International Journal on Advanced Science Engineering Information Technology

Vol.7 (2017) No. 5
ISSN: 2088-5334

Grasp Stability Analysis of an Isotropic Direct Driven Three-Finger Soft Robot Hand

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***Abstract*—Grasp stability is considered to be an important aspect in object manipulation of a multifingered robot hand. Multifingered hand contacts the object at some arbitrary locations during the object manipulation and applies the gripping force to hold and manipulate the object without slip. It is desirable to use the optimum gripping force during the grasp manipulation for two reasons; firstly, to prevent the object from damages, secondly, to decrease the cost of the manipulation. With these objectives in mind, a three-fingered soft hand is designed, and gripping force and stability analysis are done experimentally. DC motors are used to actuate the joints of fingers and force sensors are used to measure the internal force at contact points. PID controller is used to controlling the internal force exerted at the contact points, and the control parameters are tweaked until a satisfactory response is achieved. The minimum gripping force required to handle the object with / without external disturbances is measured. The position variables and frictional coefficients are evaluated from the contact forces at the contact points. In future, the optimization algorithm will be integrated to carry out these tasks in constrained and unconstrained environments.**

***Keywords*— multifingered hand; isotropic hand; soft manipulation; prehension; grasp stability**

I. INTRODUCTION

Robot grasping is considered to be the most fundamental component in object manipulation. The stable object manipulation has two important tasks to be solved; firstly, placement of fingers on the object envelope in the right positions. Secondly, applying sufficient grip forces on the contact points to ensure the stable grasping without slip. The stable grasp requires no slippage or break of contact between the finger and the object. The grasp stability must be achieved and maintained by choosing forces such that the friction constraints at all contact points are satisfied [1]. For the past two decades, various algorithms have been developed in order to solve the grasping force optimization problems. The algorithms are aimed for two different reasons; one kind of algorithms are aimed to search for optimal grasp points for counteracting gravitational force [2]-[3], and other types of algorithms are aimed for force closure. The force closure algorithms are able to counteract the external forces and moments and restrain the motion of the object in the desired direction [4]-[10]. The simplex algorithm used by Kerr and Roth [11] and dual linear programming method used by Cheng and Orin [12] are some force closure algorithms for which the accuracy depends on the number of planes used in the approximation. Cornellà et al. [13] presented a new mathematical approach to determine a suitable set of grasping forces by using the dual-theorem of non-linear programming. In all force closure algorithms, the upper bound of the magnitude of the resistible external force and moment are computed firstly and set as the criterion for the grasps. This research focuses on finding the optimum gripping force experimentally rather than using any algorithm.

The design of robot hands can be divided into anthropomorphic and minimalistic. The former focuses on creating a duplicate of the human hand, with its respective structures and capabilities. In the latter, functionality is emphasized while having reduced design complexity compared to anthropomorphic. Dexterous hands are incorporated to robots in order to make them more flexible and do the fine manipulation. A three-fingered robot hand is considered suitable for basic manipulation purposes. Popular three-fingered robot hands include Namiki Hand [14] and the Barrett Hand [15]. The Namiki Hand is an impressive design with high speed and power capabilities. The application of soft fingers in robotic hands have been recognized in the recent years. The soft pads allow to better sustain and damp dynamic effects, like shocks and vibrations, and to better dissipate repetitive strains, that are induced during manipulation [16]. In a human finger, soft and pulpy tissues act as the cushion between the skeletal bone and skin. Likewise, a robotic finger can itself be made from hard materials and enveloped by a softer material. Many different soft materials; silicone of different grades, neoprene, viton, silicone RTV, gum rubber, gel, and polyurethane have been investigated [17]-[23]. Few researches have been published in soft robot hands. The contact model of the soft finger is different from hard finger model. Elango and Marappan[20] has developed a soft finger contact model and evaluated the contact forces. Elango et al. [22] investigated and reported Silicone of grade 10 is more suitable for soft fingers.

In grasp planning and manipulation, the grasp synthesis that determines the best stable and proper grasp for a given object is done. i.e., where should the fingers be placed on the object and in which direction should the forces be exerted in order to grasp the object. Once the grasping points on the object are known, the inverse kinematics of the hand-arm ensemble must be solved in order to determine the joint positions for the actual configuration of the object. This is a complex problem due to the great number of involved degrees of freedom and the tree structure of the kinematic chain. This fact involves many specific planning and control problems. This paper outlines the design of a three-fingered robot hand with six joints. The tests are conducted to obtain the minimum grasping force for the fingers to handle the object, even under external disturbances.

II. Materials and Method

A. Hand Design

There are two patterns of grasping according to the function; precision-grasping and power grasping as shown in Fig. 1. Precision grasp grasps and manipulates objects by fingertips, performs fine or dexterous manipulation. Power grasp manipulates the object with multiple contact points between the object and the surfaces of finger and palm. Power grasp has a large area of contacts between the object and the fingers / palm and little or no ability to impart motion with the fingers. Power grasp emphasizes security and stability whereas Precision grasp focuses on dexterity and sensitivity.

Fig. 1 Types of grasping [23]

The current hand was developed for precision grasping and dexterous manipulation. There are three types of contacts; point contact, line contact, and area contact. Point contact is a common type of contact, in which any finger contacts an object at a point. The line contact and area contacts are other two types which occur in a few cases of gripping. Interestingly, point contact of the soft finger will grow in the area and become area contact. This makes the gripper to use less gripping force for handling the object. Hence, a layer of foam has been attempted at the fingertip of each finger by many researchers. A contact which allows the finger to exert a frictional moment about the common normal at the point of contact $\tau_z \neq 0$ is called the soft contact. The contact area will conform to the local shape of the contacted object. Expressions for frictional force and moment depend on the pressure distribution inside the contact. A grasped object is in equilibrium if the sum of all forces and moments acting on a body equals zero,

$$\sum F_x = 0 , \sum F_y = 0, \sum F_z = 0, \sum M = 0 \tag{1}$$

These parameters can be measured through force sensors. The fixing of a force sensor at different contact points will measure the gripping force at different locations. The equilibrium condition is achieved as follows;

$$f_{ext} = Wxc \tag{2}$$

where f_{ext} represents the external force vector, W is the grip transformation matrix describing the geometric relation between contact wrench space and object coordinate frame, and c refers to the contact forces vector. A gripper which provides a uniform contact pressure at contact points is said to be isotropic [1]. Khairudin et al [24] developed neural network(NN) based PID controller for two link flexible robot. and simulations of the dynamic model was carried out in the time domains where the system responses including angular positions, deflection, and end-point acceleration were studied. Yassen et al [25] proposed the application of the Binary Particle Swarm Optimization (BPSO) algorithm for structure selection of The Nonlinear Auto-Regressive Moving Average with Exogenous Inputs (NARMEX) model of a Flexible Robot Arm. Triharminto et al [26] conducted research on kinematic based path planning for which the contact force analysis is required.

The proposed hand in the present study has 3 fingers, each finger with two phalanges; distal and proximal. Revolute joints are used to connect proximal phalange to the palm and distal phalange to the proximal. The fingers are arranged at 120° apart, and joints are actuated by DC motors individually. Encoders are attached to each joint in order to have feedback. The bevel gear is used for power transmission between the motor and finger joint. With this arrangement, the hand holds 6 DOF, which can locally be controlled by a PID controller.

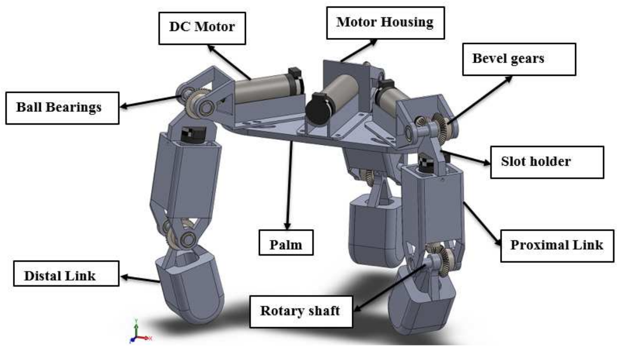


Fig. 2 Hand model and finger arrangement

The fingers were fabricated by 3D printing and assembled as shown in Fig. 2. The whole assembly including the controller interface was mounted on a wooden stand. High torque DC gear motors with encoders were used to drive the joints. A force-sensing resistor (FSR-402) was attached to the tip of each finger and surfaced with a soft and deformable material in order to measure the contact force. The whole hand system was fully managed by an Arduino Mega microcontroller. Using the prototype, grasp tests were performed on a custom-built object. The force-sensitive resistors were calibrated and ensured before experiments are started. PID control system was implemented to achieve a constant gripping force exertion at contact points. The control parameters were tweaked until the uniform pressure is applied to all contacts.

III. Results and Discussions

The experiment was started by extending the proximal link of fingers from the home position. A small amount of force was applied at each fingertip after confirming the prehension. The gripping force in each contact point was then increased/decreased to set the uniform contact force to all contact points. Once the object was lifted with uniform contact force, the contact force is decreased to measure the minimum gripping force required to hold the object without slip. The grasp is said to be stable when there is no slippage or break of contact between the hand and object. Minimal external forces are then introduced to instigate the slipping to occur. The contact forces are increased/decreased to find the minimum grasping force for the system, which named equilibrium point (Fig. 3)

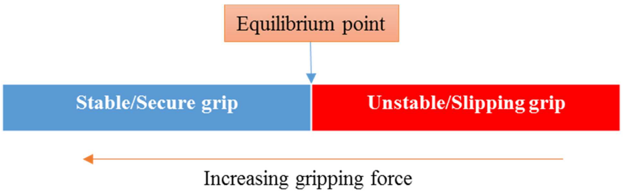


Fig. 3 Illustration of obtaining lowest gripping force

Fig. 4 shows the gripping of 100 g mass and its respective minimum gripping force required. The stable grasping was achieved with 0.2 N at t=11 second and reached the steady state in 1 second. Fig. 5(a) and (b) show grasping a 100g object with 0.18 N and 0.19 N contact force respectively. The red circle indicates the point where the external disturbance was applied. The grip is lost at the 23 seconds when 0.18 N of gripping force was applied. The object remains gripped throughout external disturbance when the gripping force was increased to 0.19 N. Therefore; it is found that the fingers are able to grip the object without slip, even with external disturbances with the gripping force of 0.19 N.

In the similar fashion, the minimum gripping force required for the masses range from 100 g to 400 g were recorded and plotted in Fig. 6. From the experimental results, a linear force relationship equation was arrived as $F_{min} = 0.0019x$, where x is the mass of the object to be grasped. It was further verified for other masses 500 g and 600 g in order to confirm the force relation equation. Firstly, the minimum force was estimated from the equation for masses 500 g and 600 g and they were 0.95 N and 1.14 N respectively. The experiments were further conducted to measure the minimum gripping force for them. Fig. 7 shows the stable grasping of 500 g at 0.95 N. The slipping of the object was noticed when the gripping force is reduced to 0.94 N (Fig. 8). The same procedure was repeated for 600 g of mass as well. It is ensured that the equation predicts well the minimum gripping force required to handle the mass.

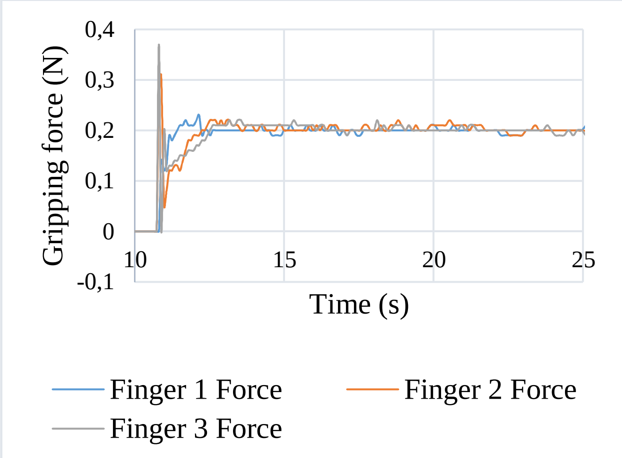
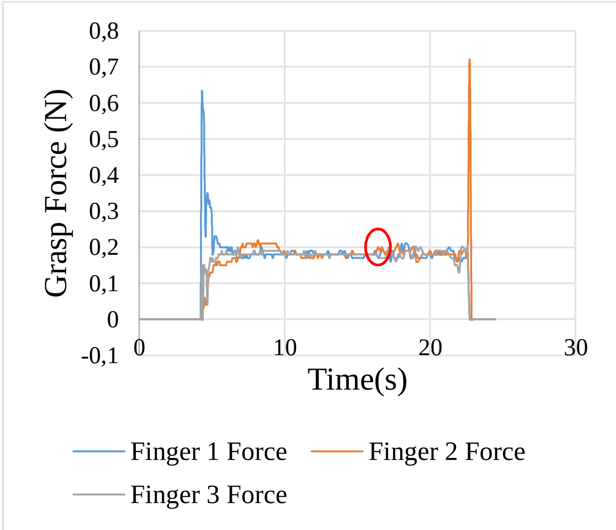
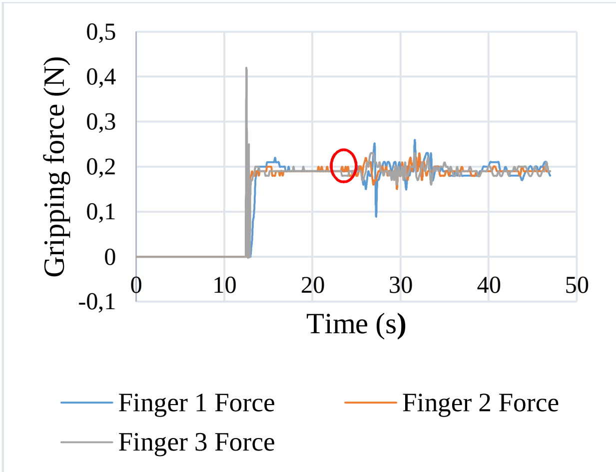


Fig. 4 Steady state response of gripping of 100g mass



(a)



(b)

Fig. 5 (a) Gripping of 100g mass with external disturbances, (b) Gripping of 100g mass with external disturbances

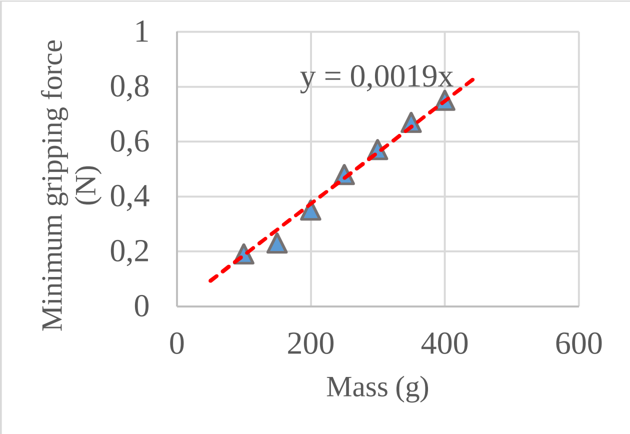


Fig. 6 Linear relationship between mass of the object and minimum gripping force

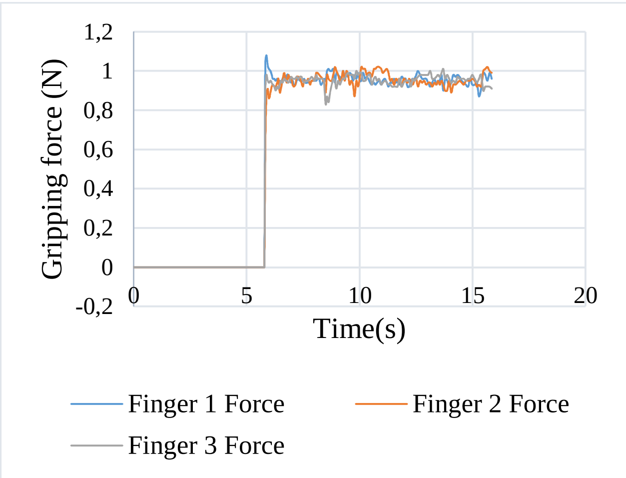


Fig. 7 Stable grasping of 500g mass with 0.95 N

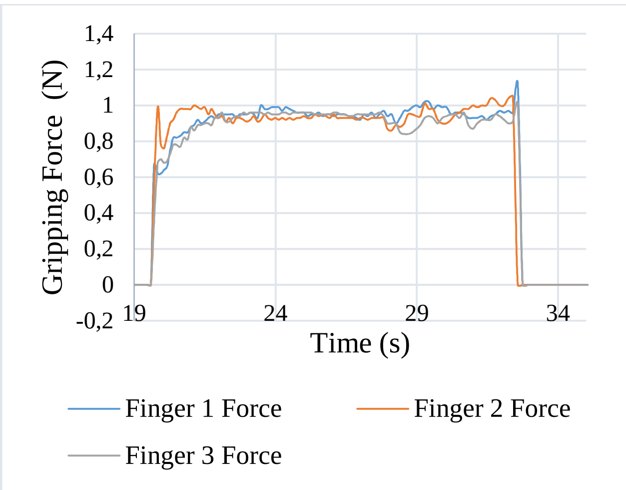


Fig. 8 Unstable grasp – slipping of 500g with 0.94 N

IV. Conclusions

This research was started with developing three finger hand model in Solidworks. After the assembly of the robot hand was done, the prototype was developed by 3D printing. The soft pad was attached to each fingertip in order to have the soft manipulations. High torque DC gear motors with encoders were used to drive the joints. A force-sensing resistor (FSR-402) was attached to the tip of each finger and surfaced with a soft and deformable material in order to measure the contact force. The system is implemented using Arduino Mega 2560 as the micro-controller. PID control systems have been embedded inside the program loop. The experiments were conducted with different masses, and the lowest gripping force for each mass was recorded. From the experimental results, a linear force relationship equation was arrived as $F_{min} = 0.0019x$, where x is the mass of the object to be grasped. Consequently, the linear relationship expression was verified for masses of 500 g and 600 g. In both instances, the prediction proved to be correct. An optimum grasp force will result in an overall efficient operation while providing other advantages such as preventing damage to the grasped object and mechanical wear and tear.

Acknowledgment

The authors would like to give special thanks to UCSI University, Malaysia for the fund support under YSIF, Grant No.: YSIF-2015-000033.

References

[1] Martin BUSS, Hideki Hashimoto and John B. Moore, “Dextrous Hand Grasping Force Optimization” IEEE Transactions on Robotics and Automation, Vol. 12, Issue 3. pp. 406-418, June 1996.

[2] J. C. Trinkle and R. P. Paul, “Planning for dexterous manipulation with sliding contacts” The International Journal of Robotics Research, Vol. 9, Issue 3, pp.24–48, 1990.

[3] T. Omata, “Fingertip positions of a multifingered hand”, Proceedings of IEEE International Conference on Robotics and Automation, pp. 1562–1567, 1990.

[4] V. Nguyen “Constructing force-closure grasps” The International Journal of Robotics Research, Vol. 7, Issue 3, pp.3-16, 1988.

[5] B. Mirtich and J. Canny “Easily computable optimum grasps in 2-D and 3-D”, Proceedings of IEEE International Conference on Robotics and Automation, pp. 739–747, 1994.

[6] X. Markenscoff and C. H. Papadimitriou “Optimum grip of a polygon” The International Journal of Robotics Research, Vol. 8, Issue 2, pp.17-29, 1989.

[7] M. Y. Wang and D. M. Pelinescu “Optimizing fixture layout in a point-set domain” IEEE Transactions on Robotics and Automation, Vol. 17, Issue 3, pp.312–323, 2001.

[8] L. Mangialardi, G. Mantriota and A. Trentadue “A three dimensional criterion for the determination of optimal grip points” Robotics & Computer-Integrated Manufacturing, Vol. 12, Issue 2, pp.157–167, 1996.

[9] M. Teichmann and B. Mishra “Probabilistic algorithms for efficient grasping and fixturing”, Algorithmica, Vol.26, pp.345–363, 2000.

[10] Tetsuyou Watanabe and Tsuneo Yoshikawa, “Optimization of Grasping by Using A Required External Force Set”, Proceedings of the 2003 IEEE International Conference on Robotics & Automation Taipei, Taiwan, pp. 1127-1132, September, 2003

[11] Jeffrey Kerr Bernard Roth , “Analysis of Multifingered Hands”, The International Journal of Robotics Research, Vol. 4, Issue 4, pp. 3-17, 1986.

[12] F.T. Cheng, D.E. Orin, “Efficient algorithm for optimal force distribution-the compact-dual LP method”, IEEE Transactions on Robotics and Automation, Vol. 6, Issue 2, pp. 178-187, April 1990

[13] Jordi Cornella, Raúl Suárez, Raffaella Carloni, Claudio Melchiorri, “Dual programming based approach for optimal grasping force distribution”, Mechatronics, Vol 18, Issue 7, pp. 348-356, September 2008.

[14] Namiki A., Imai Y., Kaneko M. and Ishikawa M. (2003), ‘Development of a high-speed multifingered hand system and its application to catching’, Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems, Las Vegas, pp. 2666-2671.

[15] Townsend, W. (2000), The Barrett Hand Grasper - Programmable Flexible Part Handling and Assembly, International Journal of Industrial Robot, Vol. 27, No. 3, pp. 181-188.

[16] Shimoga K.B. and Goldenberg A.A. (1992), 'Soft materials for robotic fingers', IEEE International Conference on Robotics and Automation, France, Vol. 2, pp. 1300-1305.
[17] Cutkosky M.R., Jourdain J.M. and Wright P.K. (1987), 'Skin materials for robotic fingers', Proceedings of IEEE Conference on Robotics and Automation, Stanford, pp. 1649-1654.
[18] Tiezzi P., Lotti F. and Vassura G. (2003), 'Polyurethane gel pulps for robotic fingers', Proceedings of IEEE International Conference on Advanced Robotics, ICAR 03, Italy, pp. 1-7.
[19] Elango N, Ph.D. thesis titled 'Investigation on the suitability of different soft materials and configurations for robot fingers', 2009.
[20] Elango, N. and Marappan, R. (2011), Analysis on the Fundamental Deformation Effect of a Robot Soft Finger and Its Contact Width During Power Grasping, The International Journal of Advanced Manufacturing Technology, Vol. 52, No. 5, pp. 797-804.
[21] Elango N., Faudzi A.A.M., Rusydi M.R.M., Nordin I.N.A.M., (2014), 'Determination of Non-linear Material Constants of RTV Silicone Applied to a Soft Actuator for Robotic Applications', Key Engineering Materials, Vols. 594-595, pp 1099-1104.
[22] Natarajan Elango, Ahmad Athif Mohd Faudzi, Azman Hassan, Muhammad Razif Muhammad Rusydi, (2014), 'Experimental investigations of skin-like material and computation of its material properties', International Journal of Precision Engineering and Manufacturing, Vol. 15, No. 9, pp 1909-1914.
[23] Elango N., Faudzi. A "A review article: Investigations on soft materials for soft robot manipulations", International Journal of Advanced Manufacturing Technology, Vol. 80 Issue 5-8, pp. 1027-1037, September 2015.
[24] Moh. Khairudin, . Sudiyatno, Fatkhul Arifin "NN robust based-PID Control of A Two-Link Flexible Robot Manipulator", International Journal on Advanced Science, Engineering and Information Technology, Vol. 2, Issue 1, pp. 7-12, DOI:10.18517/ijaseit.2.1.144, 2012.
[25] Ihsan Mohd Yassin, Azlee Zabidi, Megat Syahirul Amin Megat Ali, Nooritawati Md Tahir, Husna Zainol Abidin, Zairi Ismael Rizman, "Binary Particle Swarm Optimization Structure Selection of Nonlinear Autoregressive Moving Average with Exogenous Inputs (NARMAX) Model of a Flexible Robot Arm", International Journal on Advanced Science, Engineering and Information Technology, Vol. 6, Issue 4, pp. 630-637, 2016.
[26] Hendri Himawan Triharminto, Oyas Wahyunggoro, Teguh Bharata Adji, Adha Imam Cahyadi, "An Integrated Artificial Potential Field Path Planning with Kinematic Control for Nonholonomic Mobile Robot", Vol. 6, No. 4, pp. 410-418, 2016.