An Overview of Active Compliance Control for a Robotic Hand

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Abstract. It is vital to ensure that a robotic hand can successfully grasp the objects without damaging them. In order to allow a safe grasping, a technique called an active compliance control has been deployed. Active compliance control is an increasingly employed technique used in the robotic field such as service robotics, virtual reality and haptics, telemanipulation, human augmentation, and assistant. Recent research trends show that there are two main methods used in establishing active compliance control for robotic hand namely the force control and the impedance control. This paper highlights a summary of currently related works on active compliant control by using the force control and the impedance control. In addition, several control strategies of active compliance control are also discussed and highlighted for a safe grasping.

Introduction

In the context of robot control, compliant control can be defined as the allowance of deviations from its own equilibrium position, depending on the applied external force. The equilibrium position of a compliant actuator is defined as the position of the actuator where the actuator generates zero force or zero torque. Hence, by this definition, compliance will allow us to minimize the impact during collision of an end-effector with the contact environment. Detail definition of compliant control can be found in [1] and [2]. One way to attain a compliant control is via an active compliant control strategy. In general, an active compliance control can be divided into two categories which are force control and impedance control [3] as depicted in Fig. 1.

Over the last ten years, the work on active and passive compliance control have been extensively deployed on the robotic hand to imitate human hand capability. The active compliance control uses the force feedback method while passive compliance control applies the element of elasticity and mechanical structure to specifically generate compliance tasks at the robot endpoint [4]. The work presented here is an attempt to highlight the latest current research activities on an active compliance control for a robot hand.

Position/force control is defined as a control technique where both desired interaction force and robot position are controlled. Moreover, in force control, a desired force trajectory is commanded and force is measured in real time to realize the feedback control. There are two types of force control that have been widely used; hybrid position/force and unified position/force. Hybrid position/force control can be described as the position and force control that are controlled in two orthogonal subspaces. One the other hand, the unified position/force control, both position and force are along each task space direction.

Impedance control is basically based on position control which requires positioning commands and measurements in order to close the feedback loop. In addition, force measurements are also needed to realize 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), general impedance (position, velocity and acceleration proportional).

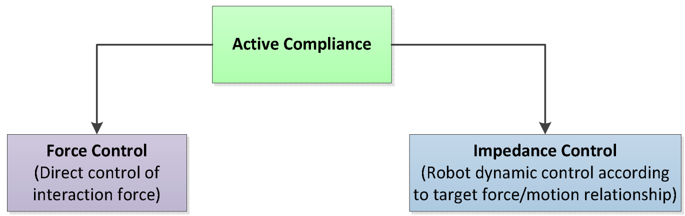

Fig. 1: Classification of Active Compliance Control

Active Compliance with Force Control

In 2010, a group in [5] has conducted a research on an active compliance control to improve the stability of multi-fingered robot hand by the measurement of disturbance. Additionally, a linear elastic stiffness was analyzed by considering contact-gravity effect. The drawback has been identified where the compliance performance decreased in the z-direction because the finger tip rolled on the plate when the contact points are located above the center of gravity [5].

Later, in 2011, an active compliance control was introduced by utilizing F/T sensor on the finger tips of KIST-Hand [6]. The sensors initially calibrated and the signals were going through a low-pass filtering which is necessary for accurate detection. However, the results from this approach showed that the quality of the output signals from the F/T sensor were low due to the presence of noises. Eventually, additional filtering process was required in order to filter the noises [6].

In 2012, a research on a real-time detection and physical modeling of robot folding a paper by using the Shadow Dexterous Hand had been demonstrated [7]. The improvement was done by attaching tactile sensors on the right hand finger and PST sensors on the left hand finger [7]. However, the drawbacks were identified where the requirement of visual fiducial guide and the response of tactile sensors restricted on the sensor areas only.

Moreover, in 2013, the group in [2] introduced an approach of active compliance control via the Integral Sliding Mode Control (ISMC) on a BERUL fingers. The results showed that the implementation of positioning error control and force control with a robust posture optimization had improved the tracking performance although the levels of stiction and friction were remarkably high.

Recently, in 2014, a research had been carried out to study the robot hand grasping for typical small objects such as pens, screwdrivers, cellphones, and hammers [8]. The researcher had implemented a closed-loop hybrid strategy and contact-rich strategy for fingers placement. The study suggested that the grasping dynamic force/torque equilibrium required further improvement. Also in the same year, a prototype of robot hand which was affordable, modular, light-weight, intrinsically-compliant as well as, underactuated had been developed. The prototype was equipped with Arduino board and sensors such as force and joint angle sensors. However, the performance of grasping was limited since the object tended to last from the grasp [9].

Active Compliance with Impedance Control

Apart from the force control strategy, an impedance control had also been frequently introduced to achieve active compliant control for robotic hand. For example, in 2010, a Cartesian impedance control was proposed in the application of joint torque and nonlinearity compensation for the elasticity of dexterous robot joints. The method realized a desired dynamical relationship between the motion of the end-effector and the external forces/torques. Based on the results, the impedance control response that relates to the friction observer and the stability analysis need to be improved [10]. In 2011, a research had been conducted to study the robot dynamic stiff in term of robustness, dynamic performance and dexterity of the DLR Hand Arm System. The group had proposed a variable stiffness actuation with impedance control [11]. However, the researchers claimed that a higher power density was needed to carry the torques resulting from the finger tendon loads at the wrist [12]. In 2011, improvement had been made on the same robot by implementing internal force impedance controller which then had successfully controlled the squeezing force. However, since the internal controller was not purposely designed to compensate with certain undesired motions, the trajectory problem was aroused [11].

In 2013, a research on the evaluation of the structural compliance of hand links, joints and the gains of impedance controllers had been carried out. However, the results suggested that the compliance design mainly for grasping force distribution required further improvement [13]. A year after, a new study on the implementation of a teleimpedance controller with tactile feedback on the Pisa/IIT SoftHand had been conducted. In the study, an active impedance controller was applied to the motor to establish safe and reliable control of the applied pressure [14]. The study however found that there were slight reductions of physiological load with force feedback. Further testing on the actual amputees is required for results validation.

Discussion

Several factors have been identified may influence the performance of force control and impedance control to achieve active compliance control. The factors can be summarized as shown in Fig. 2. It is essential to properly design the mechanical part and the sensory system at the contact point of the robot hand. Applying the force control always requires good sensory system. Note that insufficient sensory information can lead to errors in controller [4]. The possible solution is to express the contact models as a function of unknown parameter. This allows the recognition state simultaneously perform with the parameter estimation. Thus, this will improve the force control, the contact state transition monitoring and the contact state recognition [15].

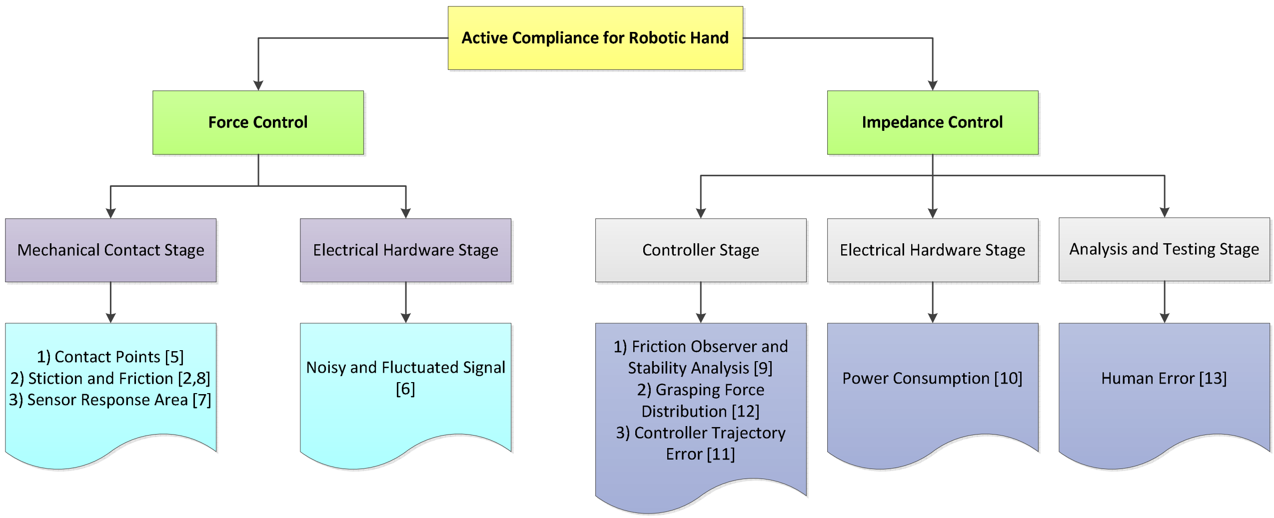

Fig. 2: Summary of Problems for Achieving Active Compliance Control

On the other hand, the primary issue hampered during the implementation of the impedance control is at the controller stage where the algorithms and system judgments must be catered for [16]. Here, the contact state modeling is the key towards the capability of a controller [3]. The more accurate parameters are applied in the contact model, the lesser errors will be generated by the robot controller. This can be achieved by exploiting an adaptive impedance control which can yield an extremely flexible way to provide high fidelity kinaesthetic feedback [4].

The other aspects of impedance and force control problem are, both control strategies depend on the effectiveness of the electrical hardware. The presence of noise and fluctuated signal affects the performance of force control. Meanwhile, the use of power consumption in robotics hand for impedance control must be carefully designed to retain the reliability of the electrical hardware [12]. In addition to impedance control, human error may contribute to the poor performance of active compliance control.

Control Methods for Active Compliance Control

Several methods are proposed in order to achieve a compliant control for a robot [18]. A few approaches seem to be the most promising in a humanoid robot control environment:

1. Model-based Passivity based control [17] [18].
2. Intelligent non-model based neural network control [19].
3. Adaptive control [20]
4. A synergy of passivity and Intelligent non-model based neural network or adaptive control will guarantee social context dependent compliant control [19].

Firstly by using passivity based control [17] [18]. A passivity based controller for control of a humanoid requires only the available motor position and joint torque signals, as well as their first-order derivatives [17]. The approach of passivity relies on the idea of energy conservation. A system is passive if it is dissipating energy rather than producing energy. Hence, by having two passive systems creating a control loop than it is intuitively clear that the relevant closed loop control is also passive and stable. The advantage of this model based control approach is that it provides a high degree of robustness to unmodeled robot parameters and dynamics. Moreover, the passivity based controller ideally lends itself to compliance control, where the environment can be modelled to be passive and the notion of the impedance of obstacles can be introduced. Compliance is quantified by the ('mechanical') stiffness of the controller rather through position accuracy usually required for servo-control.

Secondly, a non-model based controller namely Neural Network Controller is proposed and to be applied. It is known that Neural Networks are capable to work in a highly nonlinear environment and the design method is not time consuming [21]. The fact is that humanoid robots are very nonlinear systems; therefore, neural networks can be very helpful. Thirdly, it is known that adaptive control is capable to work in highly nonlinear and uncertain environments and the design method is not time consuming. Adaptive control allows adaptation to large parameter changes in the robot and also a better adjustment to unmodelled dynamics of the environment. The fact is that humanoid robots are highly nonlinear systems; therefore, adaptive control can be very helpful. Lastly, the synergy of both control methods, i.e. intelligent non-model based neural network/adaptive control and passivity based control, will allow at first adaptation to large parameter changes in the robot and also better adjustment to the unmodelled dynamics of the environment. Most importantly the synergy of both control approaches should allow for 'social' context compliance control.

The aforementioned controllers clearly shown their advantages for the implementation of the active compliance control strategy. However, the drawbacks of each controller are inevitable. It is to note that the passivity based controller deals with the energy dissipation and transformation (i.e. energy conservation) and not easy to control. There is no theoretical guideline for choosing additional energy function; it is not easy to evaluate the control performance and to determine design parameters [22]. Moreover, the neural network has its own limitation where it requires a highly computational level during control execution, prone to over fitting and unstructured control method (see [23] and [24] for other drawbacks). Meanwhile, adaptive control could easily go unstable in the presence of small disturbances as discussed in [25] which will become a challenge to realize active compliance control. More problems with adaptive control were highlighted in [25] and [26]. Nonetheless, the above mentioned problems can be resolved and feasible.

Conclusion

A summary of current studies on an active compliance control has been highlighted for the past 5 years. It has been shown that there are many factors must be considered to achieve a desired performance of active compliant control. The research areas are open to many alternative solutions for a greater grasping performance. There is no unique solution for safely grasping an object/human; therefore the control approaches for grasping are diversified. Some potential techniques can be employed to introduce an active compliant control. Robotic hands on the hand are still a long way from matching the grasping and manipulation capability of their human counterparts.

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References

[1] R. Ham, T. Sugar, B. Vanderborght, K. Hollander, and D. Lefeber, "Compliant actuator designs," *Robot. Autom. Mag. IEEE*, vol. 16, no. 3, pp. 81–94, Sep. 2009.

[2] J. Jalani, N. Mahyuddin, G. Herrmann, and C. Melhuish, "Active Robot Hand Compliance using Operational Space and Integral Sliding Mode Control," pp. 1749–1754, 2013.

[3] M. Vukobratovic and B. Branislav, *Dynamics and Robust Control of Robot-environment Interaction*. 2009.

[4] T. Lefebvre, J. Xiao, H. Bruyninckx, and G. de Gersem, "Active compliant motion: a survey," *Adv. Robot.*, vol. 19, no. 5, pp. 479–499, Jan. 2005.

[5] A. Nakashima, Y. Yoshimastsu, and Y. Hayakawa, "Analysis and Synthesis of Stable Grasp by Multi-Fingered Robot Hand with Compliance Control," pp. 1582–1589, 2010.

[6] J. Jo, S. Kim, Y. Oh, and S. Oh, "Compliance Control of a Position Controlled Robotic Hand Using F / T Sensors," pp. 446–450, 2011.

[7] C. Elbrechter, R. Haschke, and H. Ritter, "Folding Paper with Anthropomorphic Robot Hands using Real-Time Physics-Based Modeling."

[8] M. Kazemi, J.-S. Valois, J. A. Bagnell, and N. Pollard, "Human-Inspired Force Compliant Grasping Primitives," *Auton. Robots*, pp. 1–16, 2014.

[9] A. G. Zisimatos, M. V Liarokapis, C. I. Mavrogiannis, and K. J. Kyriakopoulos, "Underactuated Robot Hands," *EEE/RSJ Int. Conf. Intell. Robot. Syst.*, 2014.

[10] Z. Chen, N. Y. Lii, T. Wimboeck, S. Fan, M. Jin, C. H. Borst, and H. Liu, "Experimental study on impedance control for the five-finger dexterous robot hand {DLR-HIT II}," in *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 2010, pp. 5867–5874.

[11] D. Prattichizzo, M. Malvezzi, M. Aggravi, and T. Wimböck, "Object motion – decoupled internal force control for a compliant multifingered hand," pp. 1508–1513, 2012.

[12] M. Grebenstein, A. Albu-Schaffer, T. Bahls, M. Chalon, O. Eiberger, W. Friedl, R. Gruber, S. Haddadin, U. Hagn, R. Haslinger, H. Hoppner, S. Jorg, M. Nickl, A. Nothhelfer, F. Petit, J. Reill, N. Seitz, T. Wimbock, S. Wolf, T. Wusthoff, and G. Hirzinger, "The {DLR} hand arm system," in *IEEE International Conference on Robotics and Automation (ICRA)*, 2011, pp. 3175–3182.

[13] M. Malvezzi and D. Prattichizzo, "Evaluation of Grasp Stiffness in Underactuated Compliant Hands," pp. 2074–2079, 2013.

[14] A. Ajoudani, S. B. Godfrey, M. G. Catalano, M. Bianchi, G. Grioli, N. G. Tsagarakis, and A. Bicchi, "Exploring Teleimpedance and Tactile Feedback for Intuitive Control of the Pisa/IIT SoftHand," *IEEE Trans. Haptics*, vol. 7, pp. 203–215, 2014.

[15] C. von Albrichsfeld and H. Tolle, "A self-adjusting active compliance controller for multiple robots handling an object," *Control Eng. Pract.*, vol. 10, no. 2, pp. 165–173, 2002.

[16] A. Gams, M. Do, A. Ude, T. Asfour, and R. Dillmann, "On-line periodic movement and force-profile learning for adaptation to new surfaces," *2010 10th IEEE-RAS Int. Conf. Humanoid Robot.*, pp. 560–565, Dec. 2010.

[17] A. Albu-Schäffer, C. Ott, and G. Hirzinger, "A Unified Passivity-based Control Framework for Position, Torque and Impedance Control of Flexible Joint Robots," *Int. J. Robot. Res.* , vol. 26 , no. 1 , pp. 23–39, Jan. 2007.

[18] H. K. Khalil, *Nonlinear Systems, Second Edition,*. CRC Press, Inc., 1996.

[19] S. G. Khan, G. Herrmann, F. L. Lewis, T. Pipe, and C. Melhuish, "Reinforcement learning and optimal adaptive control: An overview and implementation examples," *Annu. Rev. Control*, vol. 36, no. 1, pp. 42–59, 2012.

[20] S. Khan, G. Herrmann, A. G. Pipe, and C. Melhuish, "Safe Adaptive Compliance Control of a Humanoid Robotic Arm with Anti-Windup Compensation and Posture Control," *Int. J. Soc. Robot.*, vol. 2, no. 3, pp. 305–319, 2010.

[21] R. Zaier and F. Nagashima, "Motion Generation of Humanoid Robot based on Polynomials Generated by Recurrent Neural Network," *Proc. First Asia Int. Symp. Mechatronics*, pp. 659–664, 2004.

[22] S. Yoshiki, K. Ogata, and Y. Hayakawa, "Control of manipulator with 2 flexible-links via energy modification method by using modal properties," in *Advanced Intelligent Mechatronics, 2003. AIM 2003. Proceedings. 2003 IEEE/ASME International Conference on*, 2003, vol. 2, pp. 1435–1441 vol.2.

[23] J. V Tu, "Advantages and disadvantages of using artificial neural networks versus logistic regression for predicting medical outcomes," *J. Clin. Epidemiol.*, vol. 49, no. 11, pp. 1225–1231, 1996.

[24] C. Duarte-Galvan, I. Torres-Pacheco, R. Guevara-Gonzalez, R. Romero-Troncoso, L. Contreras-Medina, M. Rios-Alcaraz, and J. Millan-Almaraz, "Review. Advantages and disadvantages of control theories applied in greenhouse climate control systems," *Spanish J. Agric. Res.*, vol. 10, no. 4, 2012.

[25] J. A. Karl and W. Bjorn, *Adaptive Control*, 2nd Editio. Addison-Wesley Publishing Company, 1994.

[26] B. Egardt, "Stability of Adaptive Controllers," in *Lecture Notes in Control and Information Sciences*, Springer-Verlag, Berlin Heidelberg, 1979.