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Analysis of Grasping Force of Irregular Shapes Objects for Low-Cost 3D-Printed Prosthetic Robotic Arm

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Abstract: *Additive manufacturing, particularly 3D printing, and computer-aided design (CAD) have been instrumental in recent advances in prostheses. This work focuses on using 3D printing to make personalized prosthetic limbs, especially for pediatric applications. Although the future looks bright, a lack of clinical proof and technical details prevents wider use. This study examines user input, 3D printing procedures, and design complexity, emphasising both durability issues and useful advantages. Using bio-inspired design in 3D-printed upper-limb prosthetics, particularly hand prostheses, is a major area of focus. An innovative prosthetic hand with movable fingers was created by imitating the structure of human fingers. These prototypes demonstrated enhanced grasp adaptability and produced superior pinch force, providing reasonably priced and lightweight alternatives. In this study, three irregular-shaped objects have been tested to measure the grasping force, with the properties of each object being detailed, including several fingers used to grasp the irregular objects. The study concluded that the average total grasping force required to grasp irregular objects for 54 g of puzzle pieces is 0.514 N, for 107 g of books is 0.726 N and 3 g of balls is 0.694 N are the outcomes of the grasping.*

Keywords: 3D printing, children's prosthetic hands, grasping irregular shapes.

1. INTRODUCTION

This study focuses on the creation and assessment of a children-specific functioning 1 Degree of Freedom (DOF) 3D-printed prosthetic hand. For people with upper limb problems, prosthetic hands are essential for aiding daily activities [1]. However, a lot of current prosthetic hands are unable to change grasping force independently of visual input. This research addresses three primary objectives. It aims to create a functional prosthetic hand tailored for pediatric users. The development of computer-aided design (CAD) software and additive manufacturing, especially 3D printing, has fuelled recent advances in prostheses. The exciting possibility of creating customised upper limb prostheses for a fraction of traditional expenses is made possible by this technique. This study aims to overcome the deficiency of clinical evidence and technological details that are impeding the broad adoption of 3D-printed prosthetics. It thoroughly investigates design nuances, 3D printing procedures, and adherence to FDA recommendations with a focus on pediatric instances. Three studies provide complex perspectives on efficacy and practicality, highlighting possible advantages in addition to durability concerns that a significant portion of participants reported [2, 3]. 3D printing has become widely used in the field of upper limb prostheses; yet, few designs are bio-inspired, frequently ignoring important anatomical details, and the devices must be affordable, lightweight, and assembly-free options for areas where prosthetic resources are scarce [4, 5]. The effectiveness of 3D printing hand prostheses with affordable fused deposition modelling (FDM) equipment is investigated in this work. The research produces 2.3 mm-thick sheets by optimising settings for laser-cutting poly-lactic acid (PLA) strips. Analysing mechanical characteristics, the research shows that non-assembly 3D-printed prostheses with various grasping methods are feasible, providing a cheap and accessible option for people living in less developed areas. [6, 7]. After a thorough analysis of online databases and scientific literature, six studies and twenty-five 3D-printed upper limb prosthetic prototypes were found. Although functional tasks demonstrate potential, more research is necessary because technological specifications are not systematically reported. Standardised criteria and rigorous validation are necessary for therapeutic efficacy and teamwork [8]. For those living in areas with limited resources or access to healthcare, 3D printing presents a viable, cost-effective, and easily obtainable option for creating personalised prostheses [9].

2. SENSOR PLACEMENT

Leave one extra blank line between sections and continue as shown. For the Table contents, Table and Figure captions, use Times Roman 10 as shown below. Due to financial, spatial, and power limitations, research by [10] discusses the difficulties in reducing the number of sensors on 3D-printed prostheses. Through testing a commonly available 3D-printed prosthetic hand, the research pinpoints areas of high contact with items. The research provides useful insights for intelligent prosthetic functions under resource restrictions by using image processing and ten experiments to provide design criteria for ideal sensor sites. Additionally, a study by [11] presents a closed-loop force control system for a soft robotic prosthetic hand, utilising an affordable force-sensing method without the need for finger-implanting sensors. The actuator's housing contains an aluminium test specimen that is precisely positioned by the system to provide the best force measurement. Trials exhibit the accuracy (±2%) of the suggested system, highlighting its noteworthy contribution by removing the difficulties related to conventional fingertip-embedded sensors, guaranteeing monolithic integrity, and reducing expenses. To guarantee a solid grasp, the work by [12] addresses techniques for identifying item slides in a prosthetic hand. To detect slides, surface vibrations, as well as variations in the tangential and normal forces between the item and the digits, are analysed. The Southampton tube sensor's performance on varied surfaces is assessed in this study, which concentrates on the force and acoustic sensors in the Southampton Hand versions. These techniques can be used in the field regularly due to their low-frequency signals and efficient processing. However, the difficulty of placing sensors in the context of soft robotic hands with dexterity highlights the shortcomings of traditional frameworks for structures that are pliable. The suggested three-step architecture uses readily available sensors for simple reconfiguration and is adjustable to different hand designs. While contact point sensors are ideal for forecasting qualitative success, off-the-shelf sensors at these places may perform less well in estimating quantitative manipulation measures because of disturbance factors, according to real-world studies on a soft robotic hand [13].

3. GRASPING MECHANISM

When grabbing things, various forces are applied, and those forces are acknowledged in addition to the force recorded by the FSR sensor during this experiment [14]. As the objects' contact points span the entire surface of the finger, every contact point in this experiment has a force acting in the direction of the finger's surface [15]. However, because the FSR sensor is only placed on the prosthetic hand's fingertip, the force acting on the remaining portion of the finger is not measured. In certain tests, the object being gripped may roll a little because the grabbing force may alter the object's starting position that requires clutching, and the FSR sensor's contact may increase or decrease, resulting in variations in the reading [16]. The role of the object is influenced by the non-static geometric movement of the prosthetic hand's fingers, palm, and joints [17]. The work of [18] emphasises how crucial it is to accurately calculate the proper gripping force required to manage shaped objects. They created a brand-new technique that uses a force-sensitive resistor (FSR) sensor to gauge a robotic hand's grasping force. A robotic hand's fingertips were equipped with an FSR sensor, and the sensor's resistance change was used to determine the grasping force. This technique offered a simple and affordable way to calculate the grabbing force. Although the study produced some interesting results, it did not provide a standard approach to using tactile feedback to determine the grasping force, indicating a need for more research. By concentrating on the function of tactile feedback in establishing the grasping force, a different strategy was utilised. They created a tactile sensor with the ability to gauge an object's torque and force. The sensor was built inside a robotic hand, and real-time adjustments to the hand's grasping force were made using the sensor's data. The study highlighted how crucial tactile feedback is for object manipulation. However, the study did not suggest a common method for calculating the grasping force using tactile feedback, suggesting a possible area for further research [19, 20, 21].

4. RESULTS

4.1 Experiment 1

Fig. 1 below shows the grasping experiment for the puzzle piece.

Fig. 1. Puzzle Piece grasping

Table 1. Properties of puzzle piece data

Properties	Details
Type of object	Puzzle Piece
Type of grasping	Palmar Pinch (thumb & index) fingers only
Mass of object (g)	54
Weight of object (N)	0.5297
Servo motor angle (˚)	120˚

Table 2. Experiment data table of puzzle piece

Sets	The highest peak force of fingers in contact with the object (N)		Total measured grasping force of FSR, F_t (N)
	Thumb	Index	
1	0.566	0.385	0.952
2	0.337	0.333	0.669
3	0.302	0.281	0.583
4	0.247	0.294	0.542
5	0.185	0.253	0.438
6	0.193	0.289	0.482
7	0.239	0.325	0.563
8	0.218	0.031	0.249
9	0.118	0.235	0.353
10	0.100	0.211	0.312
Average	0.251	0.264	0.514
SD	0.133	0.096	0.202

Table 1 describes the properties of the puzzle piece. Table 2 shows the grasping force data measured from the experiment of grasping a 54 g Puzzle Piece. Results from the table were then plotted into the graph, as shown in **Error! Reference source not found.**. **Error! Reference source not found.**2 shows the graph of measured FSR force readings respectively to the number of repetition experiment sets. The graph indicates the average grasping force of the thumb and index finger with 0.251 N and 0.264 N, while the standard deviation (SD) is 0.133 and 0.096, respectively.

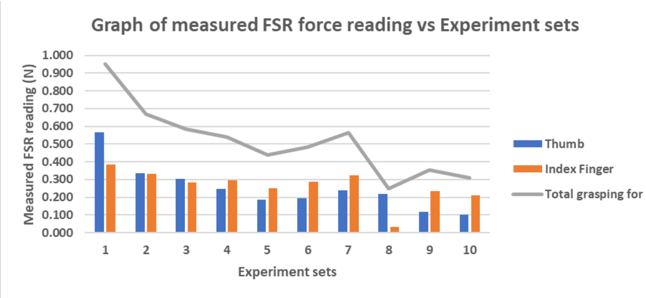

Fig. 2. Graph of puzzle piece grasping force versus experiment sets.

Table 3. Table of mini-book data

Properties	Details
Type of object	Mini Book
Type of grasping	tripod pinch (thumb, index & middle) fingers only
Mass of object (g)	107
Weight of object (N)	1.0497
Servo motor angle (˚)	117˚

4.2 Experiment 2

Fig.3 below shows the grasping experiment for the mini book.

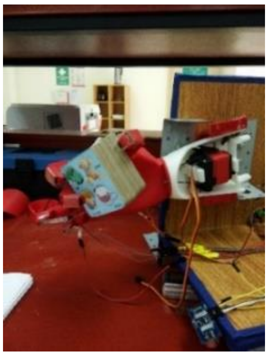

Fig. 3. Mini Book

Table 4. Experiment data of the mini book.table of mini-book data

Sets	The highest peak force of fingers in contact with the object (N)			Total measured grasping force of FSR, F_t (N)
	Thumb	***Index***	***Middle***	
1	0.145	0.620	0.564	1.328
2	0.157	0.319	0.406	0.882
3	0.034	0.068	0.210	0.312
4	0.051	0.092	0.142	0.284
5	0.054	0.060	0.179	0.293
6	0.071	0.108	0.387	0.566
7	0.050	0.009	0.379	0.438
8	0.015	0.042	0.464	0.521
9	0.163	0.415	0.871	1.449
10	0.124	0.509	0.556	1.189
Average	0.086	0.224	0.416	0.726
SD	0.055	0.222	0.218	0.451

Table 3 describes the properties of the mini-book. Table 4 shows the grasping force data measured from the experiment of grasping a 107 g mini book. Results from the table were then plotted into the graph, as shown in Fig.4. Fig.4 shows the graph of FSR force reading respectively to the number of repetition experiment sets. The graph indicates the average grasping force of the thumb, index finger, and middle finger of 0.086 N, 0.224 N and 0.416 N while the standard deviation (SD) is 0.055, 0.222 and 0.218, respectively.

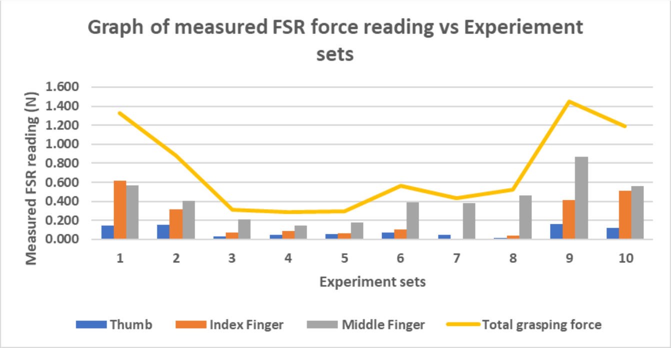

Fig. 4. Graph of mini book grasping force versus experiment sets.

4.3 Experiment 3

Fig. 5 below shows the grasping experiment for a plastic ball.

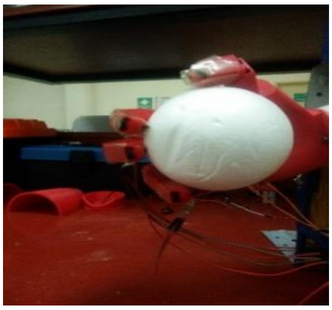

Fig. 5. Plastic Ball

Table 5. Table of plastic ball data.

Properties	Details
Type of object	Plastic ball
Type of grasping	tripod pinch (thumb, index, middle & ring) fingers only
Mass of object (g)	3
Weight of object (N)	0.0294
Servo motor angle (˚)	121˚

Table 6. Experimental data of the plastic ball

Sets	**The highest peak force of fingers in contact with the object (N)**				**Total measured grasping force of FSR, F_t (N)**
	Thumb	***Index***	***Middle***	***Ring***	
1	0.148	0.068	0.193	0.464	0.873
2	0.149	0.049	0.112	0.442	0.751
3	0.177	0.042	0.064	0.628	0.911
4	0.074	0.070	0.116	0.469	0.728
5	0.029	0.040	0.165	0.469	0.702
6	0.011	0.047	0.113	0.114	0.285
7	0.026	0.006	0.215	0.476	0.723
8	0.016	0.017	0.122	0.389	0.545
9	0.034	0.005	0.157	0.460	0.655
10	0.031	0.014	0.210	0.516	0.771
Average	0.069	0.036	0.147	0.443	0.694
SD	0.0637	0.0241	0.0493	0.1308	0.1769

Table 5 describes the properties of the plastic ball. Table 6 shows the grasping force data measured from the experiment of grasping of 3 g plastic ball. Results from the table were then plotted into the graph, as shown in Fig.6. **Error! Reference source not found.** shows the graph of FSR force reading respectively to the number of repetition experiment sets. The graph indicates the average grasping force of the thumb, index finger, middle finger and ring finger of 0.069 N, 0.036 N, 0.147 N and 0.694 N while the standard deviation (SD) is 0.0637, 0.0241, 0.0493 and 0.1308, respectively.

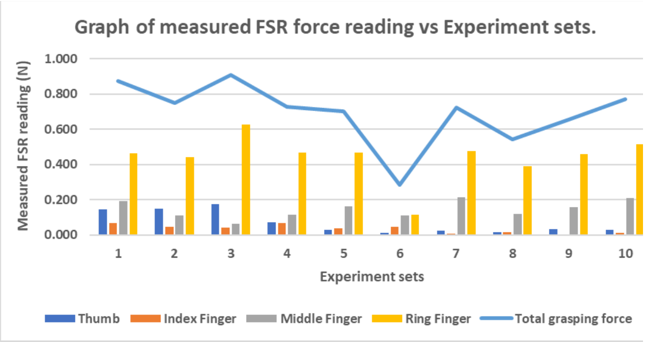

Fig. 6. Graph of plastic ball grasping force versus experiment sets.

A 54 g puzzle piece, a 107 g mini book, and a 3 g plastic ball were the three different objects used in the experiment to measure gripping forces. With standard deviations of 0.133 and 0.096, respectively, the average grabbing force for the 54 g puzzle piece was 0.251 N for the thumb and 0.264 N for the index finger (Figure 4.19). The average stresses on the thumb, index finger, and middle finger of the 107 g mini book were 0.086 N, 0.224 N, and 0.416 N, respectively, with standard deviations of 0.055, 0.222, and 0.218 (Figure 4.21). The average forces applied to the thumb, index finger, middle finger, and ring finger for the 3 g plastic ball were 0.069 N, 0.036 N, 0.147 N, and 0.694 N, respectively, with standard deviations of 0.0637, 0.0241, 0.0493, and 0.1308.

5. DICUSSION

These data showed that the plastic ball had a significant variation in the force produced by various fingers, suggesting that the grabbing force varied based on object weight and shape. These statistics provide useful information for manual dexterity-demanding applications like robotics and ergonomic tool design. The shape of an object has a big impact on how much force is needed to manipulate it. Owing to their uneven weight distribution and possible points of contact, things with irregular shapes usually require more effort to move. Variations in leverage and torque are the result of irregular geometries' uneven mass distribution. The measured force is different from one shape to another because the grasped object may roll a little as the grasping force may change the initial position of the object placed that needs to be grasped during the experiment carried out, and the contact on the FSR sensor reduces or increases, which causes differences in the reading. The geometry of the prosthetic hand's palm, finger, and joint movement, as they are not static, contributes to the role of the object. As a result, more power may be needed to get such objects moving in the first place, maintain them, or alter their direction. To produce force, using different grasping techniques is also crucial. Power grasps, which make complete contact with the object, often permit the application of greater force than precision grasps, which have fewer contact points.

6. ACKNOWLEDGEMENT

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