Optimising Soft Fin Ray Robotic Fingers using Finite Element Analysis to Reduce Object Slippage

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***Abstract*—This research aims to optimise soft fin ray robotic fingers by finding relationships between design parameters and the performance of the fingers using simulation and eventually experimental validation. The design parameters that were chosen to optimise were the rib angle increments of the fingers. This was done by simulating an object being displaced in the x-direction moving into the finger to simulate gripping, then being displaced in the y-direction out of the gripper to simulate slipping. To measure the gripping performance of the fingers, the deformation of the fingertip, as well as force reaction of the finger were recorded. This paper includes initial results from the conducted simulations.**

Keywords— soft robotics, optimisation, simulation, FEA

I. Introduction

This project involves the optimisation of a soft Fin Ray robotic fingers using Finite Element Analysis and experimental validation. The Fin Ray Effect® is based on the deflection of fish fin ribs that allows them to conform to different shapes [1]. Designing robotic fingers based on the Fin Ray effect enables passive adaptation to the shape of a grasped object which increases the contact area for a more stable grasp [2]. Creating Fin Ray fingers from soft materials enables the picking of delicate objects that are could otherwise be damaged by rigid fingers [3]. This has many applications especially in the agriculture/food industry which involves moving or harvesting delicate produce with varying delicacy and shapes. The fingers need to be able to adapt to the shape of the target object while applying the minimal amount of force that is necessary so as not to damage the object. They also need to be able to exert larger forces for denser targets or for harvesting tasks. This is where the concept of layer jamming, which is the friction between deforming ribs, is used to create variable stiffness in the soft material fingers [3]. For this reason, the aim is to optimise for both shape adaptation and force generation while still allowing minimal contact forces for delicate objects by changing key design parameters of the fingers.

II. Literature review

A. *Soft Robotic Grippers*

Soft robotic grippers have many advantages over rigid-body robotic grippers, one such advantage is their ability to handle delicate objects without damaging them. Soft grippers are usually constructed of flexible materials that allow them to conform to many different shapes in different circumstances. With more demand to automate agricultural and industrial processes there is a need for manipulators that are adaptable and can safely handle delicate objects, soft robotic grippers are capable of filling these roles [4].

B. *Hyperelastic Materials and Mathematical Models*

Modelling of the materials used for soft robotic grippers is very important as it allows researchers to quickly and efficiently test changes to the geometry or parameters of the grippers without having to produce a physical copy and test it experimentally. This research uses Ninjaflex which is "a thermoplastic polyurethane" [5]. It is a material used in FDM (Fused Deposition Modelling) 3D printers, and is a good candidate to create soft grippers due to its material properties that offer flexibility and strength.

Previous work showed that only two pairs of parameters are needed to render the measured experimental data in a proper way [5] using the Ogden's material model. The values that were found were then applied to a simulation software and the results that were produced were consistent with the experimental data [5]. This was the model used for the simulations in this research.

C. *Fin Ray Robotic Fingers*

The Fin Ray effect works well for passive grippers, these only require power to open and close and not to sustain grip on an object. Previous research has shown that these fingers are well suited to picking up "convex and/or light" objects [6], however, struggled with thin, heavy objects. It has also been shown that a gripper using fin ray fingers was much more effective at holding objects when it was orientated perpendicular to the ground rather than parallel two it, being able to hold double the weight. Changing the geometry of the fingers, such as the angle and position of the ribs, effects the force generation and shape adaptation of the finger. Previous research has shown that when these ribs are orientated in specific ways friction between the ribs can occur causing an increase to the stiffness of the finger and in turn increases the force generation of the finger [7]. This is called the layer jamming effect and presents opportunities for fin ray fingers to be able to have variable force generation depending on the amount of layer jamming occurring in the finger [7]. Further work was done looking at using a fixed increment when increasing rib angle as well [8].

The contribution of this research is to explore the effect of rib angle increment variation on force generation and tip displacement of the finger. A particular interest here is to evaluate how the angle increments affect the slippage of a grasped object out of the fingers.

III. FEA SIMULATION

The initial stage of this research required many simulations to be run to attempt to find the most important design features that have the largest impact on the targeted performance characteristics, those being shape adaptation and force generation. The incremental changes in rib angle were one of these such design features found to influence the performance of the finger. A twelve ribbed finger had been used for previous research with a fixed angle increment. It was not possible to optimise for the twelve rib angles simultaneously this finger due a limitation of ANSYS software in relation to the number of input parameters. Therefore, the geometry was reduced to only eight ribs to simplify the optimisation process. The original increment of 3 degrees between each rib gap was used as the initial angle and a boundary of three degrees was applied for each rib angle to attempt to optimise the finger. The simulation involves a circular object being displaced in the x-axis into the centre of the finger (stage 1), then being displaced in the y-axis up out of the finger (stage 2). This was intended to simulate the finger grasping an object then having the object slipping out from the finger.

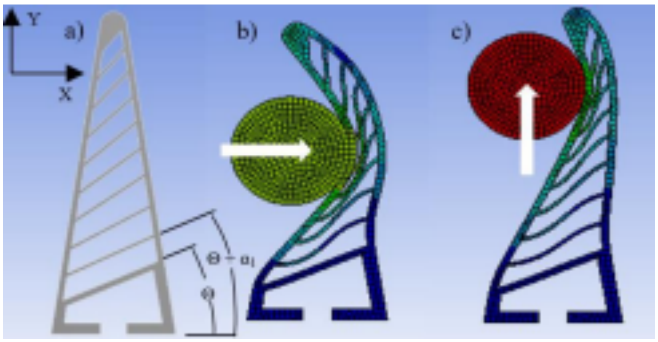

Figure 1: Shows (a) before deformation with labelled design parameters tabulated below (b) Stage 1 in the x-direction and (c) Stage 2 in the y-direction.

Table 1: This shows the optimised increment between each of the ribs

	Alpha 1	Alpha 2	Alpha 3	Alpha 4	Alpha 5	Alpha 6	Alpha 7
Angle Increment (degrees)	3.33	5.39	3.02	2.99	2.53	3.43	2.95

The new angle increments found by the optimisation can be found in Table 1. They didn't follow a regular progression, but rather tended to remain around 3° ±0.5°. There was an exception as the increment between ribs 2 and 3 was over 1.5 times larger than any of the other increments. This may be due to the contact of the object with the finger, but further research is needed to determine the true cause of this.

IV. RESULTS AND DISCUSSION

The maximum force reactions in the x and y-axis were measured during both stages of the simulations so that there could be a comparison made between the original design and the optimised design to highlight improvements. Table 2 shows the results of the two simulations during the first stage and the percentage difference between the values found. Table 3 shows the same during the second stage.

Table 2: Simulation results for object displacement in the x-axis

	Deformation of Tip Y-axis (mm)	Deformation of Tip X-axis (mm)	Maximum Force Reaction X-axis (N)	Maximum Force Reaction Y-axis (N)
Optimised	-7.9272	-3.1923	2.8885	-0.1714
Percentage Difference	4%	22%	11%	-2%

Table 3: Simulation results for object displacement in the y-axis

	Deformation of Tip Y-axis (mm)	Deformation of Tip X-axis (mm)	Maximum Force Reaction X-axis (N)	Maximum Force Reaction Y-axis (N)
Optimised	-0.0063581	-0.0009634	2.4732	0.35513
Percentage Difference	2%	52%	13%	4%

These results show that changing the rib angles can have a large effect on the performance of the fin ray finger. Every aspect of the finger performance was improved by the optimisation except for the force reaction in the y-direction during the first stage of the simulation. An increase of 22% in the directional deformation of the tip of the finger in the x-axis during the first stage shows a large improvement in the fingers ability to grasp an object more securely and reduce the likelihood of the object slipping. There were also improvements in the force reaction on the object in the x-axis during both stages of the simulation showing a potentially firmer gripping finger. Finally, there was an increase of 4% in the force reaction in the y-axis during stage 2 of the simulation. This suggests the finger would be less susceptible to having the object slip out of its grasp.

V. CONCLUSIONS AND FUTURE WORK

The optimised geometry of the finger was shown to improve shape adaptation as well as produce small improvements in the force applied in the y-axis during the simulation of object slippage. Possible future work that could be done on this subject is researching the effects of using variable spacing between the ribs to continue to maximise the force generation and shape adaptation of the fingers.

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