9-Pick and Place Algorithm for Online Waste Removal Process in LOM

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Pick and Place Algorithm for Online Waste Removal Process in LOM

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Abstract: One significant issue in rapid prototyping using Laminated Object Manufacturing (LOM) is its difficulty to fabricate a prototype having hollow and shell-shaped part due to internal waste material removal. Even though waste material is crosshatched to small pieces for ease to remove, the traditional offline waste material removal remains very difficult and may damage the prototype. To make this well known sheet-based RP technique appropriate for objects that have cavity inside, online waste material removal process has been researched and has led to the development of another LOM technique that creates internal and external profiles separately at different locations. Presented is this paper is an algorithm for online inner waste removal process where the waste is removed right after the internal profile is cut and before the sheet is bonded onto the previous layer. According to the shape and size of waste area, the algorithm will make a recommendation either to a material removal unit regarding a location to pick up the waste material or to a cutting unit to subdivide the area before recommending the material removal unit to take them away. The algorithm has been tested with some samples and the results are reported also in this paper.

Keywords: LOM, de-cubing, RP, sheet deflection.

1 INTRODUCTION

Laminated Object Manufacturing (LOM) is a well known rapid prototyping technology that constructs a prototype layer by layer from sheet material, mainly paper. For each layer creation, a fresh sheet from a roll of paper is fed onto the fabrication platform that is lowered down, and bonded on top of the previous layer with heated roller that activates thermoplastic adhesive underneath the paper as it travel across the platform. A contour is then cut with laser beam as illustrated in Figure 1 or a cutting tool for an inexpensive LOM. Waste material is left in place as support structure but is diced into small tiles for ease of de-cubing. The bond-then-cut process is repeated until the topmost layer is constructed.

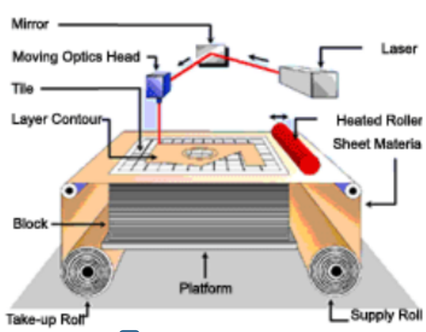

Figure 1. Laminated Object Manufacturing

LOM is a cost effective rapid prototyping technology with a variety of applications. It has been applied in several fields, such as architecture (Ryder et al., 2002), foundry (Mueller et al., 1999), etc. LOM technology gave a 50 percent saving in time and cost compared to aluminum pattern making (Wang et al., 1999). LOM has also been reported on Die Making for Diesel Engine (Yu et al., 2009). Besides its applications, researchers have tried to improve LOM technology for ease of producing object with curve. A new algorithm that combines the flat layer and curved layer has been introduced to eliminate stair step effect, increase build speed, and reduce waste when constructing a prototype (Klosterman et al., 1999). Sheet materials used in LOM have been extended to sheets of ceramics, polymers as well as metal.

However, LOM technology has many drawbacks. Cross hatching is time consuming. It consumes much more time comparing to contour cutting. Even though waste material is diced to small pieces, de-cubing process is still laborious because excess adhesive material infiltrates gaps during bonding any two layers. A prototype can also be easily damaged. Furthermore, LOM is limited to solid model construction. Some parts that are hollow, have vase-shape or have thin wall are hardly constructed by regular LOM due to the inner waste material removal (Liao et al., 2003).

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For allowing these parts to be constructed on LOM, the inner waste materials should be removed online during the construction process. This paper presents the development of an algorithm for online inner waste material removal that is executed right after the internal profile is cut and before the sheet is bonded onto the previous layer. Next section will report a couple researches on online inner waste material removal. The proposed algorithm is presented in the third section, followed by the implementation and conclusion.

2 RELATED WORKS

A couple approaches have been reported for solving the limitation of LOM when it is applied for constructing parts that are hollow and have shell shape. Liao et al (2003) has proposed an online de-cubing process, which allows inner waste material to be removed during the process. Bond-then-cut remains the principle applied in this proposed approach but instead of using paper coated underneath with thermoplastic adhesive, paper with self-adhesive is chosen. Similar to the traditional LOM, the fresh paper is fed into the process and bonded with the previous layer that its adhesive side is exposed to the air by a pressing force. Shielding paper that covered the adhesive side is peeled off from the new layer before contour cutting is made. Carbon powder is then sprayed on the waste material region that makes the area become non-adhesive. Inner waste material is removed by recovering the cut layer with shielding paper, pressing it and peeling it. The process is illustrated in Figure 2.

Bridge-LOM is another approach (Chiu et al., 2003). The process follows the principle of “cut-then-bond” instead of “bond-then-cut”. Layer contours are created at one platform and stacked up on top of the previous layers at another platform. The contours are separated from waste material after cutting. Frame structure is introduced and bridges are created to link cut contours with the frame and between themselves for ease of handling between two platforms. The new layer is

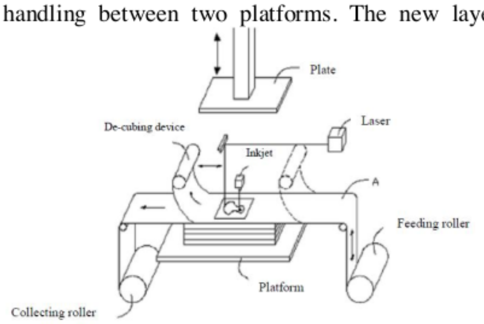

Figure 2. “Press and peel” LOM (Liao et al., 2003)

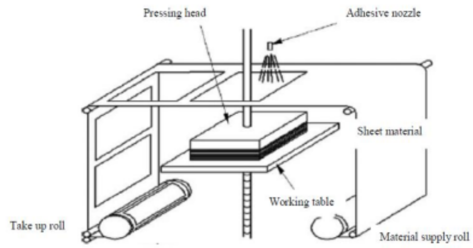

Figure 3. Bridge-LOM equipment (Chiu et al., 2003)

placed on top of the previous one that has already been pre-coated with adhesive material, and pressed. Feed-cut-press and spray are repeated for forming a 3D prototype. The process is illustrated in Figure 3.

3 ALGORITHM DEVELOPMENT

Similar to bridge-LOM, cut-then-bond principle has been applied in this research for creation of a prototype that has a cavity inside, but instead of using bridges, interior surface and exterior surface are created at different platforms. Unless it is a solid layer, a sheet material will be delivered onto the first platform for internal contour cutting before being transferred to the second platform for stacking up on the work-in-process prototype and for external contour cutting. At the first platform, after the internal contour is cut, inner waste material is removed from the platform by using one single removal unit as illustrated in Figure 4. Thus, it is required that the removal unit can lift up the waste sheet and removed it without dragging the sheet that remains attached on the platform.

Due to the flexible nature of a sheet and arbitrary shapes of waste material, a concern is more on sheet deflection causing the waste sheet to be in contact with the platform after lifting up. This requires the waste material to be cut to smaller pieces and more traveling time for the removal unit. An algorithm, therefore, is developed to determine whether or not the waste material can be lifted up above the platform and removed within one trip. It will recommend

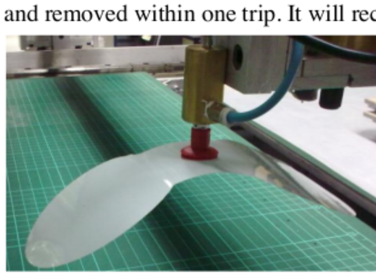

Figure 4. Waste material removal unit

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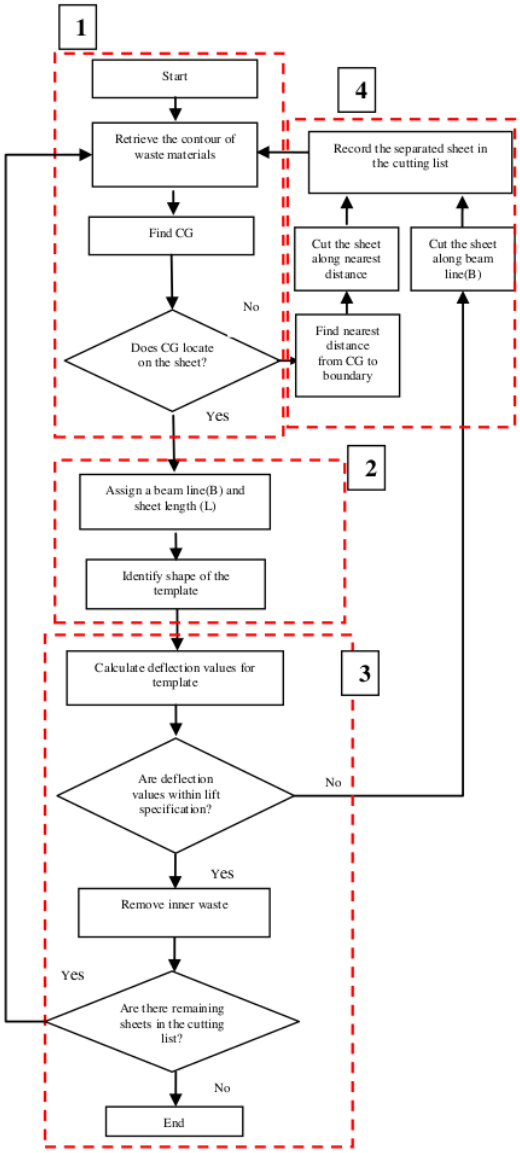

Figure 5. Flow chart of the proposed algorithm.

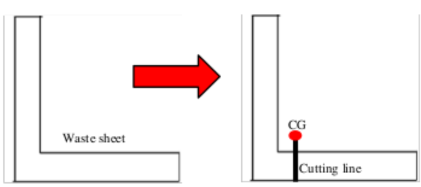

Figure 6. The cut line when the CG is outside the sheet

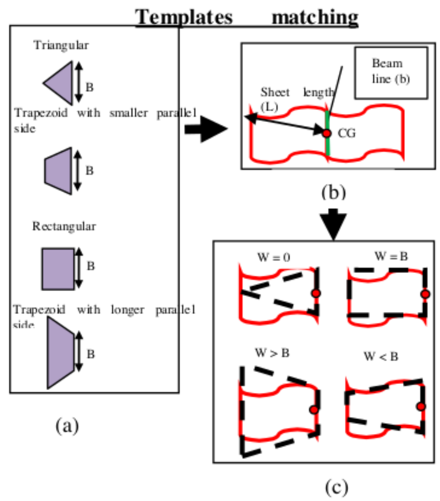

Figure 7. Template identification a). Template shapes b). Beam line and sheet length c). Template is selected according to W value

slicing the waste material if the waste material cannot clear the ground. As illustrated in Figure 5, the algorithm composes of four activities: identifying the location of the center of gravity (CG) on the waste area; identifying template; estimating sheet deflection from the template and cutting waste sheet to smaller pieces. The algorithm starts with identifying the CG of the first contour in the list of waste material. If the CG where the removal unit will lift the sheet locates outside the contour, the waste material is cut along the line that gives the shortest distance from CG to the contour as illustrated in Figure 6. The two new waste sheets are recorded in the list of waste material. The next one in the list is then called.

The parameters to be considered when selecting a template include beam line (B), sheet length (L) and area (A) as Figure 7. Beam line is the shortest straight line that connects two points on contour and passes through the CG. Sheet length is defined as the longest straight line from the CG to the contour. The length on the parallel side to the beam line (W) for known area can be determined from equation 1

$$W = \frac{2A}{L} - B \qquad (1)$$

The template can be chosen according to the value of W. In case that W is zero, a triangular shape is selected. In case that W is greater than zero but smaller than beam line, a trapezoid shape with larger

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base is selected. Rectangular and trapezoid with smaller base are selected when W is equal to and greater than beam lime respectively.

After the template is identified, its sheet deflection is estimated. The estimation follows the deflection of a solid beam that one of its ends is fixed and that is deflected by uniform load of its own weight. The deflection formula is described in equation 2

$$Y = \frac{3QL^4}{2EBt^3} \quad (2)$$

where Y = deflection value, Q = force per length, E= Young modulus and t = thickness of the beam.

According to the formula, the deflection is proportional to the force, and the function of the length. It is also proportional to the reciprocal of young modulus, beam line length and thickness of sheet. However, the material used may be non-homogeneous and the Young modulus of a sheet becomes unknown. Furthermore, the formula is for uniform cross section but the waste material has arbitrary shape. Therefore, the equation is modified and put in 2 generic forms as described in equations 3 and 4. Equation 3 will be applied for rectangular shape that the cross sections are uniform throughout the length. The power (a) of the length and Young modulus are assumed to be unknown and will be identified from experiment by using linear regression. The obtained Young modulus will be used in equation 4 that the coefficient k is introduced to handle the non-uniform cross sections of triangular and trapezoidal shapes. The power (a) of the length and the coefficient k will be identified from experiment for these templates. Please note that $\bar{Q}$ in equation 4 is the forces per area.

$$Y = \frac{3QL^a}{2EBt^3} \quad (3)$$

$$Y = \frac{3k\bar{Q}L^a}{2EBt^3} \quad (4)$$

From the estimation of sheet deflection, if the deflection is smaller than the lifting height, the algorithm sends a command to move the removal unit to the position to pick up and drop the waste material at assigned location. On the other hand, the waste material is cut along the beam line and recorded into the list. The algorithm completes the process after all waste materials are removed.

4 IMPLEMENTATION

The material used in this study was polypropylene (PP), and experiments were conducted to determine the unknown parameters which are the powers of

Table 1. Parameter setups for identifying the power of the length and Young modulus for all templates

Template shape	B(cm)	L(cm)	Number of data
Triangular	6	10-19	10
Trapezoid(W<B)	6	10-19	10
Rectangular	6	10-19	10
Trapezoid(W>B)	6	10-19	10

Table 2. The result from the experiments and regress model analysis for each template

Templates	Y(cm)	R^2	**Slope**	**Intercept**
Triangular	3-14	0.967	2.582	ln(-2.13)
Trapezoid(W<B)	4-16	0.991	2.0267	ln(-2.15)
Rectangular	6 -16	0.996	1.59	ln (25.7)
Trapezoid(W>B)	6.5-17	0.981	1.704	ln(-2.71)

Table 3. Deflection equation of each template

Templates	**Deflection equation**
Triangular	$Y = \frac{(0.263)3QL^{2.582}}{2Ebt^3}$; E =149415970272Pa
Trapezoid	$Y = \frac{(0.115)3QL^{2.0267}}{2Ebt^3}$; E = 149415970272 Pa
rectangular	$Y = \frac{3QL^{1.59}}{2Ebt^3}$; E = 149415970272Pa
Trapezoid	$Y = \frac{(0.07)3QL^{1.704}}{2Ebt^3}$; E = 149415970272 Pa

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length, Young modulus and coefficient k for the four templates. In the experiment, sheet materials were cut for all templates according to the parameters presented in Table 1. All the cut sheets had beam line of 6 cm while the lengths were varied at equidistance of 1cm from 10 to 19 cm. The removal unit was directed to lift up these sheets one by one at their CG positions. The lifting height was 20 cm. The deflections were then measured and recorded.

Ten data were obtained from the experiment for each template. Linear regression was applied to identify the unknown parameters. Beginning with rectangular template, the power of the length and Young modulus were determined first from the slope and intercept of linear regression of Equation 3. The power of length and coefficient k for each of other templates were determined next from the slope and intercept of linear regression of Equation 4. The results from all templates are presented in Table 2. According to the high R-squared values in all cases, linear equations can be used to represent the data. The deflection formulae for all templates are presented in Table 3. The estimated and measured deflections are presented in Figure 8. According to the comparison, the errors are within 10%.

The algorithm has been tested with several shapes of waste material, and some of them are presented in Figures 9-11. The results show that the deviations of estimated deflections from their actual values are within 10%. In fact all the values are overestimated which give some cushion. The overestimation prevents the waste material to drag on the sheet when a decision to pick up a waste material is made.

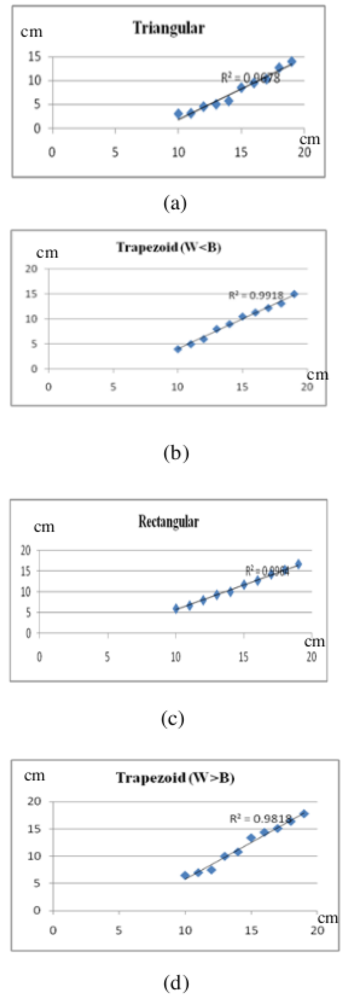

Figure 8. The comparison between the length (X axis) and measured deflections (Y axis) for the four templates

5 CONCLUSION

An algorithm has been developed for online waste material removal. According to the shape and size of waste area, the algorithm will make a recommendation either to a material removal unit to pick up the waste material or to a cutting unit to subdivide the area before recommending the material removal unit to take them away. Sheet deflection which is a key decision making criterion is estimated from primitive shape templates instead of being calculated according to its shape that may be arbitrary.

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The experiments have given promising results. The errors from the overestimation are within 10%.

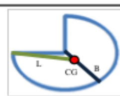
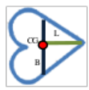
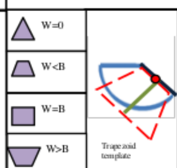
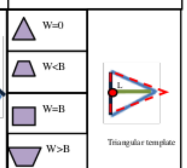
Input / Steps	Model 1	Model 2
		
Identifying CG and beam line	 A = 2545380, B = 6873.6, L = 7339.58 Unit =pixels	 A = 2327400, B = 10496, L = 8394 Unit =pixels
Sheet cutting in case CG out of contour	None	None
Identify shape of template	 W>B; W = 6998.474	 W=0
Calculate deflection values for template	5.6 cm	4.8 cm
Sheet cutting in case CG out of lift specification (20 cm)	None	None
Actual deflection	5.5 cm	4.8cm

Figure 9. The implementation of the algorithm on Model 1and 2

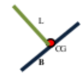
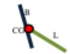
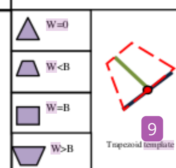
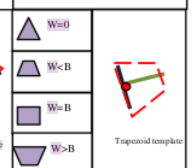
Input / Steps	Model 3	Model 4
Identifying CG and beam line	 A = 190903, B = 6873.6, L = 7339.58 Unit =pixels	 A = 2202860, B = 10496, L = 8394 Unit =pixels
Sheet cutting in case CG out of contour	None	None
Identify shape of template	 W<B; W = 4782	 W<B; W = 9279
Calculate deflection values for template	5.7 cm	12 cm
Sheet cutting in case CG out of lift specification (20 cm)	None	None
Actual deflection	5 cm	11 cm

Figure 10. The implementation of the algorithm on Model 3 and 4

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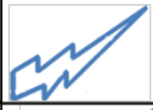
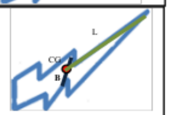
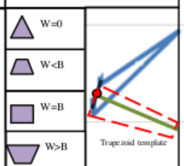
Input / Steps	Model 5
	
Identifying CG and beam line	 A = 1100430, B = 4050, L = 14670 Unit =pixels
Sheet cutting in case CG out of contour	None
Identify shape of template	 W<B; W = 450.73
Calculate deflection values for template	17.5 cm
Sheet cutting in case CG out of lift specification (20 cm)	None
Actual deflection	17 cm

Figure 11. The implementation of the algorithm on Model 5

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