Simulation Analysis of Grasping Forces for a 3-DOF Robotic Manipulator

Somer M. Nacy (Corresponding author)
Alkhwarizmi College of Engineering, University of Baghdad
Jaderyia, 10071, Baghdad - Iraq

Ahmed A. Nayif
Alkhwarizmi College of Engineering, University of Baghdad
Jaderyia, 10071, Baghdad - Iraq

Abstract

In this paper, an attempt is made to simulate the grasping process of an underactuated robotic manipulator. A mathematical model of grasping forces of the manipulator was introduced, then a simulation model was built using MSC. Visual Nastran software. In order to validate the simulation model, different locations of the grasped object were considered. Contact forces were calculated theoretically and obtained from simulation of each grasped object location. Results obtained for each case are in good agreement, thus validating the simulation procedure followed in this study.

Keywords: Underactuated manipulator, Grasping force, Simulation analysis

1. Introduction

The idea behind underactuation in grasping is to use an ingenious mechanical system that can adapt to the shape of the object automatically. The four-bar linkage mechanism is one of the most common mechanisms used as a transmission mechanism in industrial underactuated robotic manipulators where large grasping forces are needed, as compared to the tendon and pulley mechanism.

Many researchers have investigated the underactuated mechanism as related to its analysis and design [1] and [2], its usage as robotic hands or grippers [3], [4], [5], [6] and [7], its geometric optimization [8]. In their work they derived a mathematical model to calculate the forces induced on the grasped object and studied the performance of the robotic manipulator and the stability of grasping.

Due to the non-linear dynamic behaviour of the underactuated mechanism, many issues arise in investigating grasping, control and optimum design of underactuated manipulators. For this reason, research wok, [9], [10], [11], [12], [13], [14], [15], [16] and [17] mainly in the last 10 years, started to implement different simulation procedures and algorithms to solve this problem.

In this work, contact forces between the underactuated manipulator and the grasped object were calculated theoretically for different locations of the grasped object on the workspace of the robotic manipulator where it can be reachable and grasped. Then a simulation model was built using MSC. VisualNastran software, from which contact forces were obtained and compared with those obtained theoretically. The main purpose of this work was to obtain a simulation for the force transmission from the underactuated robotic manipulator to the object. Results showed good verification for the accuracy of the proposed simulation procedure.

2. Theoretical Analysis

A model of the underactuated manipulator used in this study is shown schematically in Figure 1.

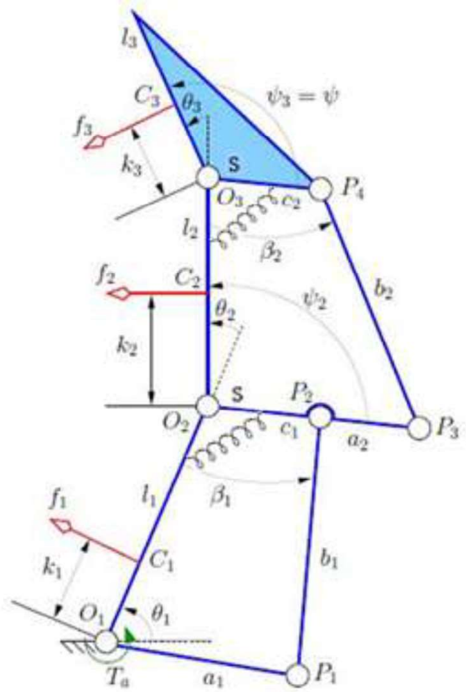


Figure 1. 3-DOF Linkage Type Underactuated Manipulator

It is a planner 3-DOF manipulator with 1 degree of actuation. The general contact forces expressions have been derived by Birglen and Gosselin [1] and are as listed below;

$$f_1 = \frac{l_1 U T_a}{k_1 k_2 k_3 (h_2 + l_1)(h_3 + l_2)} - \frac{(k_2 + l_1 \cos\theta_2) T_2}{k_1 k_2} + \frac{l_1 V T_3}{k_1 k_2 k_3} \quad (1)$$

$$f_2 = \frac{h_2 l_2 (k_3 - h_3 \cos\theta_3) T_a}{k_2 k_3 (h_2 + l_1)(h_3 + l_2)} + \frac{T_2}{k_2} - \frac{(k_3 + l_2 \cos\theta_3) T_3}{k_2 k_3} \quad (2)$$

$$f_3 = \frac{h_2 h_3 T_a}{k_3 (h_2 + l_1)(h_3 + l_2)} + \frac{T_3}{k_3} \quad (3)$$

With

$$U = k_2 k_3 h_3 + k_2 k_3 l_2 - h_2 k_3 l_2 cos\theta_2 + h_2 h_3 l_2 cos\theta_2 cos\theta_3 - h_2 h_3 k_2 \cos(\theta_2 + \theta_3) \quad (4)$$

$$V = l_2 cos\theta_2 cos\theta_3 + k_3 cos\theta_2 - k_2 cos(\theta_2 + \theta_3) \quad (5)$$

$$h_i = c_{i-1}(\cos(\theta_i - \varphi_i) - \sin(\theta_i - \varphi_i)\, cot\beta_{i-1}) \quad (6)$$

Where

T_a: Torque of the actuator

T_2: Torque of spring 1

T_3: Torque of spring 2

f_1, f_2, f_3 : Normal forces of proximal, middle and distal phalanx respectively

l_1, l_2, l_3 : Length of proximal, middle and distal phalanx respectively

k_1, k_2, k_3 : contact locations on their respective phalanges

θ_2, θ_3 : angles between the phalanges

The above equations were derived hence to maintain the mechanism in static equilibrium for a known actuation torque and a known manipulator position.

3. Simulation Procedure and Case Study

The simulation procedure was achieved by using MSC. VisualNastran software. The model of 3-DOF underactuated robotic manipulator is shown in Figure 2, presenting the main parts of the manipulator.

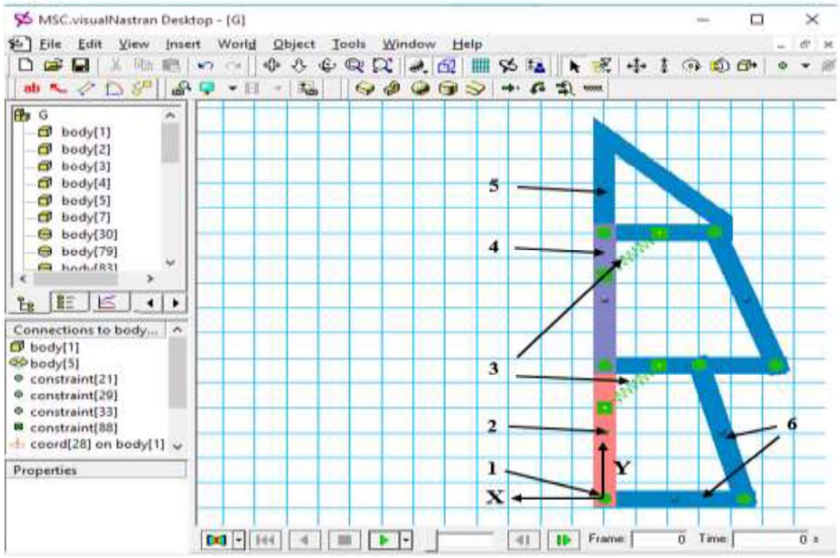


Figure 2. Model of the manipulator; (1) Rotary actuator, (2) Proximal phalanx, (3) Identical springs, (4) Middle phalanx, (5) Distal phalanx, (6) Transmission mechanism

Referring to Figure 1, the design parameters of the manipulator are listed in Table 1

Table 1. Design parameters of the manipulator

l_1	l_2	l_3	a_1	b_1	c_1	a_2	b_2	c_2	s	K
266 mm	265 mm	233 mm	220 mm	278 mm	151 mm	272 mm	283 mm	175 mm	85.6 mm	46 N/m

Other parameters such as $k_1, k_2, k_3, \theta_1, \theta_2$ *and* θ_3 are determined according to the size of the object to be grasped and its location on the work space of the manipulator. The grasped object taken into consideration is a cylinder of 240 mm diameter. This cylinder is placed in 10 different locations, the x and y coordinates of its center with respect to the location of the rotary actuator, point 1 in Figure 2, are as listed in Table 2.

Table 2. Location of the grasped object

CASE		1	2	3	4	5	6	7	8	9	10
POS (mm)	X	150	138	150	189	200	247	244	214	300	500
	Y	181	214	381	171	131	33	81	131	31	31

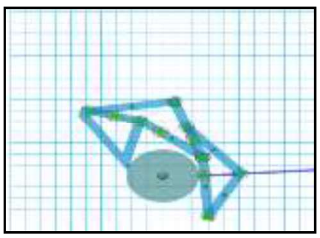
4. Results and Discussion

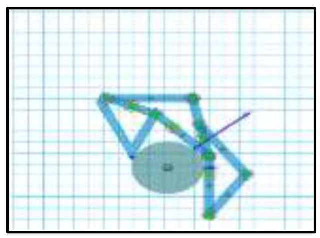
Grasping forces calculated theoretically and obtained from the simulation procedure followed in this research for the ten cases are listed in Table 2, where each case represents a specified location of the cylindrical grasped object. All the cases taken into consideration are for a stable grasping condition in which all the contact forces are positive thus insuring no ejection of the grasped object. The results obtained for these forces are listed in Table 3.

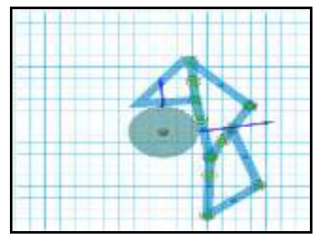
Table 3. Grasping forces for cylindrical object D = 240 mm

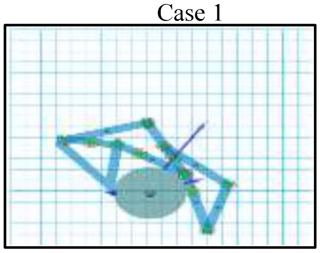
CASE	Theoretical (N)			Simulation (N)			% Error		
	F1	F2	F3	F1	F2	F3	F1	F2	F3
1	15.86	-	0.81	15.59	-	0.76	1.7	-	6.2
2	1.48	9.69	0.97	1.59	10.21	1.03	7.4	5.4	6.2
3	-	5.87	5.86	-	5.51	5.72	-	6.1	2.4
4	2.17	8.87	0.96	2.29	8.68	1.02	5.5	2.1	6.3
5	14.63	-	0.81	14.41	-	0.75	1.5	-	7.4
6	0.29	12.52	0.94	0.31	12.39	1.02	6.9	1.0	8.5
7	1.34	9.47	0.88	1.42	9.21	0.93	6.0	2.7	5.7
8	1.42	10.59	0.97	1.33	10.57	1.01	3.5	0.2	4.0
9	-	9.69	1.37	-	9.26	1.43	-	4.4	4.4
10	-	-	7.47	-	-	6.86	-	-	8.2

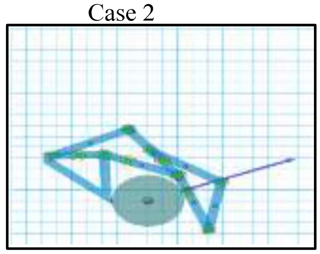
It can be seen that the percentage error between the grasping forces calculated theoretically and those obtained by simulation is almost acceptable for all the ten cases, the maximum value of this error was found to be 8.5% for case 6. Some of the forces are not apparent in the table, this is attributed to the effect of location of the cylindrical grasped object, for which contact is lost between the object and one of the links of the manipulator. This can be clarified in Figure 3, where each case represents the simulation of one of the ten cases of location of the cylindrical grasped object.

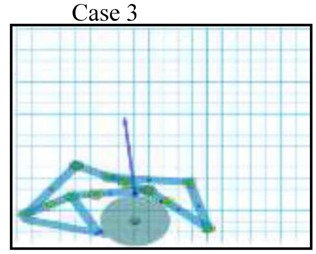

Case 1

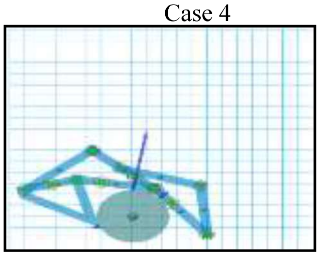

Case 2

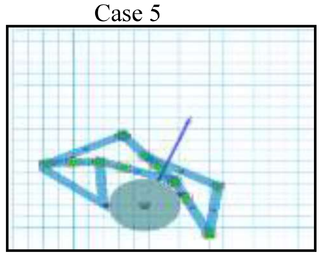

Case 3

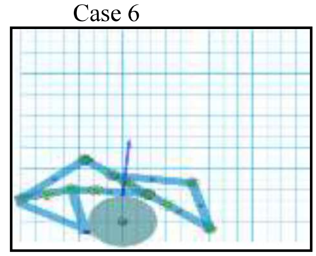

Case 4


Case 5


Case 6


Case 7


Case 8


Case 9

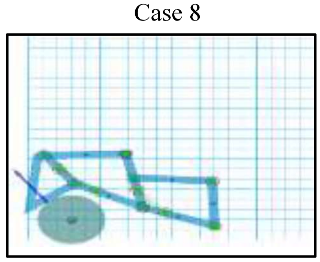

Case 10

Figure 3. Grasping of cylindrical object

It is obvious that contact is lost between one of the links and the grasped object as shown in cases 1,3,5 and 9. While in case 10, contact occurred between the grasped object and the distal link only.

5. Conclusions

From the results obtained, the following concluding remarks can be withdrawn,

1- Grasping forces calculated theoretically and those observed from the simulation procedure seem to be in good agreement, where the maximum percentage error was found to be 8.5%.
2- Grasping forces obtained by both methods showed the same trend of variation as related to the location of the grasped cylindrical object.
3- Grasping forces have higher values when the cylindrical grasped object is located near the fixed center of rotation of the underactuated robotic manipulator.
4- Full contact between the grasped object and the three links of the manipulator is dependent on the grasped object location.

References

[1] Lionel Birglen and Cl´ement M. Gosselin, "Kinetostatic Analysis of Underactuated Fingers", IEEE Transactions on Robotics and Automation, vol. 20, no. 2, pp. 211–221, 2004.
[2] Lionel Birglen and Cle´ment M. Gosselin, "Geometric Design of Three-Phalanx Underactuated Fingers", J. Mech. Des, vol. 128, no. 2, pp. 356-364, 2005.
[3] Thierry Lalibertey, Lionel Birgleny, and Clement M. Gosselin, "Underactuation in robotic grasping hands", Machine Intelligence & Robotic Control, Vol. 4, No. 3, pp. 1–11, 2002.
[4] Lionel Birglen, Thierry Laliberté and Clément Gosselin, "Underactuated Robotic Hands", vol. 40, no. 40. Springer Berlin Heidelberg, 2008.
[5] Gert A. Kragten, "Underactuated Hands, Fundamentals, Performance Analysis and Design", 2011.
[6] Jelmer Korstanje, "An underactuated gripper mechanism for picking objects from a tabletop", MSc. Thesis, January 2012.
[7] S. M. Nacy, M. A. Tawfiq, I. A. Baqer, "Grasping force prediction for underactuated Multi-Fingered Hand by using Artificial Neural Network", Control Theory and Informatics IISTE, vol.3, issue 1, 2013.
[8] S. M. Nacy, S. S. Hassan, S. H. Bakhy, "Geometric Optimization of three-phalanx prosthesis underactuated fingers using particles swarm, algorithm", American Journal of Engineering and Applied Sciences, vol. 2, issue 2, 2009.
[9] J. Tegin, B. Iliev, A. Skoglund, D. kragic and J. Wikander, "Real Life Grasping using Under-actuated Robot Hand - Simulation and Experiments", International Coference on Advanced Robotics, ICAR 2009.
[10] J. A. Corrales, C. A. Jara and F. Torres, "Modeling and Simulation of a Multi-Fingered Robotic Hand for Grasping Tasks", 11 th. Int. Conf. Control, Automation, Robotics and Vision, 2010, pp 1577-1582.
[11] Tian Zhixiang and Wu Hongtao, "Spatial Operator Algebra for Free-Floating Space Robot Modeling and Simulation", Chinese Journal of Mechanical Engineering, vol. 23, 2010.
[12] Qui Ying and Rao Bing, "Modeling and Simulation of Manipulator Grasping Based on Underactuated Mechanism", Advanced Materials Research, vols. 433-440, pp 2726-2729, 2012.
[13] Mohsen moradi dadalvand, bijan shirinzadeh and Saeid Nahavand, "Swing- Up and Stability Control of Wheeled Acrobat (WAC robot)", Automatika 55(1), pp. 32-40 (2014).
[14] C. I. Mavrogiannis, C. P. Bechlioulis, M. V. Liarokapis and K. J. Kyriakopoulos, "Task-Specific Grasp Selection for Underactuated Hands", IEEE International Conference on Robotics and Automation (ICRA), 2014.
[15] Francesco Romano, Daniele Pucci and Francesco Nori, "Collocated Adaptive Control of Underactuted Mechanical Systems", IEEE Transactions on Robotics, vol. 31, issue 6 (2015), pp. 1527-1536.
[16] Yu Ya-Xin, Wu Fei, Zhu Rong and Zhang Fei, "Principle Analysis and Parameter Optimization for Underactuated End-Effector Manipulator for Apple Picking", The Open Materials Science Journal, 9, 2015, pp. 50-55.
[17] M. Liarokapis and A. M. Dollar, "Post-Contact, In-Hand Object Motion Compensation for Compliant and Underactuated Hands", 25th IEEE International Symposium on Robot and Human Interactive Communication, (RO-MAN), 2016.