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Proceeding Paper

Performance Comparison of Parallel and 3 Finger Gripper Using Human Hand Grasping Taxonomies †

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Abstract: The selection of best gripper for pick and place robot arm, is always a tedious task to choose from various grippers available. Most of the gripper does not comply with pay load capacity of robot arm and also lacks in efficient handling of objects. This paper assists in solving the issue i.e., how to choose an adequate gripper for pick and place operation considering its object handling property. Therefore, performance testing of parallel and 3 finger gripper are done under simulation environment based on human hand grasping taxonomy. Grasping force and number of contact points between gripper and objects are parameters for comparative study. Simulation experiments are conducted by gazebo simulator running under ROS, to pick and place 10 objects. Based on human hand grasping taxonomy simulation experiments are divided into 3 categories such as normal, misaligned and rotation grasping. Points 0 and 1 are awarded to grippers i.e., 1 is for easy grasping and 0 for difficult grasping or no grasping. From experiments, overall grasping score of parallel and 3 finger gripper are 0.8779 and 0.9667 respectively which leads to conclusion that not only grasping of 3 finger gripper is superior as compared to parallel gripper but also it performs very well on 3 grasping taxonomies of human hand and able to handle fragile and deformable objects efficiently. By addressing the objectives of proposed study, researcher can easily select gripper for a particular application and also can develop more capable, adaptable, and cost-effective manipulation systems.

Keywords: parallel gripper; gazebo simulator; contact points; mis-aligned grasping; URDF; slipping metric; ROS

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1. Introduction

Shah. Vijesh [28] presented the incorporation of an industrial robot in the operation line and end effector is designed to manage product quality which needs to be handled delicately, but in order to handle delicate objects, contact points of grasping needs to be specified that factor was not taken into consideration.

Atakuru Taylan [29] developed a two-degree-of-freedom gripper for industrial manipulator further more preliminary analyses are performed for a typical pick-and-place task. Also, the developed gripper is integrated into manipulator and tested for certain performance criteria. In manuscript technical parameters specifying grippers are missing. Alebooyeh M. [30] proposed research to experiment validate innovatively designed grippers using flexible carbon material for efficient material pick and place tasks. Also, tests are performed to validate the new-designed gripper enhanced performance on the slippage and material wrinkling based on the gripping forces, but no criterion was given to choose a gripper suitable for particular task.

Doğan, B. [31] developed and manufactured a two-fingered gripper and a four-fingered multipurpose gripper. In addition to development of robotic hands, computer control hardware and software are also developed for computer control of both hands. But in literature no performance comparison between 3 finger and parallel gripper been specified.

Blanes, C. [32] reviewed the requirements and phases used in the process of manipulation, summarizes and analyses of the existing, potential and emerging techniques and their possibilities for the manipulation of fresh horticultural products from a detailed study of their characteristics but human hand grasping taxonomies which is a crucial parameter for picking fruits and vegetables in agriculture industry is missing.

Monkman G. J. [33] described in book about robot gripper classification, pretension and prehension technology, instrumentation, control circuitry used in gripper design but did not talk about jaw factor of gripper which is a key parameter while taking pretension and prehension technology into account.

The literature review about to choose among various grippers and their analysis for pick and place operation revealed unsatisfactory results. Therefore, this paper intends to provide readers with a planning model to help them determine which gripper to choose and the necessary parameters for designing and developing a gripper for successful pick and place operation. In addition, by following the guidelines, more consistent research might be conducted using human hand grasping taxonomies and reported for the betterment of object pick and place by robot arm. Current literature lacks standardized methodologies for evaluating grippers across multiple performance matrices. Furthermore, there's a gap in systematic studies assessing gripper performance across a wide range of objects, including deformable objects and irregular shapes. Current literature also lacks systematic evaluations of the energy consumption of different gripper types and design optimizations for energy efficiency. In addition to that research is needed to explore the robustness and reliability of gripper designs under object variability. In current literature, there is limited research comparing the cost-effectiveness of different gripper options, considering factors like initial cost, maintenance requirements, and overall lifespan. There's also need for research on integrated robotic systems leveraging visual feedback to improve grasping performance in real-world scenarios.

"The contribution of the research is to help the researchers to choose between parallel and 3 finger gripper based upon their specific pick and place requirements based upon performance comparison between them on various parameters such as grasping force, slipping metric, cost and human hand grasping taxonomies [26].

2. Materials and Methods

2.1. Proposed Methodology

- Comparison of grasping force to hold same object by different grippers;
- Comparison of grippers based upon no. of contact points between gripper jaws and object;
- Comparison of grippers based on human hand grasping taxonomies;
- Performance testing of grippers under simulated environment using gazebo simulator;

The aim is to compare grasping of parallel gripper and 3 finger gripper, to grasp household objects like water bottle, can, egg, shoe, orange, plastic box, fable brick, cup, marker and teddy bear. Selected gripper serves the purpose if successfully grasps 9 objects from given list without doing any damage to them. The grasping objects are indexed from 0 to 9 as shown in Figure 1.

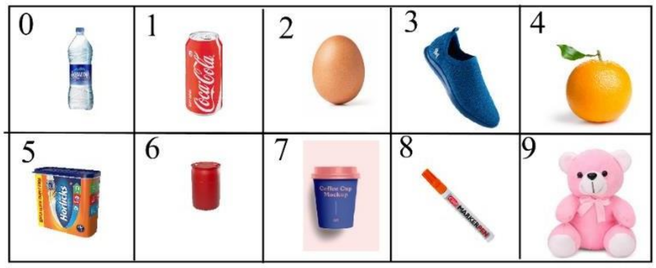
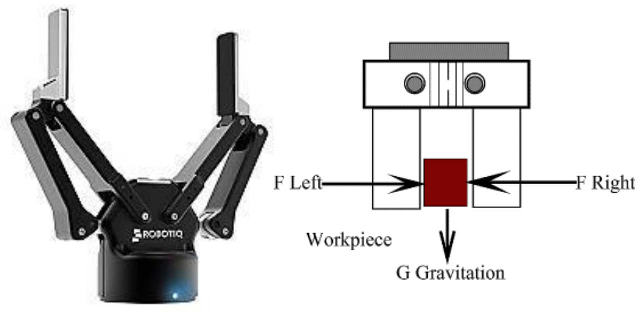


Figure 1. 10 Daily Based Sample Household Objects for Picking by Gripper.

2.2. Compariosn of Grasping Force to Hold Same Object by Both Grippers

Parallel gripper usually has two jaws with two degrees of freedom and force distribution between jaws as shown in Figure 2 [9,10].



(**a**) (**b**)

Figure 2. (**a**) Parallel Gripper; (**b**) Force Distribution in a Parallel Gripper.

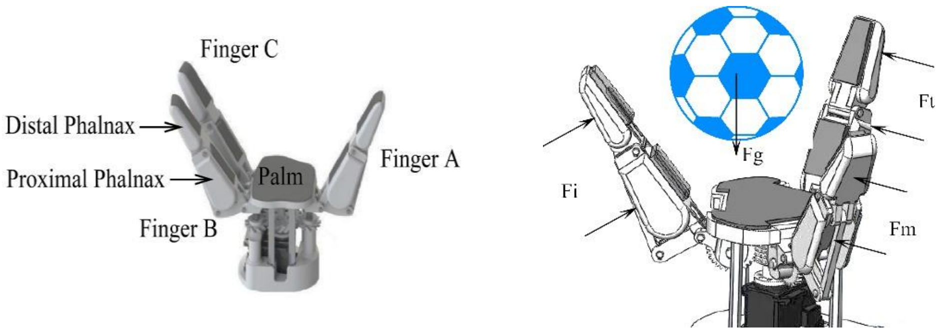
$$\boldsymbol{F_g = m(g + a)\frac{S}{\mu}} \tag{1}$$

where Fg = Grasping force (N) m = Object weight (Kg)

g = Gravitational acceleration (m/s²) μ = Coefficient of friction

a = Object acceleration (m/s²) = 0 (For Stationary object) S = Safety factor = 2 [21]

While 3 finger gripper provides functionality of human hand in robots as shown in Figure 3 [11]. The generalized rule shows that the force required by parallel gripper is 4 times as that by encompassing gripper to hold the same object. Jaw factor for a parallel gripper is assumed to be 4 and for 3 finger Encompassing Grip is assumed to be 1 [14–17].



(**a**) (**b**)

Figure 3. (**a**) 3 Finger Gripper; (**b**) Force Distribution in a 3 Finger Gripper [25].

$$\mathbf{F_G = m(1 + g)\,J} \tag{2}$$

where J = Jaw Factor [22]

For Grasping 0.5-pound football in parallel gripper with 1.5 g acceleration by the robot arm,

$$F_g = 0.5(1 + 1.5 \times 9.8) * 4 = 32 \text{ lbf}$$

For grasping 0.5-pound football, in 3 finger gripper with 1.5 G acceleration by the robot arm [8],

$$F_g = 0.5(1 + 1.5 \times 9.8) * 1 = 8 \text{ lbf}$$

Thus, grasping force required by 3 finger gripper is 25% of grasp force required by parallel gripper, also motor rating is reduced by 75% [1,3].

2.3. Comparison of Grippers Based upon Number of Contact Points

Contact points is the gripper surface area which is in between object and jaws of gripper. The contact points are classified as point, line, surface, circular, and double line. Arrow in Figures 4 and 5 [4]. indicates contact points between gripper and object surface. The gripper jaw's design is a determining factor for a proper prehension mechanism which is solely responsible for grasping force distribution [12,13].

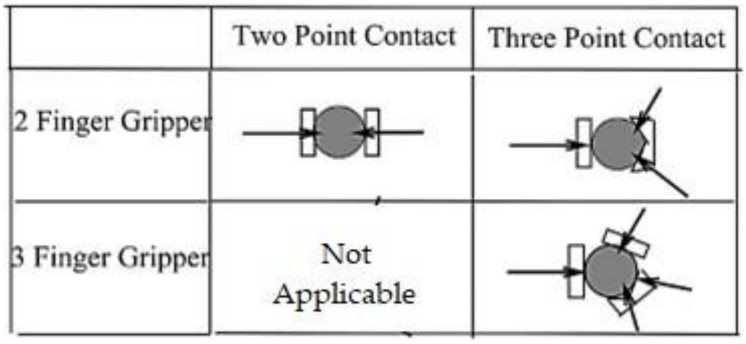


Figure 4. Contact Points on Parallel and 3 finger Gripper [16,37].

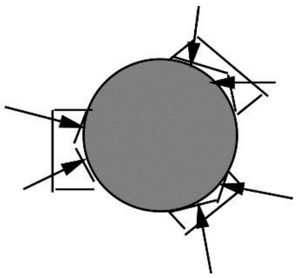


Figure 5. Gripper Contact Points Well Suited for Pick and Place Operation [24].

2.4. Comparison of Grippers Based upon Human Hand Grasping Taxonomies

Grasping taxonomy are a set of rules that defines how human hand grasp various objects in a real-world environment [2]. For adequate grasping, it is necessary to have minimum two points of contact between object and gripper jaws [12]. Gripper design should be similar to Figure 6 [5]. As the no. of contacts points are 6, more friction exists between contact surfaces i.e., better is the grasping force thereby lowers chances of slipping of object and symmetric force distribution [6].

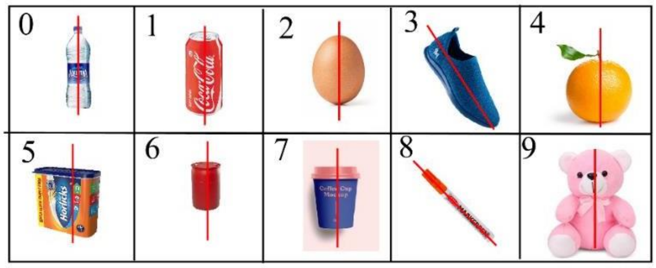


Figure 6. Transversal Axis on Objects Under Normal Grasping. Note: Red color transversal axis depicts, from which side object need to be grasped (Lengthwise).

For adequate grasping, it is necessary to have minimum two points of contact between object and gripper jaws [12]. Gripper design should be similar to Figure 5 [5]. As the no. of contacts points are 6, more friction exists between contact surfaces i.e., better is the grasping force thereby lowers chances of slipping of object and symmetric force distribution [34–36]. The gripper jaws should align itself with red axis as shown in Figure 6.

Each experimental test is meant for three grasping types: normal, misaligned and rotation grasping and red line in Figure 6 indicates the object axis [26]. During simulation test, all the 10 objects shall be subjected to above grasping taxonomies and result can be either passed or failed attempt [27]. During Normal grasping, gripper jaw axis is parallel to object axis shown by red transversal line i.e., angle between them is 00 as shown in Figure 7, while during misaligned grasping gripper jaw axis is rotated at 450 with object axis also shown in Figure 6 [7,29], While during Rotation grasping, object axis and gripper jaw axis rotated at 90°. Figures 8–11 shows contact points colored in red, where gripper should hold object during normal, rotational and misaligned grasping [51].

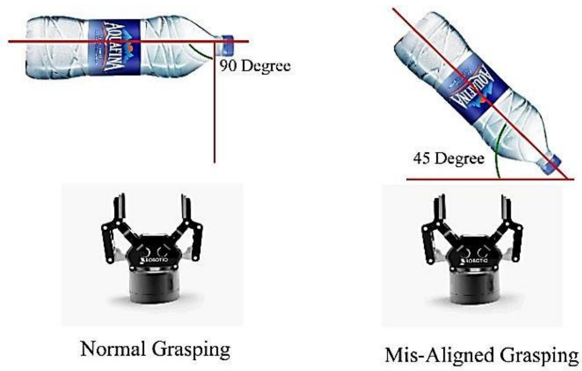


Figure 7. Transversal Axis on Objects Under Normal and Misaligned Grasping [47–50].

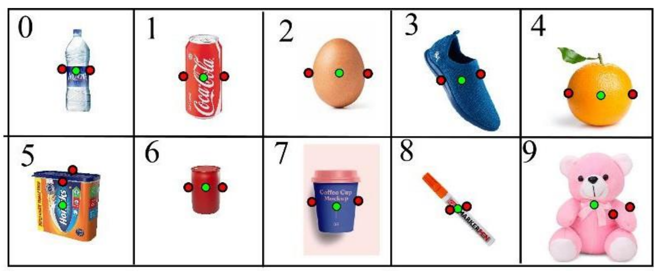


Figure 8. Parallel Gripper Contact Points on Objects during Normal Grasping.

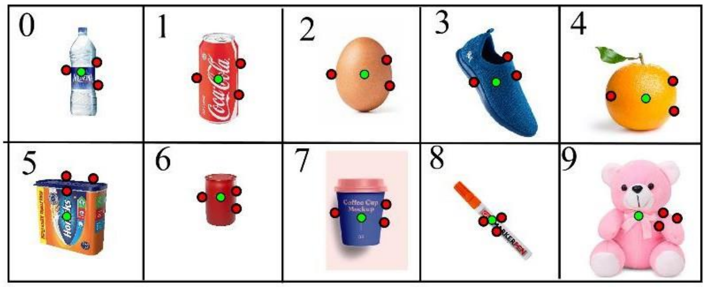


Figure 9. 3 Finger Gripper Contact Points on Objects during Normal Grasping. Note: Green dot shows objects center of mass while red dot shows point of contact of the gripper with the object [2].

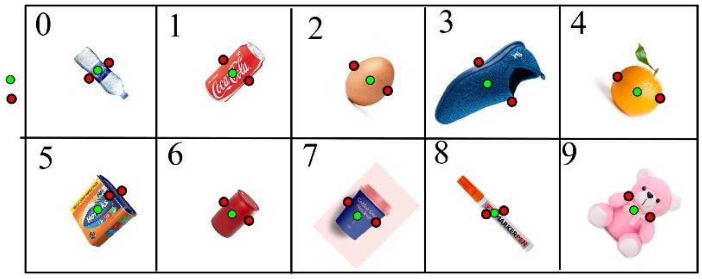


Figure 10. Parallel Gripper Contact Points on Objects During Misaligned Grasping [23].

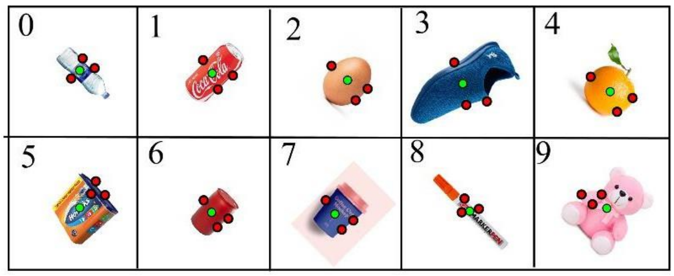


Figure 11. 3 Finger Gripper Contact Points On Objects During Misaligned Grasping.

2.5. Block Diagram for Gripper Testing Using Gazebo Simulator

Gazebo is an open-source 3D robotics simulator that provides a platform for simulating the dynamics of robots and environments using ROS (Robot Operating System) [43,44], URDF (Unified Robotics Description Format) file, in a realistic and controlled virtual environment and before deploying them to physical robots as shown in Figures 13 and 14 [18–20].

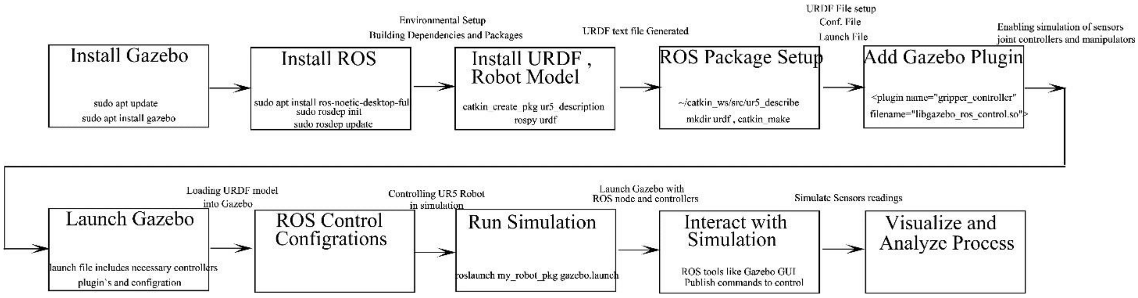
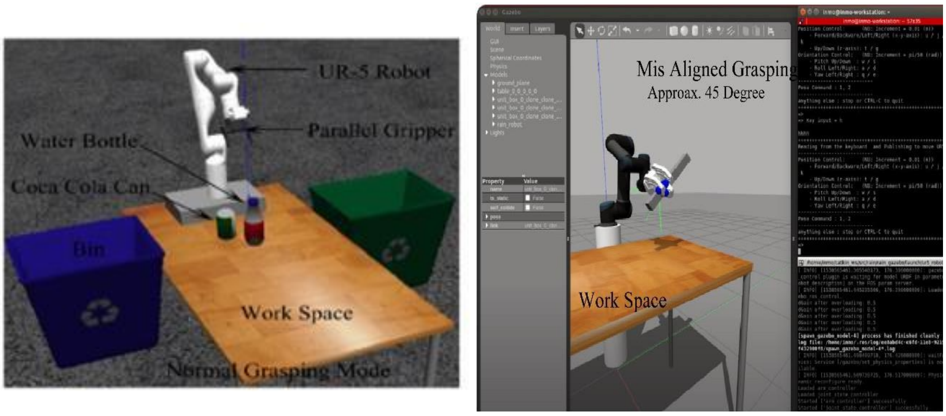


Figure 12. Block Diagram To Simulate UR5 Robot along with gripper Gazebo Simulator [38–42].



(**a**) (**b**)

Figure 13. (**a**) Normal Grasping (Parallel Gripper); (**b**) Misaligned Grasping (3 Finger Gripper) [45,46].

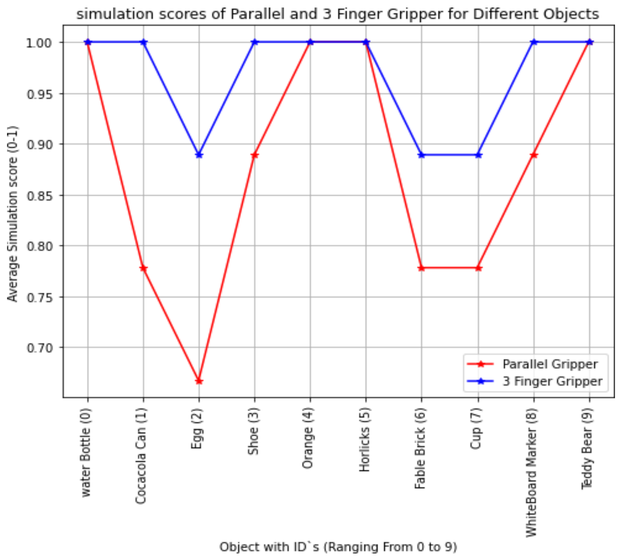
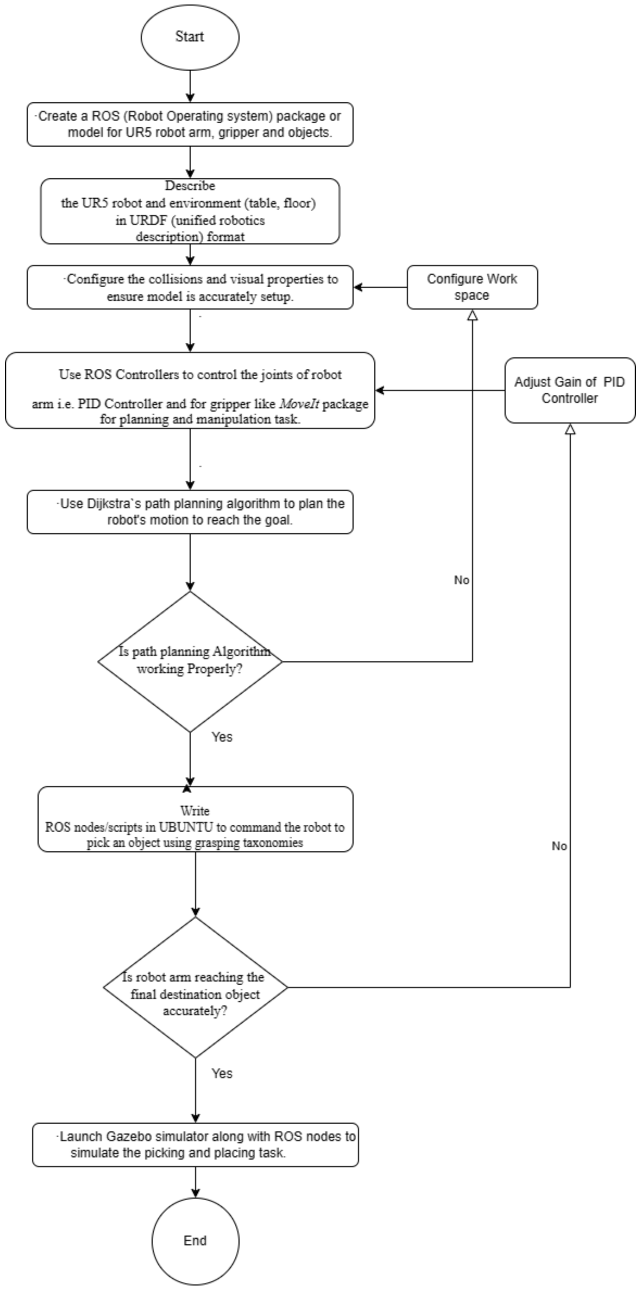


Figure 14. Performance Curve of Grippers Under Simulated Environment.

2.6. Flowchart Diagram for Gripper Testing Using Gazebo Simulator



3. Simulation Results

Under simulation, 3 attempts are made by robot arm integrated with gripper to grasp Sample objects under study.

3.1. Performance Curve of Grippers Under Simulation

Tables 1 and 2 shows the grasping scores obtained by parallel and 3 finger gripper during simulation experiments under 3 grasping taxonomies. In each grasping taxonomy, every object has to be picked 3 times in a row. 0 and 1 are awarded for failed and successful attempts made by gripper. The overall grasping scores of parallel and 3 finger gripper are 0.8779 and 0.9667 respectively i.e 3 finger gripper score is more than parallel gripper by 0.088. From the curve as shown in Figure 15 illustrates that object ID's 1, 2, 6 and 7 are difficult to be grasped by parallel gripper, while object ID's 2, 6 and 7, the difficulty level is quite low for 3 finger gripper. Also from the Tables 1 and 2, object ID's 0, 4, 5 and 9 are the objects easily grasped by both of the grippers.

Table 1. Simulation Results For Parallel Gripper.

Object ID	Normal Grasping			Mis Aligned Grasping			Rotational Grasping			Average Score
0	1	1	1	1	1	1	1	1	1	1
1	1	1	1	0	0	1	1	1	1	0.778
2	1	1	0	1	1	0	1	1	0	0.667
3	1	1	1	1	1	1	1	1	0	0.889
4	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	0	1	0	1	0.778
7	1	1	1	1	0	1	1	1	0	0.778
8	1	1	1	1	0	1	1	1	1	0.889
9	1	1	1	1	1	1	1	1	1	1
Overall Score										0.8779

Table 2. Simulation Results For 3 Finger Gripper.

Object ID	Normal Grasping			Mis Aligned Grasping			Rotational Grasping			Average Score
0	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	0	1	1	1	0.889
3	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	0	1	1	1	0.889
7	1	1	1	1	1	1	1	1	0	0.889
8	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1
Overall Score										0.9667

From The simulation experiments and results, the following points are worth noting while making a choice between parallel and 3 finger gripper for picking objects:

3.2. Performance Metrices of Grippers

3.2.1. Success Rate of Grasping Objects

The average success rate of grasping objects of parallel and 3 finger grippers are 87.79% and 96.67% respectively. The egg is the typical object for grasping with 66.7% successful attempts with parallel gripper and 88.9% successful attempts with 3 finger gripper. Another difficult object is cup with 88.9% successful attempts for parallel gripper. Round fable brick has 77.8% success attempts with parallel gripper and 88.9% successful attempts for 3 finger gripper. Since brick is non deformable object which gives less contact surface. On other hand because of deformed surface teddy bear has got 100% successful attempts. Therefore 3 finger gripper is more suitable for picking egg as well as cup.

3.2.2. Grasping Force Impressed by Gripper Jaws

From the grasping force calculations, arrived at conclusion that the force requirement of 3 finger gripper is comparatively much lesser than parallel gripper approximately one-fourth of that of parallel gripper i.e.,75% of reduction in servo motor rating. Therefore 3 finger gripper has more suitability as compared to parallel gripper for pick and place robotic arm and its applications.

3.2.3. Slipping Metric

The chances of object slipping exist in parallel gripper while 3 finger gripper provides efficient grasping because of more no of contact points with the object. The chances of slipping are more in parallel gripper During misaligned grasping.

3.2.4. Grasp Stability

Parallel gripper offers maximum 3 and minimum 2 contact points while 3 finger gripper has minimum 3 and maximum 6 contact points. Since more no of contact points ensures more friction resulting into good grasping force. 3 finger gripper are the first choice to hold fragile and soft objects.

3.2.5. Design Complexity

Parallel grippers are simple and rugged in construction while 3 finger gripper is more complex in fabrication and design. But for good work practice, the design complexity can be out on secondary note.

4. Results and Conclusions

This research's aim was to fill a broad gap in existing knowledge related to selection of gripper for pick and place operation, while taking into consideration various parameters which makes easy for research to make a decision to choose. If the pick and place task involves handling irregular shaped objects in a cost-effective manner, a parallel gripper may not be sufficient and also if the application demands versatility, dexterity. Since 3 finger gripper also conforms to a limited human hand grasping taxonomies, definitely it has got privilege to work under dexterous pick and place environment.

The only limitation of proposed research is to work under unstructured environment where the objects are placed in workspace in non-systematic way like clutter and in that case robot arm should be equipped with adequate object detection systems to pick object of interest. The parallel gripper fails in most of the cases under such scenario while 3 finger gripper is still effective in operation. By addressing the objectives of proposed research, researcher can easily select gripper for a particular application and also can develop more capable, adaptable, and cost-effective manipulation systems well suited to work under unstructured environment in industrial and service robotics applications.

Supplementary Materials: The following supporting information can be downloaded at: https://github.com/marutdevsharma/gripper_performance_comparison_using_Gazebo.

Author Contributions: The following are the contributions of main and co author in this manuscript. Conceptualization, M.D.S.; methodology, M.D.S.; software, M.D.S.; validation, J.B.; formal analysis, M.D.S.; investigation, M.D.S.; resources, M.D.S.; data curation, M.D.S., writing—original draft preparation, M.D.S.; writing—review end editing, M.D.S. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

References

1. Sharma, M.D.; Binong, J. Performance evaluation of a specialized pressure sensor for pick and place operations. In Proceedings of the 10th International Electronic Conference on Sensors and Applications, Online, 15–30 November 2023; MDPI: Basel, Switzerland, 2023. https://doi.org/10.3390/ecsa-10-16586.
2. Sharma, M.D.; Binong, J. Testing a 6 Axis Force-Torque Tactile Sensor for Robotic Arm. In *Proceedings of International Conference on Data, Electronics and Computing. ICDEC 2022*; Das, N., Binong, J., Krejcar, O., Bhattacharjee, D., Eds.; Algorithms for Intelligent Systems; Springer: Singapore, 2023. https://doi.org/10.1007/978-981-99-1509-5_32.
3. Mehrkish, A.K.; Janabi-Sharifi, F. A comprehensive grasp taxonomy of continuum robots. *Robot. Auton. Syst.* **2021**, *145*, 103860. https://doi.org/10.1016/j.robot.2021.103860.
4. Martin-Brevet, S.; Jarrassé, N.; Burdet, E.; Roby-Brami, A. Taxonomy based analysis of force exchanges during object grasping and manipulation. *PLoS ONE* **2017**, *12*, e0178185. https://doi.org/10.1371/journal.pone.0178185.
5. Stival, F.; Michieletto, S.; Cognolato, M.; Pagello, E.; Müller, H.; Atzori, M. A quantitative taxonomy of human hand grasps. *J. Neuroeng. Rehabilit.* **2019**, *16*, 28. https://doi.org/10.1186/s12984-019-0488-x.
6. Sun, Y.; Amatova, E.; Chen, T. Multi-object grasping-types and taxonomy. In Proceedings of the 2022 International Conference on Robotics and Automation (ICRA), Philadelphia, PA, USA, 23–27 May 2022; IEEE: New York, NY, USA, 2022. https://doi.org/10.1109/ICRA46639.2022.9812388.
7. Liu, C.-H.; Chung, F.-M.; Chen, Y.; Chiu, C.-H.; Chen, T.-L. Optimal design of a motor driven three-finger soft robotic gripper. *IEEE/ASME Trans. Mechatron.* **2020**, *25*, 1830–1840. https://doi.org/10.1109/TMECH.2020.2997743.
8. Sadun, A.S.; Jalani, J.; Sukor, J.A.; Jamil, F. Force control for a 3-Finger Adaptive Robot Gripper by using PID controller. In Proceedings of the 2016 2nd IEEE International Symposium on Robotics and Manufacturing Automation (ROMA), Ipoh, Malaysia, 25–27 September 2016; IEEE: New York, NY, USA, 2016. https://doi.org/10.1109/ROMA.2016.7847807.
9. Tlegenov, Y.; Telegenov, K.; Shintemirov, A. An open-source 3D printed underactuated robotic gripper. In Proceedings of the 2014 IEEE/ASME 10th International Conference on Mechatronic and Embedded Systems and Applications (MESA), Senigallia, Italy, 10–12 September 2014; IEEE: New York, NY, USA, 2014. https://doi.org/10.1109/MESA.2014.6935605.
10. Rebollo, D.R.R.; Ponce, P.; Molina, A. From 3 fingers to 5 fingers dexterous hands. *Adv. Robot.* **2017**, *31*, 1051–1070. https://doi.org/10.1080/01691864.2017.1393349.
11. Lu, Y.; Xie, Z.; Wang, J.; Yue, H.; Wu, M.; Liu, Y. A novel design of a parallel gripper actuated by a large-stroke shape memory alloy actuator. *Int. J. Mech. Sci.* **2019**, *159*, 74–80. https://doi.org/10.1016/j.ijmecsci.2019.05.041.
12. Zhang, X.; Xu, Q. Design and testing of a novel 2-DOF compound constant-force parallel gripper. *Precis. Eng.* **2019**, *56*, 53–61. https://doi.org/10.1016/j.precisioneng.2018.09.004.
13. Guo, M.; Gealy, D.V.; Liang, J.; Mahler, J.; Goncalves, A.; McKinley, S.; Ojea, J.A.; Goldberg, K. Design of parallel-jaw gripper tip surfaces for robust grasping. In Proceedings of the 2017 IEEE International Conference on Robotics and Automation (ICRA), IEEE: New York, NY, USA, 2017. https://doi.org/10.1109/ICRA.2017.7989330.
14. Cirillo, A.; Costanzo, M.; Laudante, G.; Pirozzi, S. Tactile sensors for parallel grippers: Design and characterization. *Sensors* **2021**, *21*, 1915. https://doi.org/10.3390/s21051915.
15. Atakuru, T.; Samur, E. A robotic gripper for picking up two objects simultaneously. *Mech. Mach. Theory* **2018**, *121*, 583–597. https://doi.org/10.1016/j.mechmachtheory.2017.10.027.
16. Monkman, G.J.; Hesse, S.; Steinmann, R.; Schunk, H. *Robot Grippers*; John Wiley & Sons: Hoboken, NJ, USA, 2007.
17. Nie, K.; Wan, W.; Harada, K. A hand combining two simple grippers to pick up and arrange objects for assembly. *IEEE Robot. Autom. Lett.* **2019**, *4*, 958–965. https://doi.org/10.1109/LRA.2019.2893153.
18. Noori, F.M.; Portugal, D.; Rocha, R.P.; Couceiro, M.S. On 3D simulators for multi-robot systems in ROS: MORSE or Gazebo?. In Proceedings of the 2017 IEEE International Symposium on Safety, Security and Rescue Robotics (SSRR), Shanghai, China, 11–13 October 2017; IEEE: New York, NY, USA, 2017. https://doi.org/10.1109/SSRR.2017.8088134.
19. Takaya, K.; Asai, T.; Kroumov, V.; Smarandache, F. Simulation environment for mobile robots testing using ROS and Gazebo. In Proceedings of the 2016 20th International Conference on System Theory, Control and Computing (ICSTCC), Sinaia, Romania, 13–15 October 2016; IEEE: New York, NY, USA, 2016. https://doi.org/10.1109/ICSTCC.2016.7790647.
20. Pitonakova, L.; Giuliani, M.; Pipe, A.; Winfield, A. Feature and performance comparison of the V-REP, Gazebo and ARGoS robot simulators. In Proceedings of the Towards Autonomous Robotic Systems: 19th Annual Conference, TAROS 2018, Bristol, UK, 25–27 July 2018; Proceedings 19; Springer International Publishing: Berlin/Heidelberg, Germany, 2018. https://doi.org/10.1007/978-3-319-96728-8_30.
21. Marian, M.; Stinga, F.; Georgescu, M.-T.; Roibu, H.; Popescu, D.; Manta, F. A ROS-Based Control Application for a Robotic Platform Using the Gazebo 3D Simulator. In Proceedings of the 2020 21st International Carpathian Control Conference (ICCC), High Tatras, Slovakia, 27–29 October 2020; IEEE: New York, NY, USA, 2020. IPR Worldwide. Calculation of Gripping Force. Available online: https://en.iprworldwide.com/calculation-of-gripping-force/ (accessed on).
22. Grippers.com. Size. Available online: https://www.grippers.com/size.htm (accessed on).
23. Monkman, G.J.; Hesse, S.; Steinmann, R.; Schunk, H. *Robot Grippers*; WILEY-VCH Verlag GmbH & Co. KGaA: Weinheim, Germany, 2007.
24. Kothari, A.; Morrow, J.; Thrasher, V.; Engle, K.; Balasubramanian, R.; Grimm, C. Grasping objects big and small: Human heuristics relating grasp-type and object size. In Proceedings of the 2018 IEEE International Conference on Robotics and Automation

(ICRA), Brisbane, QLD, Australia, 21–25 May 2018; IEEE: New York, NY, USA, 2018; pp. 4237–4242. https://doi.org/10.1109/ICRA.2018.8460860.
25. Liu, C.H.; Chung, F.M.; Chen, Y.; Chiu, C.H.; Chen, T.L. Optimal design of a motor-driven three-finger soft robotic gripper. *IEEE/ASME Trans. Mechatron.* **2020**, *25*, 1830–1840. https://doi.org/10.1109/TMECH.2020.2997743.
26. Liu, C.H.; Chung, F.M.; Chen, Y.; Chiu, C.H.; Chen, T.L. Optimal design of a motor-driven three-finger soft robotic gripper. *IEEE/ASME Trans. Mechatron.* **2020**, *25*, 1830–1840. https://doi.org/10.1109/TMECH.2020.2997743.
27. Liu, C.H.; Chung, F.M.; Chen, Y.; Chiu, C.H.; Chen, T.L. Optimal design of a motor-driven three-finger soft robotic gripper. *IEEE/ASME Trans. Mechatron.* **2020**, *25*, 1830–1840. https://doi.org/10.1109/TMECH.2020.2997743.
28. Ariyanto, M.; Munadi, M.; Setiawan, J.D.; Mulyanto, D.; Nugroho, T. Three-fingered soft robotic gripper based on pneumatic network actuator. In Proceedings of the 2019 6th International Conference on Information Technology, Computer and Electrical Engineering (ICITACEE), Semarang, Indonesia, 26–27 September 2019; IEEE: New York, NY, USA, 2019; pp. 1–5. https://doi.org/10.1109/ICITACEE.2019.8904145.
29. Caldera, S.; Rassau, A.; Chai, D. Review of deep learning methods in robotic grasp detection. *Multimodal Technol. Interact.* **2018**, *2*, 57. https://doi.org/10.3390/mti2030057.
30. Shah, V.; Gilke, N.; Dhore, V.; Phutane, C.; Kondhol, B. Design of gripper and selection of robotic arm for automation of a pick and place process. In *Advances in Manufacturing Systems: Select Proceedings of RAM 2020*; Springer: Singapore, 2021; pp. 95–107. https://doi.org/10.1007/978-981-33-4466-2_10.
31. Atakuru, T.; Samur, E. A robotic gripper for picking up two objects simultaneously. *Mech. Mach. Theory* **2018**, *121*, 583–597. https://doi.org/10.1016/j.mechmachtheory.2017.10.027.
32. Alebooyeh, M.; Wang, B.; Urbanic, R.J. *Performance Study of an Innovative Collaborative Robot Gripper Design on Different Fabric Pick and Place Scenarios (No. 2020-01-1304)*; SAE Technical Paper; SAE International: Warrendale, PA, USA, 2020. https://doi.org/10.4271/2020-01-1304.
33. Doğan, B. Development of a Two-Fingered and a Four-Fingered Robotic Gripper. Master's Thesis, Middle East Technical University, Ankara, Türkiye, 2010. Available online: http://etd.lib.metu.edu.tr/upload/12611863/index.pdf (accessed on).
34. Blanes, C.; Mellado, M.; Ortiz, C.; Valera, A. (1). Review. Technologies for robot grippers in pick and place operations for fresh fruits and vegetables. *Span. J. Agric. Res.* **1970**, *9*, 1130–1141. https://doi.org/10.5424/sjar/20110904-501-10.
35. Monkman, G.J.; Hesse, S.; Steinmann, R.; Schunk, H. (Eds.) *Robot Grippers*; John Wiley & Sons: Hoboken, NJ, USA, 2007; Google Books.
36. Ariyanto, M.; Munadi, M.; Setiawan, J.D.; Mulyanto, D.; Nugroho, T. Three-fingered soft robotic gripper based on pneumatic network actuator. In Proceedings of the 2019 6th International Conference on Information Technology, Computer and Electrical Engineering (ICITACEE), Semarang, Indonesia, 26–27 September 2019; IEEE: New York, NY, USA, 2019; pp. 1–5. https://doi.org/10.1109/ICITACEE.2019.8904145.
37. Zhou, J.; Chen, S.; Wang, Z. A soft-robotic gripper with enhanced object adaptation and grasping reliability. *IEEE Robot. Autom. Lett.* **2017**, *2*, 2287–2293. https://doi.org/10.1109/LRA.2017.2716445.
38. Backus, S.B.; Dollar, A.M. An adaptive three-fingered prismatic gripper with passive rotational joints. *IEEE Robot. Autom. Lett.* **2016**, *1*, 668–675. https://doi.org/10.1109/LRA.2016.2516506.
39. Koustoumpardis, P.N.; Nastos, K.X.; Aspragathos, N.A. Underactuated 3-finger robotic gripper for grasping fabrics. In Proceedings of the 2014 23rd International Conference on Robotics in Alpe-Adria-Danube Region (RAAD), Smolenice, Slovakia, 3–5 September 2014; IEEE: New York, NY, USA, 2014; pp. 1–8. https://doi.org/10.1109/RAAD.2014.7002271.
40. Widhiada, W.; Nindhia TG, T.; Budiarsa, N. Robust control for the motion five fingered robot gripper. *Int. J. Mech. Eng. Robot. Res.* **2015**, *4*, 226.
41. Sadeghian, R.; Sedigh, P.; Azizinezhad, P.; Shahin, S.; Masouleh, M.T. Design, development and control of a three flexible-fingers gripper based on hand gesture. In Proceedings of the 2018 6th RSI International Conference on Robotics and Mechatronics (IcRoM), Tehran, Iran, 23–25 October 2018; IEEE: New York, NY, USA, 2018; pp. 359–363. https://doi.org/10.1109/ICRoM.2018.8657517.
42. Koenig, N.; Howard, A. Design and use paradigms for gazebo, an open-source multirobot simulator. In Proceedings of the 2004 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) (IEEE Cat. No. 04CH37566), Sendai, Japan, 28 September–2 October 2004; IEEE: New York, NY, USA, 2004; Volume 3, pp. 2149–2154. https://doi.org/10.1109/IROS.2004.1389727.
43. Mingo Hoffman, E.; Traversaro, S.; Rocchi, A.; Ferrati, M.; Settimi, A.; Romano, F.; Natale, L.; Bicchi, A.; Nori, F.; Tsagarakis, N.G. Yarp based plugins for gazebo simulator. In *Modelling and Simulation for Autonomous Systems: First International Workshop, MESAS 2014, Rome, Italy, 5–6 May 2014*; Revised Selected Papers 1; Springer International Publishing: Cham, Switzerland, 2014; pp. 333–346. https://doi.org/10.1007/978-3-319-13823-7_29.
44. Chikurtev, D. Mobile robot simulation and navigation in ROS and gazebo. In Proceedings of the 2020 International Conference Automatics and Informatics (ICAI), Varna, Bulgaria, 1–3 October 2020; IEEE: New York, NY, USA, 2020; pp. 1–6. https://doi.org/10.1109/ICAI50593.2020.9311330.
45. Uslu, E.; Cakmak, F.; Altuntaş, N; Marangoz, S.; Amasyalı, M.F.; Yavuz, S. An architecture for multi-robot localization and mapping in the Gazebo/Robot Operating System simulation environment. *Simulation* **2017**, *93*, 771–780. https://doi.org/10.1177/0037549717710098.

46. Bingham, B.; Aguero, C.; McCarrin, M.; Klamo, J.; Malia, J.; Allen, K.; Lum, T.; Rawson, M.; Waqar, R. Toward maritime robotic simulation in gazebo. In Proceedings of the OCEANS 2019 MTS/IEEE SEATTLE, Seattle, WA, USA, 27–31 October 2019; IEEE: New York, NY, USA, 2019; pp. 1–10. https://doi.org/10.23919/OCEANS40490.2019.8962724.
47. Nogueira, L. Comparative analysis between gazebo and v-rep robotic simulators. *Semin. Interno Cognicao Artif.-SICA* **2014**, *2*, 1–5.
48. Farley, A.; Wang, J.; Marshall, J.A. How to pick a mobile robot simulator: A quantitative comparison of CoppeliaSim, Gazebo, MORSE and Webots with a focus on accuracy of motion. *Simul. Model. Pract. Theory* **2022**, *120*, 102629. https://doi.org/10.1016/j.simpat.2022.102629.
49. Hawkes, E.W.; Christensen, D.L.; Eason, E.V.; Estrada, M.A.; Heverly, M.; Hilgemann, E.; Jiang, H.; Pope, M.T.; Parness, A.; Cutkosky, M.R. Dynamic surface grasping with directional adhesion. In Proceedings of the 2013 IEEE/RSJ International Conference on Intelligent Robots and Systems, Tokyo, Japan, 3–7 November 2013; IEEE: New York, NY, USA, 2013; pp. 5487–5493. https://doi.org/10.1109/IROS.2013.6697151.
50. Park, W.; Seo, S.; Bae, J. Development of a sensorized hybrid gripper to evaluate grasping quality. In Proceedings of the 2019 2nd IEEE International Conference on Soft Robotics (RoboSoft), Seoul, Republic of Korea, 14–18 April 2019; IEEE: New York, NY, USA, 2019; pp. 149–154. https://doi.org/10.1109/ROBOSOFT.2019.8722753.
51. Royo-Miquel, J.; Hamaya, M.; Beltran-Hernandez, C.C.; Tanaka, K. Learning Robotic Assembly by Leveraging Physical Softness and Tactile Sensing. In Proceedings of the 2023 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Detroit, MI, USA, 1–5 October 2023; IEEE: New York, NY, USA, 2023; pp. 6469–6476. https://doi.org/10.1109/IROS55552.2023.10341471.
52. Ruotolo, W.; Brouwer, D.; Cutkosky, M.R. From grasping to manipulation with gecko-inspired adhesives on a multifinger gripper. *Sci. Robot.* **2021**, *6*, eabi9773. https://doi.org/10.1126/scirobotics.a.
53. Han, A.K.; Hajj-Ahmad, A.; Cutkosky, M.R. Bimanual handling of deformable objects with hybrid adhesion. *IEEE Robot. Autom. Lett.* **2022**, *7*, 5497–5503. https://doi.org/10.1109/LRA.2022.3158231. Tao, L.Q.; Zhang, K.N.; Tian, H.; Liu, Y.; Wang, D.Y.; Chen, Y.Q.; Yang, Y.; Ren, T.L. Graphene-paper pressure sensor for detecting human motions. *ACS Nano* **2017**, *11*, 8790–8795.
54. Ruth SR, A.; Feig, V.R.; Tran, H.; Bao, Z. Micro engineering pressure sensor active layers for improved performance. *Adv. Funct. Mater.* **2020**, *30*, 2003491.