision grasping based on probabilistic models of unknown objects. *Proceedings - IEEE International Conference on Robotics and Automation*, June, 2016. 2016. pp.2044–2051.

112. Vezzani, G., Pattacini, U. and Natale, L. A Grasping Approach Based on Superquadric Models. 2017. pp.1579–1586.

113. Kucuk, S. and Bingul, Z., Industrial Robotics: Theory, Modelling and Control, Sam Cubero (Ed.). *Industrial Robotics: Theory, Modelling and Control*. 2006. pp.117–148.

114. Spong, M.W., Hutchinson, S. and Vidyasagar, M., Robot dynamics and control. *Automatica*. 2004. 28(3): pp.655–656.

115. Craig, J.J., Introduction to Robotics: Mechanics and Control 3rd. *Prentice Hall*. 2004. 1(3): p.408.

116. Tondu, B. Kinematic modelling of anthropomorphic robot upper limb with human-like hands. *International Conference on Advanced Robotics*. 2009. pp.1–6.

117. Wan Tarmizi, W.F.B. et al. Modeling and simulation of a multi-fingered robot hand. *2010 International Conference on Intelligent and Advanced Systems, ICIAS 2010*. 2010. pp.5–8.

118. Jalani, J., Development Of The Forward Kinematics For Robot Fingers By Using Roborealm. *Arpapress.Com*. 2011. 7(May). pp.172–180..

119. Hota, R.K., Korrapati, M. and Kumar, C.S., Kinematic Design of a Linkage Driven Robotic Hand for Prosthetics Capable of Achieving Ten Grips. *International Conference on Robotics and Automation for Humanitarian Applications (RAHA)*. 2016. pp.5–10.

120. Kim, E.-H., Lim, M.-T. and Lee, Y.-K. Analysis grasp stability for multi-fingered robot hand. *Control Automation and Systems (ICCAS), 2010 International Conference on*. 2010. pp.1456–1461.

121. Hasan, M.R., Vepa, R., Shaheed, H. and Huijberts, H., Modelling and control of the barrett hand for grasping. *Proceedings - UKSim 15th International Conference on Computer Modelling and Simulation, UKSim 2013*. 2013. pp.230–235.

122. Lee, S., Lee, K., Jung, S. and Noh, T. Kinematic Calibration System of Robot Hands using Vision Cameras. 2013. pp.175–177.

123. Chattaraj, R., Bepari, B. and Bhaumik, S. Grasp mapping for Dexterous Robot Hand: A hybrid approach. *2014 7th International Conference on Contemporary Computing, IC3 2014*. 2014. pp.242–247.

124. Guo, G. and Gruver, W.A. Dynamic grasp planning of multifingered robot hands based on asymptotic stability. *IEEE Transactions on Systems, Man, and Cybernetics, Part B: Cybernetics*. 1996. 26(5): pp.764–768.

125. Jia, P., Meng, Q. and Wang, L. Dynamic analysis on fingers of the underwater multi-fingered robot hand. *Proceedings of the 2007 IEEE International Conference on Mechatronics and Automation, ICMA 2007*. 2007. pp.757–762.

126. de Wit, C.C. and Ge, S.S. Adaptive friction compensation for systems with generalized velocity/position friction dependency. *Proceedings of the 36th IEEE Conference on Decision and Control*. December 1997. 1997. pp. 2465–2470.

127. Faizura, W. et al. A Particle Swarm Optimization-PID Controller of a DC Servomotor for Multi-Fingered Robot Hand. *2nd IEEE International Symposium on Robotics and Manufacturing Automation (ROMA)*. 2016. pp.1–6.

128. Kasim, M.K.M., Shauri, R.L.A. and Nasir, K. PID position control of three-fingered hand for different grasping styles. *Proceedings - 2015 6th IEEE Control and System Graduate Research Colloquium, ICSGRC 2015*. 2016. pp.7–10.

129. Shauri, R.L.A., Salleh, N.M. and Hadi, A.K.A. PID position control of 7-DOF three-fingered robotic hand for grasping task. *Proceedings - 4th IEEE International Conference on Control System, Computing and Engineering, ICCSCE 2014*. 2014. pp. 70–7.

130. Cheung, N.C., Kin, K. and Chan, K.-C. PID Control of a Novel Variable Reluctance Gripper. *The 27th Annual Conference of the IEEE Industrial Electronics Society PID*. 2001. pp.456–461.

131. Khodayari, A., Zarefar, B., Kheirikhah, M.M. and Mirsadeghi, E. Force control of a SMA actuated gripper by using self tuning fuzzy PID controller. *Proceedings - 2011 IEEE International Conference on Control System, Computing and Engineering, ICCSCE 2011*. 2011. pp.312–316.

132. Truşcă, M. and Lazea, G., An adaptive PID learning controller for periodic robot motion. *IEEE Conference on Control Applications - Proceedings*. 2003. 1. pp.686–689.

133. Melhuish, C., Jalani, J. and Herrmann, G. Robust trajectory following for underactuated robot fingers. *UKACC International Conference on CONTROL 2010*. 2010. pp.495–500.

134. Tajjudin, M. et al. Optimized PID control using Nelder-Mead method for electro-hydraulic actuator systems. *Proceedings - 2011 IEEE Control and System Graduate Research Colloquium, ICSGRC 2011*. 2011. (1). pp.90–93.

135. Fukui, W. et al. Fingertip force and position control using force sensor and tactile sensor for universal robot hand II. *IEEE SSCI 2011: Symposium Series on Computational Intelligence - RIISS 2011: 2011 IEEE Workshop on Robotic Intelligence in Informationally Structured Space*. 2011. pp.43–48.

136. Ahmad, M.N. and Osman, J.H.S., Application of Proportional-Integral Sliding Mode Tracking Controller to Robot Manipulators. *Proceedings of 2003 IEEE Conference on Control Applications*. 2003. pp.87–92.

137. Peng, L., Jianjun, M., Lina, G. and Zhiqiang, Z. Integral terminal sliding mode control for uncertain nonlinear systems. *Proceedings of the 34th Chinese Control Conference*. 2015. pp.824–828.

138. Defoort, M., Floquet, T., Perruquetti, W. and Drakunov, S.V. Integral sliding mode control of an extended Heisenberg system. *IET Control Theory & Applications*. 2009. 3(10): p.1409.

139. Ibrahim, B.S.K.K., Ngadengon, R. and Ahmad, M.N. Genetic algorithm

optimized integral sliding mode control of a direct drive robot arm. *2012 International Conference on Control, Automation and Information Sciences (ICCAIS)*. 2012. pp.328–333.

140. Xu, J.-X., Guo, Z.-Q. and Lee, T.H. A Synthesized Integral Sliding Mode Controller for an Underactuated Unicycle. *11th International Workshop on Variable Structure Systems*. 2010. pp.352–357.

141. Salam, B. et al. A Decentralized Proportional-Integral Sliding Mode Tracking Controller for Robot Manipulators. *ENCON '02. Proceedings. 2002 IEEE Region 10 Conference on Computers*. 2002. 0(2). pp.6–9.

142. Yousef, A.M. Experimental set up verification of servo DC motor position control based on integral sliding mode approach. *WSEAS Transactions on Systems and Control*. 2012. 7(3): pp.87–96.

143. Munoz-Vazquez, A.J., Parra-Vega, V., Sanchez, A. and Ramirez-Rodriguez, H. A passive velocity field for navigation of quadrotors with model-free integral sliding mode control. *2013 International Conference on Unmanned Aircraft Systems, ICUAS 2013 - Conference Proceedings*. 2013. pp.49–58.

144. Ramirez-Rodriguez, H., Parra-Vega, V., Sanchez, A. and Garcia, O. Integral sliding mode backstepping control of quadrotors for robust position tracking. *2013 International Conference on Unmanned Aircraft Systems, ICUAS 2013 - Conference Proceedings*. 2013. pp. 423–432.

145. Dong, B., Ding, G., Zhang, J. and Li, Y. Decentralized integral sliding mode control for modular and reconfigurable robot with harmonic drive transmission based on joint torque estimation. *Proceedings of the 2015 27th Chinese Control and Decision Conference, CCDC 2015*, 2015. pp.6167–6174.

146. Qiao, L. and Zhang, W. Double-loop Chattering-free Adaptive Integral Sliding Mode Control for Underwater Vehicles. *OCEANS 2016*. 2016. pp.1–6.

147. Nair, R.R., Behera, L. and Kumar, S. Event-Triggered Finite-Time Integral Sliding Mode Controller for Consensus-Based Formation of Multirobot Systems With Disturbances. *IEEE Transactions On Control Systems Technology*. 2017. pp.1–9.

148. Mu, B., Zhang, K. and Shi, Y. Integral Sliding Mode Flight Controller Design for a Quadrotor and the Application in a Heterogeneous Multi-Agent System. *IEEE Transactions on Industrial Electronics*. 2017. pp.9389–9397.

149. Incremona, G.P., Ferrara, A. and Magni, L. MPC for robot manipulators with

integral sliding modes generation. *IEEE/ASME Transactions on Mechatronics*. 2017. 22(3): pp.1299–1307.

150. Al-Wais, S., Al-Samarraie, S.A., Abdi, H. and Nahavandi, S. Integral Sliding Mode Controller for Trajectory Tracking of a Phantom Omni Robot. *Proceedings - 2016 International Conference on Cybernetics, Robotics and Control, CRC 2016*. 2017. pp. 6–12.

151. Noorbakhsh, M. and Yazdizadeh, A. Adaptive friction compensation in a Two-Link Planar Robot Manipulator using a new Lyapunov-based controller. *2010 8th IEEE International Conference on Control and Automation, ICCA 2010*. 2010. pp.2132–2137.

152. Zicai, W. Friction compensation based on improved performance model reference adaptive control. *1999 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (Cat. No.99TH8399)*. 1999. pp.872–877.

153. Nilkhamhang, I. and Sano, A. Model-based adaptive friction compensation for accurate position control. *Proceedings of the IEEE Conference on Decision and Control*. 2008. (2): pp.1346–1351.

154. Lee, S.W. and Kim, J.H. Robust Adaptive Stick-Slip Friction Compensation. *IEEE Transactions on Industrial Electronics*. 1995. 42(5): pp.474–479.

155. Yazdizadeh, A. Adaptive Riction Compensation Using A Lyapunov-Based Design Scheme. 1996. (December): pp.4–5.

156. Cong, S. Two Adaptive Friction Compensations for DC Servomotors Shuang. *IEEE International Conference on Industrial Technology.* 1996. pp.113–117.

157. Canudas, C., Astrom, K. and Braun, K. Adaptive friction compensation in DC motor drives. *Proceedings. 1986 IEEE International Conference on Robotics and Automation*. 1986. pp.1556–1561.

158. Baril, C.G. and Gutman, P.O. Performance enhancing adaptive friction compensation for uncertain systems. *IEEE Transactions on Control Systems Technology*. 1997. 5(5): pp.466–479.

159. Feemster, M., Vedagarbha, P., Dawson, D.M. and Haste, D. Adaptive control techniques for friction compensation. *Proceedings of 1998 American Control Conference*. 1998. 3(June): pp.1488–1492.

160. Maulana, A.P., Ohmori, H. and Sano, A. Friction compensation via smooth adaptive dynamic surface control. *American Control Conference (ACC)*. 1999. 1(June), pp.540–541.

161. Wang, G.L., Li, Y.F. and Bi, D.X. Support vector network enhanced adaptive friction compensation. *Proceedings - IEEE International Conference on Robotics and Automation*. 2006. 2006(May): pp.3699–3704.

162. Truong, N.M. et al. Adaptive friction compensation design for submicrometer positioning of high precision stage. *Proceedings of the 2007 4th IEEE International Conference on Mechatronics, ICM 2007*. 2007. pp.1–6.

163 Jia, C., Zhaohui, Y., Honghui, W. and Gong, L., Electro-hydraulic loading system based on back-stepping adaptive friction compensation. *AUS 2016 - 2016 IEEE/CSAA International Conference on Aircraft Utility Systems*. 2016. pp.367–372.

164. Guarese, G.B.M. et al. Exploiting Modbus protocol in wired and wireless multilevel communication architecture. *Brazilian Symposium on Computing System Engineering, SBESC*. 2012. pp.13–18.

165. Tamboli, S., Rawale, M., Thoraiet, R. and Agashe, S. Implementation of Modbus RTU and Modbus TCP communication using Siemens S7-1200 PLC for batch process. *2015 International Conference on Smart Technologies and Management for Computing, Communication, Controls, Energy and Materials, ICSTM 2015 – Proceedings*. 2015. (May), pp.258–263

166. Modbus Organization, I., *Modbus Protocol*

167. Lebosse, C., Bayle, B., Mathelin, M. De and Renaud, P. Nonlinear modeling of low cost force sensors. *2008 IEEE International Conference on Robotics and Automation*. 2008. pp.3437–3442

168. Garcia, G.J., Corrales, J.A., Pomares, J. and Torres, F. Survey of visual and force/tactile control of robots for physical interaction in Spain. *Sensors*. 2009. 9(12): pp.9689–9733

169. Electronics Interlink. FSR integration Guide and Evaluation parts catalog with suggested Electrical interfaces. *Version 1.0, 90-45632 Rev. D, 2007*. 2007. 1.0: pp.1–26

170. Khatib, O. A unified approach for motion and force control of robot manipulators: The operational space formulation. *Robotics and Automation, IEEE Journal*. 1987. 3(1): pp.43–53

171. Khatib, O. Inertial properties in robotic manipulation: An object-level framework. *The international journal of robotics research*. 1995.

172. Shi, J., Liu, H. and Bajcinca, N. Robust control of robotic manipulators based on integral sliding mode. *International Journal of Control*. 2008. 81(10): pp.1537–1548.

173. Tang, Z., Zhou, J., Bian, X. and Jia, H. Simulation of optimal integral sliding mode controller for the depth control of AUV. *2010 IEEE International Conference on Information and Automation, ICIA 2010*. 2010. pp.2379–238.

174. Al-Wais, S., Al-Samarraie, S.A., Abdi, H. and Nahavandi, S. Integral Sliding Mode Controller for Trajectory Tracking of a Phantom Omni Robot. *Proceedings - 2016 International Conference on Cybernetics, Robotics and Control, CRC 2016*. 2017. pp. 6–12.

175. G, S.S., L, T.H. and R, S.X. Adaptive friction compensation of servo mechanisms. 2001. 32(4).

176. Akbar, M.A. Simulation of Fuzzy Logic Control for DC Servo Motor using Arduino based on Matlab / Simulink. *2014 International Conference on Intelligent Autonomous Agents, Networks and Systems*. 2014. pp.42–46

177. Al-Busaidi, A.M. Development of an educational environment for online control of a biped robot using MATLAB and Arduino. *Mechatronics (MECATRONICS) , 2012 9th France-Japan & 7th Europe-Asia Congress on and Research and Education in Mechatronics (REM), 2012 13th Int'l Workshop on*. 2012. pp.337–344.

178. Interlink. *Interlink Electronics*. 2015.

179. Tekscan. *Pressure Mapping, Force Measurement & Tactile Sensors*. 1987

180. Unbehauen, H. and Rao, G.P.,. A review of identification in continuous-time systems. *Annual Reviews in Control*. 1998. 22. pp.145–171.

181. L. Ljiung. *System Identification: Theory for the User* 2nd editio., Prentice Hall. 1999.

182. Gevers, M. A Personal View of the Development of System Identification. *IEEE Controll Systems*. 2006. 26(6), pp.93–105.

183. Samad, A.M. et al. Model Identification and Controller Design for Servomotor. *Signal Processing and Its Applications (CSPA), 2010 6th International Colloquium on*. 2010. (1), pp.228–231

184. MathWorks, *System Identification Toolbox*. 1994.

185. Adnan, R. et al., Trajectory ZPETC Design Using Comparing Coefficients Method : The Studies on the Effects of Zero Locations to Tracking Performance. , (Icsgrc). 2012. pp.376–381.

186. Zaki, A.M., Soliman, A.M., Mahgoub, O.A. and El-Shafei, A.M. High performance robotic gripper based on choice of feedback variables. *2010 IEEE International Conference on Information and Automation, ICIA 2010*, 2010. pp.54–59.

187. Fruk, M., Vujisić, G. and Špoljarić, T. Parameter Identification of Transfer Functions Using MATLAB. 2013. pp.571–576

188. Licheng, W., Yanxuan, K. and Xiali, L.,. A fully rotational joint underactuated finger mechanism and its kinematics analysis. *International Journal of Advanced Robotic Systems*. 2016. 13(5): pp.1–9

189. Satyapal, G.R.. Modeling and Simulation of a Multi-Fingered Robot Hand. *Intelligent and Advanced Systems (ICIAS)*. 2010 4, pp.5–8.

190. Malvezzi, M. et al. SynGrasp : a MATLAB Toolbox for Grasp Analysis of Human and Robotic Hands. *Robotics and Automation (ICRA), 2013 IEEE International Conference on*, 2013. pp. 1050–4729.

191. Zodey, S. and Pradhan, S.K. Matlab toolbox for kinematic analysis and simulation of dexterous robotic grippers. *Procedia Engineering* 2014. 97. pp.1886–1895.

192. Corrales, J.A., Jara, C.A. and Torres, F. Modelling and simulation of a multi-fingered robotic hand for grasping tasks. *11th International Conference on Control, Automation, Robotics and Vision, ICARCV 2010*, 2010. (December): pp.1577–1582

193. Choi, C. et al. Understanding of hands and task characteristics for development of biomimetic robot hands. *2008 8th IEEE-RAS International Conference on Humanoid Robots, Humanoids 2008*. 2008. pp. 413–417.