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RECONFIGURABLE GRIPPER DESIGN: AN ORIGAMI SOLUTION FOR THE PICK AND PLACE OF COMPOSITE TEXTILES

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ABSTRACT

Presently, manual operations are required for material handling of flexible components such as woven textiles. The flexible nature of these fabrics allows them to bend and conform to varying curvatures (i.e., mould surfaces). This compliance coupled with a fabric's surface texture and variability in geometry, creates automation challenges related to reliable handling. To support automation efforts of flexible composite materials, pick and place operations that combine strategic flexibility for these textiles needs to be developed, which is the goal of this research. A reconfigurable, self- collapsing origami gripper for textile pick and place on non-planar mould surfaces is demonstrated in this paper. Variations in gripper size and shape are explored for lightweight flexible materials. Material extrusion based additive manufacturing is employed to build and test gripper iterations. These promising results indicate that research should continue related to origami-based automation solutions.

1 INTRODUCTION

Polymer composites are lightweight materials that offer superior stiffness and strength. However, currently there are no comprehensive, efficient, rapid, semi-automatic or automatic solutions for handling limp composite textiles (or other similar materials). Manual operations (layups) are required for material handling of flexible components such as fabrics and woven textiles. This manufacturing strategy is labour intensive, present safety issues and create process bottlenecks [1] [2]. Draping, a manual technique for positioning textile patterns onto a mold for composite manufacturing, depends on fabric properties like in-plane shear, bending stiffness, and structural stability, as well as the mold's geometric features [3] [4]. Fabrics made from heavy, coarse yarns with dense construction drape poorly, while those with long floats and made from filament yarns with little twist drape better. The flexible nature of these textiles allows them to bend and conform to varying curvatures (i.e., mould surfaces). This compliance coupled with a fabric's surface texture, construction, and variability in geometry (i.e., shape, size, presence of cut-outs and slits), creates automation challenges related to reliable handling without inherent damage to the material. Unfortunately, the significant mass reduction potential associated with polymer composite fiber based components is offset by high labor intensity and the associated long 'pick and place (draping)' cycle times. These repetitive handling tasks often involve awkward postures, leading to work-related musculoskeletal disorders, resulting in increased absences, productivity loss, and higher healthcare expenses [5]. Automation should be employed then the tasks are repetitive, risky, and remote. Consequently, we need to transform the flexible materials into a rigid structure without introducing damage. The pick and place activity can be divided into three stages: pick→transfer→place. A solution needs to be developed that 'grips' the fabrics for the picking element, provides compliance to adapt to a mould's surfaces for the placing element, and is rigid during the transfer. The goal of this research is to develop a reconfigurable, self- collapsing origami gripper for textile pick and place onto non-planar mould surfaces. For the proof of concept, material extrusion based additive manufacturing (AM) strategies are leveraged to build and test gripper iterations. In the next section, material handling approaches and the Miura fold origami are discussed.

2 LITERATURE REVIEW

2.1 Material Handling Solutions for Flexible Fabrics

To handle non-rigid parts, principles such as force closure, form closure, and material bonding are employed. Techniques include mechanical grasping, ingressive grasping (like needle grippers and Velcro systems), and adhesion grasping (using suction cups, electromagnetic or electrostatic forces, air jets, or cryogenic principles). Each technique has specific advantages and limitations depending on the material and shape of the object [6]. Soft robots, with pliable bodies that mimic biological systems, provide deformable structures and muscle-like actuation for enhanced flexibility. They are particularly effective in handling fragile or deformable objects [7-10]. Grippers made from flexible materials conform to object contours, ensuring safe and efficient handling. These grippers securely hold complex geometries, uneven surfaces, and different sizes, minimizing the risk of damage. New grippers like the sensor based Coanda gripper with a vacuum system [11]. Hybrid approaches, such as finger-tipped grippers combining grasping and clamping, are also used. However, vacuum systems are not comprehensive or cost-effective due to high power consumption and difficulty in securely grasping specific layers. Existing conventional handling methods encounter diverse challenges, ranging from fabric damage, high costs, and excessive energy consumption to inflexibility and complexity. Furthermore, soft robotics solutions documented in the literature primarily rely on either tendon-driven or pneumatic mechanisms, showcasing limitations in adaptability and controllability during operation. Therefore, another approach is required.

2.2 Miura-fold Origami

The Miura-Ori, also known as the Miura map-fold, is a traditional origami fold based on a tessellation of slanted parallelograms. It is used to fold large flat geometries into smaller surface-areas and can be refolded and returned to its collapsed shape [12][13]. It can thus be described as "shape-memory" origami [13]. The kinematics are characterized as "in-plane" and "out-of-plane", where the geometry has motion following the folds of the origami, and motion via twisting and bending, respectively [14]. The Miura-Ori can create a structure that can collapse and conform to different curvatures [15]. The folding nature of the Miura-Ori is influenced by its geometry, meaning the number of parallelograms, the distance between each of them, and the thickness of the fold. Preliminary research has been performed that illustrated the potential of this solution [16]; however, this research focused on developing small compliant grippers. The concepts must be scaled up to determine the feasibility for larger and more complex fabric shapes.

3 MATERIALS AND METHODOLOGY

A four step experimental methodology was taken for this research: (i) a complex W shape, with an internal slit was chosen as the test sample, (ii) a non-flat mould surface was designed, (iii) a tessellation pattern was determined [15, 16], and (iv) the compliant gripper was fabricated and tested (Figure 2). To simulate the process of picking and placing a sheet of fabric, a non-flat mould surface was designed (Figure 1(a)). A slight curvature was used to simplify the tessellation complexity of the gripper. As observed in previous work, larger parallelogram panels are better for adapting to gradual "S" shape curvature, and smaller panels follow tighter curvature with less surface discontinuity [Dora SAE]. A "W" fabric geometry was chosen for testing, including an internal slit (Fig. 1b). This experimental configuration was designed to represent the complexities of textiles being handled in industry as the fabric features slits and irregular boundaries, and the mould is curved. The gripper was designed to be built with 2 materials, Polylactic acid (PLA) and X-920 filament from Sakata 3D. The PLA is a rigid material used for the parallelogram panels, and the X-920 (Shore A89) is used for the flexible joints. Due to the 3D printer build plate space constraints, several gripper sub-modules needed to be assembled to fabricate gripper 'I' (Table 1). To quantify the gripper characteristics, compression data was collected for the grippers as summarized in Table 1. The open (Fig 1(c)) and closed diagonal distances (Fig 1(d)) are collected. The closed distance was achieved by forcing the gripper into its collapsed state using a table vice. Equation 1 was used to calculate the compression ratio. This data lends itself useful when designing the constraints of a collapsing frame to hold the gripper. This frame can then be used to automate the gripper, applying even force when picking a textile (Figure 3). Manual pick and place tests were performed as shown in Figure 2.

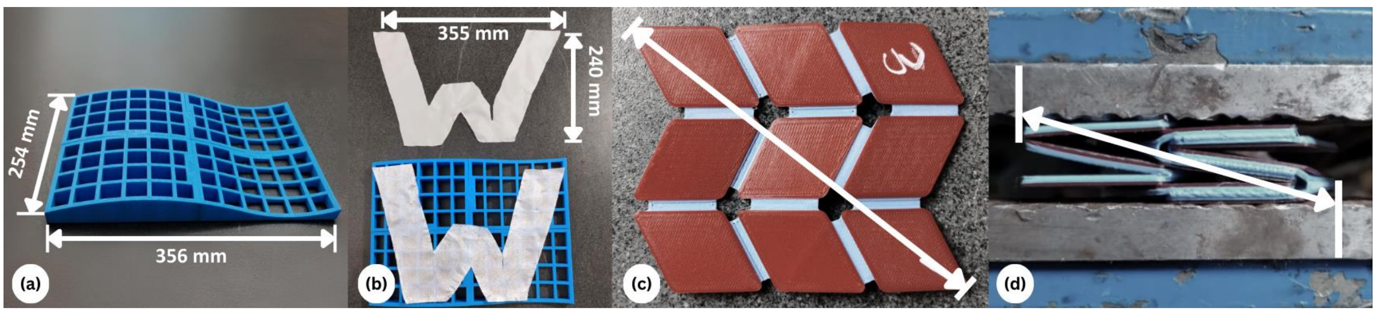


Figure 1. (a) the mould, (b) the W shape, (c) open gripper distance and (d) compressed/closed gripper distance.

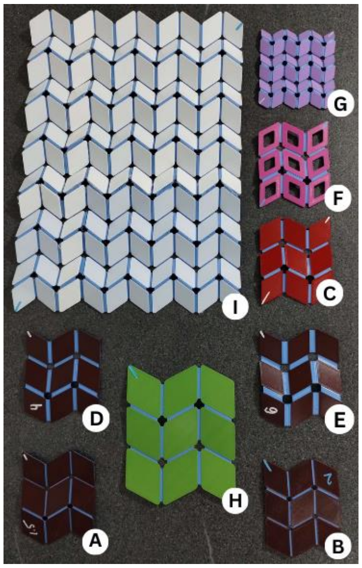
$$Compression\ Ratio = \frac{Open\ distance - Closed\ distance}{Open\ distance} \quad (1)$$

4 RESULTS AND DISCUSSION

Results of the collected compression data are shown in Table 1. Both 'C' and 'F' have the same gap distances, number of and size of panels, meaning results should be identical. The closed distance and compression ratio for grippers 'C' and 'F' show the data collection method to be repeatable as both show identical results. Interestingly, the compression ratio for all tested grippers was found to be between 0.44 and 0.46, except for gripper 'I' which is 0.49. This observed variation is believed to be attributed to gripper 'I' being a large tessellation made up of subsequent smaller prints that needed to be joined together, instead of being a homogenous print such as 'A' through 'H'.

Figure 2 shows the manual pick and place of the "W" fabric sample using the large tessellation gripper 'I' onto the non-planar mould surface. The fabric sample can be seen gripped by the Miura-Ori fold in Figure 2(b). It successfully picks the silk-like sample considering its irregular boundary geometry and the internal slit. Due to space constraints, results from handling one fabric are shown. With the gripper fully compressed, this is now essentially a rigid body, allowing the rapid transfer of this fabric sample from one location to another, without slippage. As seen in Figure 2(d), the gripper can unfold and conform to the mould surface. Wrinkles occurred, but a pneumatic bladder can be employed to press the gripper onto the surface, minimizing the wrinkles. This solution has been successfully applied to composite carbon fiber [15]. This proof of concept can be readily automated and is scalable.

Table 1. Compression data of select Miura-Ori gripper samples (A-H) and prototype large tessellation (I), each gripper having a thickness of 1.5 mm.



	Gap Distance (mm)	# of panels	Size of panels (mm)	Open distance (mm)	Closed distance (mm)	Compression Ratio
A	1.5	9.0	25.0	111.20	61.70	0.45
B	2.0	9.0	25.0	112.00	62.20	0.44
C	3.0	9.0	25.0	115.00	63.30	0.45
D	4.0	9.0	25.0	117.50	64.10	0.45
E	6.0	9.0	25.0	123.00	66.80	0.46
F	3.0	9.0	25.0	115.00	63.30	0.45
G	3.0	36.0	12.5	120.20	65.60	0.45
H	3.0	9.0	35.0	166.70	89.60	0.46
I	3.0	130.0	25.0	438.15	225.43	0.49

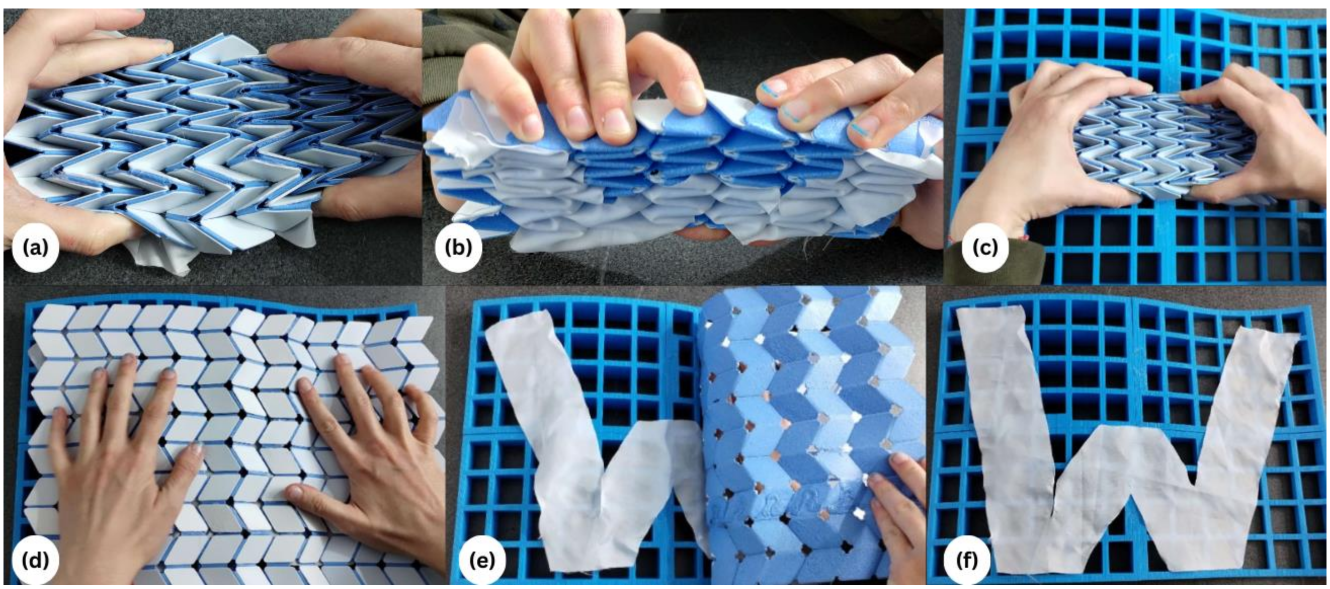


Figure 2. Manual pick and place testing including (a) pick, (b)(c) transfer, and (d)(e)(f) place.

With the appropriate frame, this solution can be automated. A mounting frame was initially built with 3D printing including the moving hinges or sliding mechanism. However, the PLA-to-PLA friction coefficient was too high for the moving parts. This design will be modified such that those contacts are replaced with circular linear bearings and a stainless-steel rod. The linear ball bearing is an LM5UU from Uxcell which uses a 5mm diameter rod. As this gripper system is to be mounted onto a robot, minimizing the weight is a design constraint.

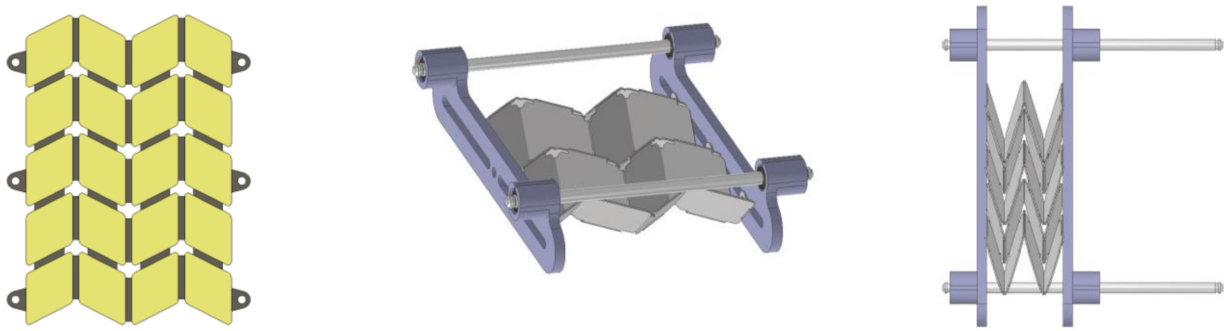


Figure 3. (a) sample gripper with frame connections (loops) (b) partially and (c) fully compressed frame and gripper (with the linear rod and bearing).

5 SUMMARY AND CONCLUSIONS

Innovative composite materials are being developed in tandem with new product ideas. However, introducing high volume production solutions for effective material handling is a roadblock. Automation solutions need to be established to produce large quantities of components efficiently and consistently to reduce per unit costs. Employing needle grippers will damage the fibers, and vacuum (and related systems) are not energy efficient. Other approaches, such as using soft robotic grippers with multiple robotic arms, will allow for pick and place actions, but is requires more capital investment, controls to synchronize the motions, and there is the potential for significant wrinkling [4]. Another approach is needed. Contacting multiple surfaces with a controlled Miura inspired fold enables fabrics to be picked up, collapsed into a 'rigid' structure, and unfolded and placed onto a curved surface, regardless of the fabric shape. This is a low-cost mechanical solution. The specialty grippers presented in this work are designed as curve-compliant, self-collapsing end-effectors, making them particularly adept at handling such limp textile materials. This approach can be scaled up. Changing the tessellation patterns will allow for compliance for different mould geometries. Exploring different build materials for the grippers needs to be done as well as durability testing. This research highlights the merits of this origami approach for limp fabric handling, and research needs to be continued to refine and optimize this strategy.

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