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Abstract
Purpose – Taping, covering objects with masking tapes, is a common process before conducting surface treatments such as plasma spraying and painting. Manual taping is tedious and takes a lot of effort of the workers. This paper aims to introduce an automatic agile robotic system and corresponding algorithm to do the surface taping.
Design/methodology/approach – The taping process is a special process which requires correct tape orientation and proper allocation of the masking tape for the coverage. This paper discusses on the design of the novel automatic system consisting of a robot manipulator, a rotating platform, a 3D scanner and a specially designed novel taping end-effectors. Meanwhile, the taping path planning to cover the region of interests is introduced.
Findings – Currently, cylindrical and freeform surfaces have been tested. With improvements on new sets of taping tools and more detailed taping method, taping of general surfaces can be conducted using such system in future.
Originality/value – The introduced taping path planning method is a novel method first talking about the mathematical model of the taping process. Such taping solution with the taping tool and the taping methodology can be combined as a very useful and practical taping package to replace the work of human in such tedious and time-consuming works.

Keywords Robotics, Path planning, Robot design

Paper type Research paper

1. Introduction

Taping, covering the surface of an object using masking tapes, is a very important process for many industrial applications such as mechanical part repairing, surface protection and crack repairing. One example is in the aeroplane engine overhaul, where the damaged engine parts need to be repaired. The repair process includes plasma-spraying, where parts of the engine is coated at high deposition rate. Before this process, the other parts of the engine that do not require coating should be covered by tapes. This taping process depends on manual workers to spend hours of work to finish only a single piece of repairing part.

Robot manipulations with 3D scanning models have been investigated in surface treatment applications such as spray painting (Chen *et al.*, 2002; 2008; Chen and Zhao, 2013; Hegels *et al.* 2015) and laser coating removal (Baker *et al.*, 2014). *These applications are scenarios that do not have contact requirement and there is no restriction other than the surface geometry. For example*, the important factor in painting is the evenness of the paints on the surface (Baker *et al.*, 2014, Hegels *et al.*, 2015).

Different from other manipulation behaviors, taping has some constraints in the orientation of the masking tape to prevent any wrinkle and to make sure that the tape is going toward the correct direction. Meanwhile, some pressing force is required to properly attach the masking tape to the correct location, as illustrated in Figure 1. *This brings difficulty to the taping process.* Taping regular shapes (tubes, bars, etc). can be easily done by using some standard taping machines (Hottendorf, 1972; Horiguchi *et al.*, 1992). However, when the geometry of the taping part becomes more complex, the taping problem becomes non-trivial, as shown in Figure 1, for example. As a result, such taping works are mainly done manually by skilled workers.

In the manual taping, the worker observes the geometry of the part and uses his hand to control the orientation of the tape. At the same time, the worker uses his finger to press and push the tape to make sure that the tape is nicely attached to the surface of the part. In the overall process, the taping path should be properly planned to let the tape cover the entire area of interests. Therefore, a taping package with proper taping devices and taping path generation strategies that allows a robot manipulator to finish the taping task can be very helpful and has large application potential in industrial manufacturing.

In the automatic robot taping system, to realize the robot taping, a motion planning strategy based on the 3D digital model of the part to be taped is very crucial (Izadi *et al.*, 2011; Newcombe *et al.*, 2011). Because for repairing works there is no standard CAD model of the broken part (because of

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Figure 1 Constraints in taping

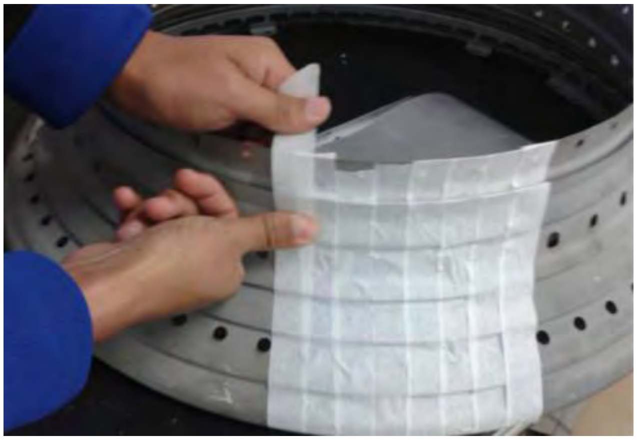
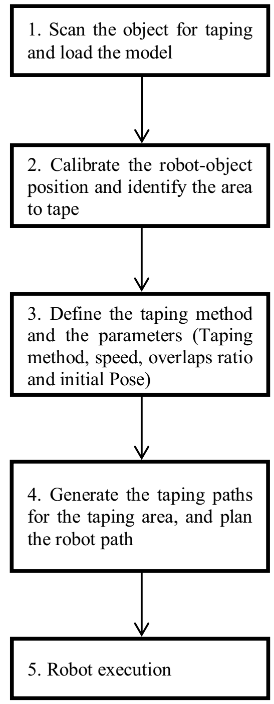


Figure 2 Working flow of the taping



deformation, cracks, losing of material, etc.), we need to use the 3D scanning device to get the digital model as a result. Meanwhile, a useful end-effector to realize the taping motion is also very important. The path planning of the taping process is not trivial because there are many geometric constraints determined by the object surface, the taping tool on the robot and the masking tapes used during the taping process.

Previous works (Lembono *et al.*, 2015; Yuan *et al.*, 2015) have been done to tape regular shapes. In this work, we start with taping strategies of standard simple geometries such as flat surface, cylindrical surface, surfaces with freeform features and cylindrical-like surfaces. Complex surfaces can be segmented into smaller and simpler surfaces for taping. This technical paper discusses on the abovementioned automatic taping technology with more general taping path planning method and tape cutting mechanism.

The overall taping process is illustrated in Figure 2.

The remaining parts of the paper are organized in the following manner. Section 2 introduces on the taping system design. Section 3 describes the path planning method. Section 4 introduces the software package and the robot execution. Section 5 discusses the further improvement required and concludes the paper.

2. Taping system

2.1 Automation robot taping system

Figure 3 shows the robot taping system. The system includes a 3D scanner for the 3D model reconstruction, a part fixing platform, a taping robot and the robot taping tool. A part fixing platform is used to mount the parts for taping. This platform can either be a simple fixed base or a rotating platform. The special design of the end-effector is required to meet the proper taping requirement. Meanwhile, the mechanism for cutting and holding the tape is also needed to accomplish the taping process.

2.2 Taping tool design

The taping tool is used as the robot end-effector to hold the tapes and conduct the actual taping process. As shown in Figure 4, the "tape holder" is used to hold the masking tapes. The tape comes across the "tape guiding roller" so that it can move smoothly. The "tape roller" is the one to be in contact with the taping surface and to push the tape onto the surface, such that it is attached firmly. The "compliance spring" mechanism is to allow some tolerance of the taping end – the "taping roller". The "fixing flange" is used to fix the taping tool on the robot.

In addition, a crucial part is the "tape cutter" which is needed to allow the separation of the tape segments. The requirements for this tape cutter are first to be able to cut the tape properly and second to keep the tape in the location that is ready for the next taping step. As shown in Figure 5, the tape cutter beside the taping roller is used for tape cutting. The taping holder is a thin roller that can have a line contact to stop the tape from going away from the tape roller.

2.3 Three-dimensional scanner

Kinect and Artec Eva are used to build the 3D model of the workspace. Both uses structured light to obtain the depth data of its environment. The accuracy of Artec Eva can achieve up to 0.1 mm, whereas Kinect has lower accuracy (its random error in depth measurement is around a 2-3 mm at 0.5 m range and increasing with the distance). However, Kinect has larger range (up to 8 m) compared to Artec Eva (maximum 1 m).

For the taping application, the required manipulation accuracy is not as high as applications such as polishing and machining. It is more on covering the surface with the correct method. The model errors from the scanner is compensated by the spring mechanism on the taping tool. In this work, the path planning is based on the 3D point cloud data (in OBJ format).

Figure 3 An automatic taping system

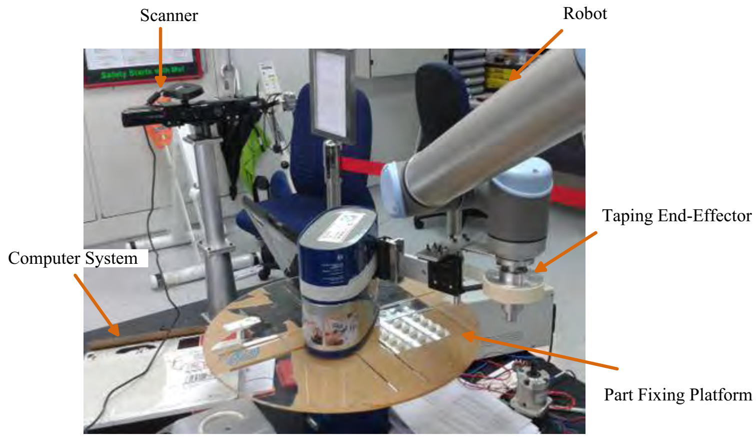


Figure 4 Taping tool design

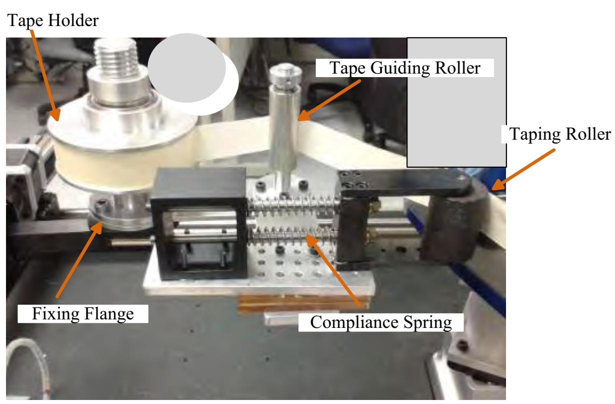
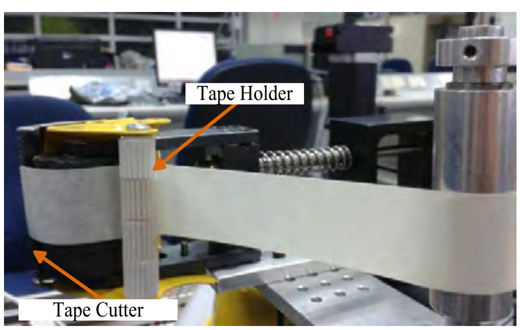


Figure 5 Tape cutter in the taping end-effector



3. Taping path planning strategy

To cover the area properly with the masking tapes, some taping strategies for surface covering to ensure proper tape attachment (firmly attached to the surface without any wrinkle) is important. *This requires not only the free path generation of the taping tool but also steady contacts between the taping tool and the taping surface.* When the skilled workers do the manual taping, they first plan the strategy to cover the area based on the geometry of the area. For example, they will decide on whether to tape vertically, horizontally or to wrap around the surface. After the strategy is decided, each tape segment to cover the surface is actually a point to point taping across the surface. In this case, the masking tape needs to be nicely attached to the surface with proper orientation to make sure that the tape goes through the path as expected.

- It is not trivial to tell what orientation the tape should exactly start with to tape from a given point A to the other given point B on an arbitrary surface.
- Also, to cover an area of interest with the masking tapes, the strategy to cover the surface is not unique.

This paper will discuss on this taping path planning approach based on the 3D point cloud model of the objects.

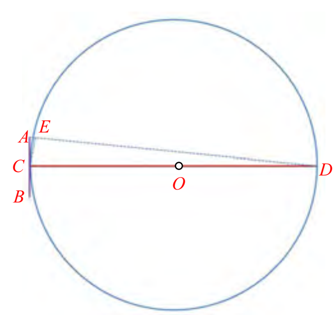
Analytically, a surface segment can be presented by a function f, provided that the coordinate frame is chosen such that f is single value in the domain C:

$$z = f(x, y), (x, y) \in C \tag{1}$$

A general solution for taping of arbitrary shapes is a very complex problem, especially when the surface is not regular or is partially concave. Here, the assumption is made that we are taping a smooth surface or a series of smooth surfaces, which means that $z = f(x, y)$ is continuous at domain $C$and differentiable (on each smooth surface).

At the same time, it is noted that the taping method is largely dependent on the surface size and the curvature. For example, how should we tape a spherical surface (with the radius r) using a tape with the tape width w_t? As illustrated in Figure 6, assume that we are taping a spherical surface. Let point C and D denotes two corresponding pole of the sphere. O is the center of the sphere. Assume AB is the tape, starting

Figure 6 Tape width choosing illustration



from point C (middle of AB), AB is along the tape width direction: $|AB| = w_t$. E is the intersection of the circle and AD. It is understandable that if the angle between segment AC and CE is large, the taping will cause large deformation (wrinkle) on the tape along the two side of AB.

Take note that if we choose $r_m = 5w_t$ *or* $AC = BD / 20$, it is equivalent to an angle of about 3° between AC and CE as shown in Figure 6, whereas $r_m = 3w_t$ is equivalent to an angle of about 10°. To ensure that the tape is suitable for the surface, here we propose the following requirement:

- The minimal curvature radius value r_m on the surface (across the taping direction) is required to be at least five times of the tape width, $r_m > 5w_t$.
- At the same time, if the surfaces area is big and the geometry is not 2D case, it needs to be segmented into small pieces for taping.

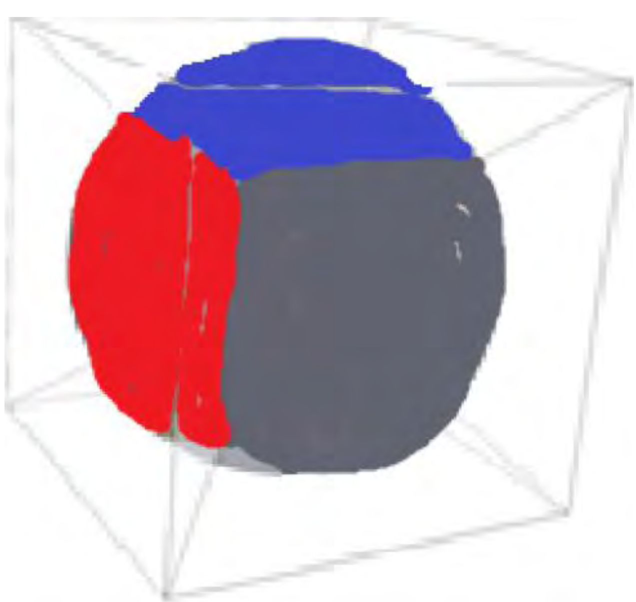
For now, a general method on how to divide an arbitrary surface for the taping problem is not yet achieved by us. The current method needs human to be involved to make a decision. In general, the separation of the surface is a very challenging job that needs more problem understanding. For example of a surface segmentation strategy in the taping, let us go back to the question – how to tape a spherical surface?

First, get a cubic that contains the sphere and shares the same center as the sphere. The sphere surface can be evenly divided into six square-like pieces as shown in Figure 7. Then the taping of the sphere becomes a problem of taping six square-like surfaces using a proper tape satisfying the condition $r_m > 5w_t$.

It is very interesting to notices that this is very similar to a volleyball surface.

The segmentation of the parts is a complex work that needs human assistant. The good thing is that, for the same workpiece, the surface separation strategy is same. Therefore, it is reasonable to just create a database for the surface segmentation methods of each workpiece based on human

Figure 7 An automatic taping system



experience just once and use the method to segment the surface for taping. For example, the sphere is segmented as shown in Figure 7.

In this paper, we will mainly discuss on the taping method for a square-like surface segment after the division. Meanwhile, we will also explain on the special case of cylindrical shape taping.

3.1. Surface area taping strategy

For a square-like shape, the general idea of the taping method is illustrated in Figure 8. The orange color is the area to be taped. The points $A_1, A_2, \ldots A_n$ are the starting points and $B_1, B_2, \ldots B_n$ are the corresponding ending points. So A_i, B_i forms a point pair to define a tape segment.

First, for an area of interest as illustrated in Figure 8, we need to determine main taping direction based on the geometry of the area. This direction can be calculated based on two manually selected points on the edge of the surface area (A_i and B_i as shown in Figure 8). Then, the other point pairs are selected on the edges to make sure that the adjacent tapes are not separated in the entire path (the tape overlapping dimension can be defined by the user input). The point selection ends until the area of interest is covered.

3.2 Point-to-point taping

In a single point-to-point taping, we start from the point A, the starting point with coordinate of(x_0, y_0, z_0). The corresponding normal vector is(u_0, v_0, w_0). For a surface $z = f(x, y)$:

$$(u_0, v_0, w_0) = \left(-\frac{\partial f}{\partial x}, -\frac{\partial f}{\partial y}, 1 \right) |_{(x_0, y_0, z_0)} \tag{2}$$

In the point-to-point taping (A to B as shown in Figure 9), the tape should be nicely attached to the surface without any sudden change in the taping orientation (otherwise the tape will be wrinkled), and the tape should end at the neighborhood of point B within the tolerance error.

3.2.1 Modeling of the taping process

At a taping point $p = (x, y, z)$, the taping frame is defined according to the orientation of the tape. The *Z* axis is defined

Figure 8 Area of interest for taping

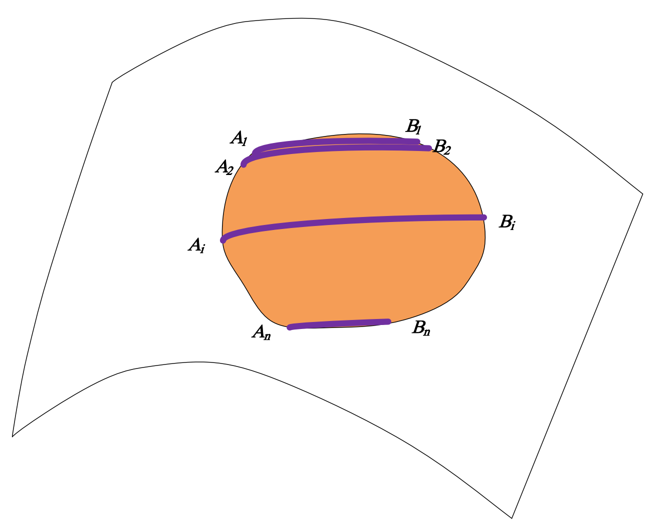
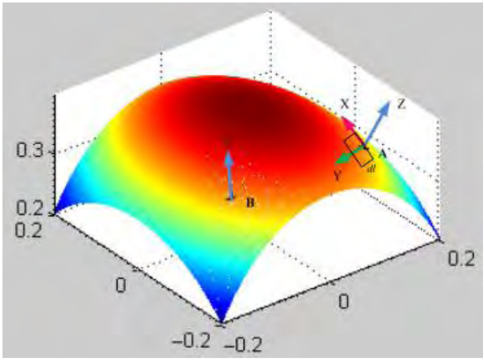


Figure 9 3D surface model for taping



by the surface normal at p. The Y axis is along the taping direction. The X axis is the dot product of the other two axes ($Y \times Z$). The path planning is numerically done based on projecting the tape toward the Y direction and flip to the surface along a certain axis. To analyze the taping path on a surface, we use the small taping element to describe the neighborhood of a taping point. The taping element is defined to be the small trapezoid form by the edge of the tape and the adjacent flipping axis–the line that the tape flip around, as shown in Figure 11. Starting from point A, the small tape element with very small length dl is attached on the surface.

For the small element, the taping starting point p_i is the middle point of the starting edge of the mini tape element as shown in Figure 10. The Z axis is defined to be along the normal vector direction:

$$z_i = n_i \tag{3}$$

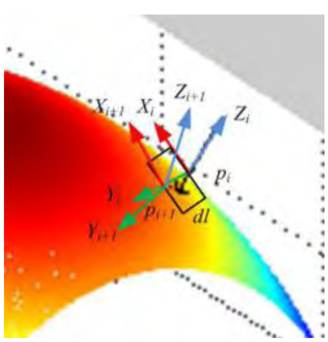
Therefore, the next taping point p_{i+1} can be estimated as follow:

$$\hat{p}_{i+1} = p_i + y_i dl \tag{4}$$

Note that the taping point should lie on the surface. Therefore, a point $\hat{p}_{i+1}$ is projected to the surface to get the next taping point p_{i+1}.

Now the critical problem comes when determining the taping orientation of the small taping element. For taping on a flat surface, the X axis (and Y axis) of the tape do not change while continuously taping on the surface. However, this is not the case for taping on general surfaces. Therefore, to match the tape with the surface nicely, the tape elements need to be properly directed to satisfy the geometric constrain of the surface.

Figure 10 Taping element model



As shown in Figure 11, while the tape attaches to the surface, it is understandable that the tape actually flip to the surface along a certain screw axis which depends on the surface geometry.

In this work, the masking tape's width is chosen properly based on the method introduced in Section 3. Therefore, it is valid to ignore the deformation (if any) of the tape along the width direction of the tape (actually, in many situations, such as taping cylindrical surface, cone surface etc., the tape does not have wrinkle at all).

In the actual taping, as shown in Figure 11, the small taping element flip to the surface along a certain axis V_i. It is noted that this axis V_i is the intersection between the small taping element surface (flat) S_i and its next small taping element flat surface S_{i+1}. As a result, this twist axis V_i is perpendicular to both z_i (the surface normal of S_i) and z_{i+1} (the surface normal of S_{i+1}).

Therefore, we have:

$$V_i = \frac{z_i \times z_{i+1}}{|z_i \times z_{i+1}|} \tag{5}$$

Geometrically, the body frame of the two taping element is identical (in orientation) when the tape is straight, the difference of them actually comes from the twist motion along this twist axis V_i for an angle φ_i. This angle is therefore the angle between z_i and z_{i+1}. Then, we have:

$$\varphi_i = \cos^{-1}(z_i \cdot z_{i+1}) \tag{6}$$

With such twist motion, it is understandable that the relationship between the orientation of the element frame of S_i, R_i, and that of element frame of S_{i+1}, are connected by the twisting motion:

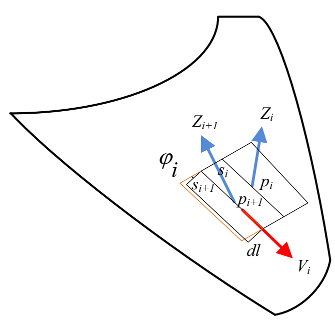
$$R_{i+1} = e^{\varphi_i \hat{V}_i} R_i \tag{7}$$

where $\hat{V}_i$ is the skew-symmetric matrix of vector V_i. Its corresponding rotation matrix is calculated by the $SO(3)$ matrix $e^{\varphi_i \hat{V}_i}$; details can be found in (Murray *et al.*, 1994; Yuan and Chen, 2014).

Therefore, the taping orientation will be:

$$y_{i+1} = e^{\varphi_i \hat{V}_i} y_i \tag{8}$$

Figure 11 Flipping of the tape element while taping



In this way, the taping process can be conducted following the geometry of the surface. Besides this surface following constraints while taping, it is important to figure out the initial taping orientation to correctly tape to the target point as expected.

3.2.2 Initial taping orientation

In the taping of a segment, we start from a starting point A_i, and we want to let the tape attach to the surface nicely without wrinkle and end at B_i. To achieve this, a correct initial taping orientation needs to be determined.

In this paper, we introduce a method to calculate the initial taping orientation. This introduced method works for square-like surfaces, not a general method for all type of surface features. For example, it is not working for spiral shape surface, but such shape is not common for most workpiece.

In point-to-point taping, we first need to get an initial guess of the orientation. *In the taping scenario on a surface with no significant change in normal vector direction*, the initial guess of the taping orientation is made such that it falls into the plane including the z_0 and segment AB and tangential to the surface, the *Y-axis as shown in* Figure 12:

$$\tilde{y}_0 = \frac{\hat{y}_0}{|\hat{y}_0|} \quad (9)$$

where, $\hat{y}_0 = z_0 \times (AB \times z_0)$.

Based on this estimated initial orientation, the taping process is conducted by following the method introduced in the last section (Figure 13).

Figure 12 Initial orientation guess

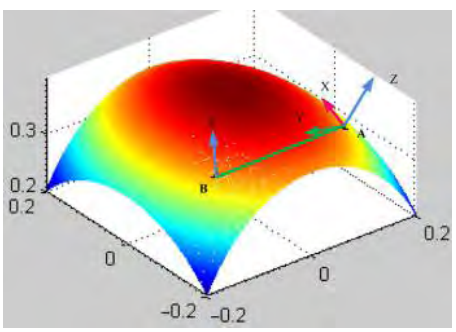
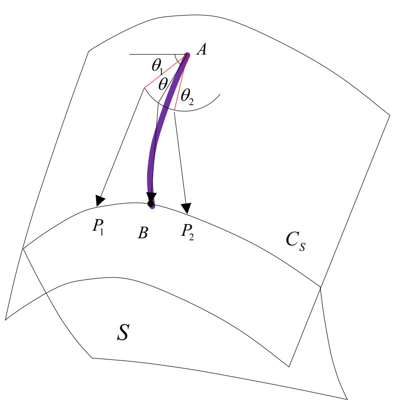


Figure 13 Illustration on solving the initial taping orientation



The section curve of the taping surface and the plane S which include point B and perpendicular to AB is denoted by C_S. With the initial and ending point A (x_0, y_0, z_0) and B (x_n, y_n, z_n), the taping process goes until C_S, where the ending point for this taping path is $P\ (x_c = x_n, y_c, z_c)$.

The initial taping orientation solution corresponds to the ending target point B. In the initial guess, the ending point is on one side of B. Through testing on another two orientations, $\theta_2 = \theta + \varphi$ and $\theta_1 = \theta - \varphi$, we can get an ending point that falls on the other side of B (initially, we let $\varphi = 20^\circ$, and φ can be increased in case all three ending points fall in the same side of B).

Let function fs be the function mapping the initial angle to the ending point, and $fs(\theta_1) = P_1$ and $fs(\theta_2) = P_2$ where the target ending point is betweenP_1 and P_2. The solution of $fs(\theta) = B$ can be found using the numerical method (Newton's method).

For taping of cylindrical, we can make an initial guess with horizontal direction, and use the Newton's method to get the correct initial taping orientation.

With the point-to-point taping method, a surface taping strategy can be conducted. There are cases that small remaining areas need to be taped after the surface separation. This very minor work can be done by human or also can let the robot finish, which is not an issue.

For a special case of the cylindrical shapes taping, the process can be conducted continuously. In this case, the condition stated in equation (2) is not required. The initial taping angle can be calculated based on the method introduced in last section.

For an area without significant change of the surface normal direction, and the cylindrical shapes, the method works nicely. It is noted that there are chances that the adjacent tape segments do not overlap somewhere along the taping path if the initial and ending points groups are not defined properly in the strategy plan, especially when the area has a large variation in surface normal (sphere shape for example). This will require further separation of the surfaces or just apply more tapes to the separated areas. Up to now, the separation of surface segments and the selection of this starting and ending points need human experience to guide. Further improvements are needed make the system less human dependent.

4. Scanning, planning and execution

The actual taping process is separated into three main parts: model scanning and editing; path planning; and robot execution.

4.1 Three-dimensional model reconstruction (scanning and editing)

A 3D scanner is used to scan the object model. We have the Kinect sensors which can provide a 3D point cloud model with 2-3 mm position accuracy. More accurate scanners can provide more accurate models (for example, Artec Eva sensor can provide 3D point cloud model with 0.1 mm accuracy).

Kinect sensor can be used as a hand held device to scan an object (Artect sensor is the same case). The 3D model of the object can be generated by holding the scanner and scan around the object. An easier way is that we can fix the scanner at a fixed location and fix the part on a rotating platform within the efficient scanning range, as shown in Figure 3. The scanning is done while the rotating platform rotates for at least on cycle. The workpiece model is available after removing the background.

Numerically, the 3D point cloud model can provide us with the 3D position (x, y, z) of each point and we can use "MeshLab" software or other existing methods to create mesh and calculate the surface normal at that point. There is also a need to filter the noises (and other unnecessary points such as the background) and smoothen the surface normal vectors (Figure 14).

4.2 Robotic system path planning

Select the area of interest for taping. Choose the tape, manually select or auto-generate the starting and ending point of the tape segments. Then, do the path planning. As an illustration in Figure 15, the taping path is generated for the taping segments. The makers are the taping paths for the robot to follow.

Figure 14 3D model acquisition and editing

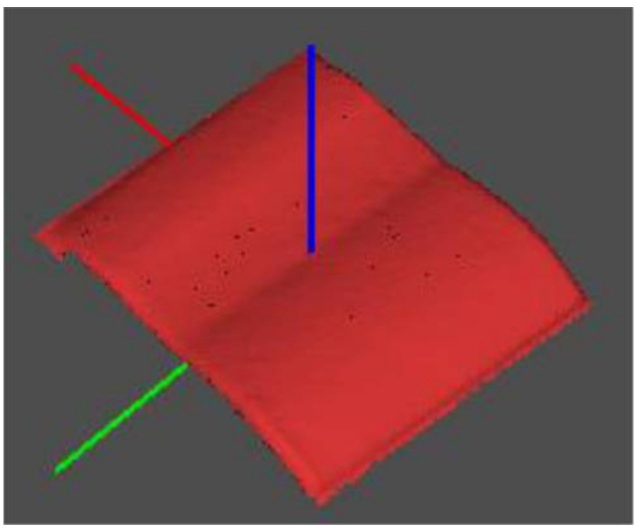
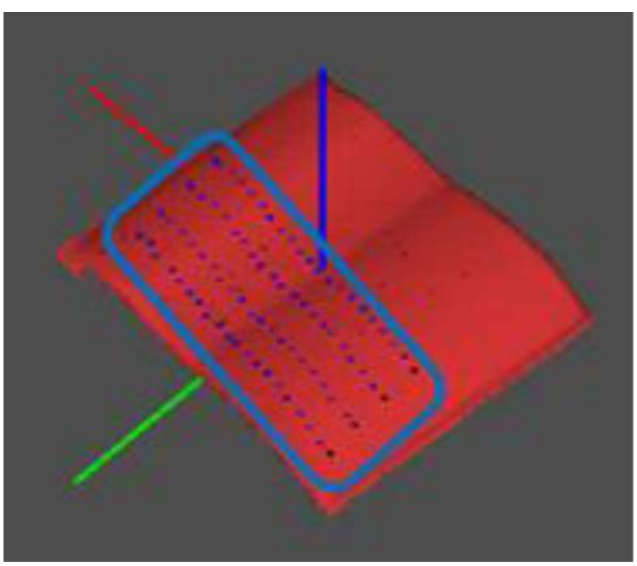


Figure 15 Taping path planning



4.3 Execution of the taping process

This module allows the robot system to execute the taping process based on the generated path. An example of taping a cylindrical surface is shown in Figure 16. In this taping example, the sample is fixed on a rotating platform. It is not possible for the robot to wrap around the surface because of the limitation of robot workspace, and collision will also happen. Therefore, the rotating platform is used to rotate the sample, collaborating with the robot arm. The example showed in the video is to tape a quarter of the outer-curve, and then rotate the platform (together with the robot tool) for 90° and then tape another quarter. As shown in equations (1)-(5), the rotational platform is in station while the robot is taping the surface. From equations (5) to (8), the platform (together with the robot tool) rotates for 90°. Then from equations (9) to (10), the platform stops, and the robot start to tape again.

The rotating patterns can be further optimized for different shapes to better collaborate with the robot taping.

Currently, the taping system does not have error feedback function. Further improvement is now under development to add on distant/force feedback to make such system more accurate and more stable for workpieces with rough surfaces or surface deformations.

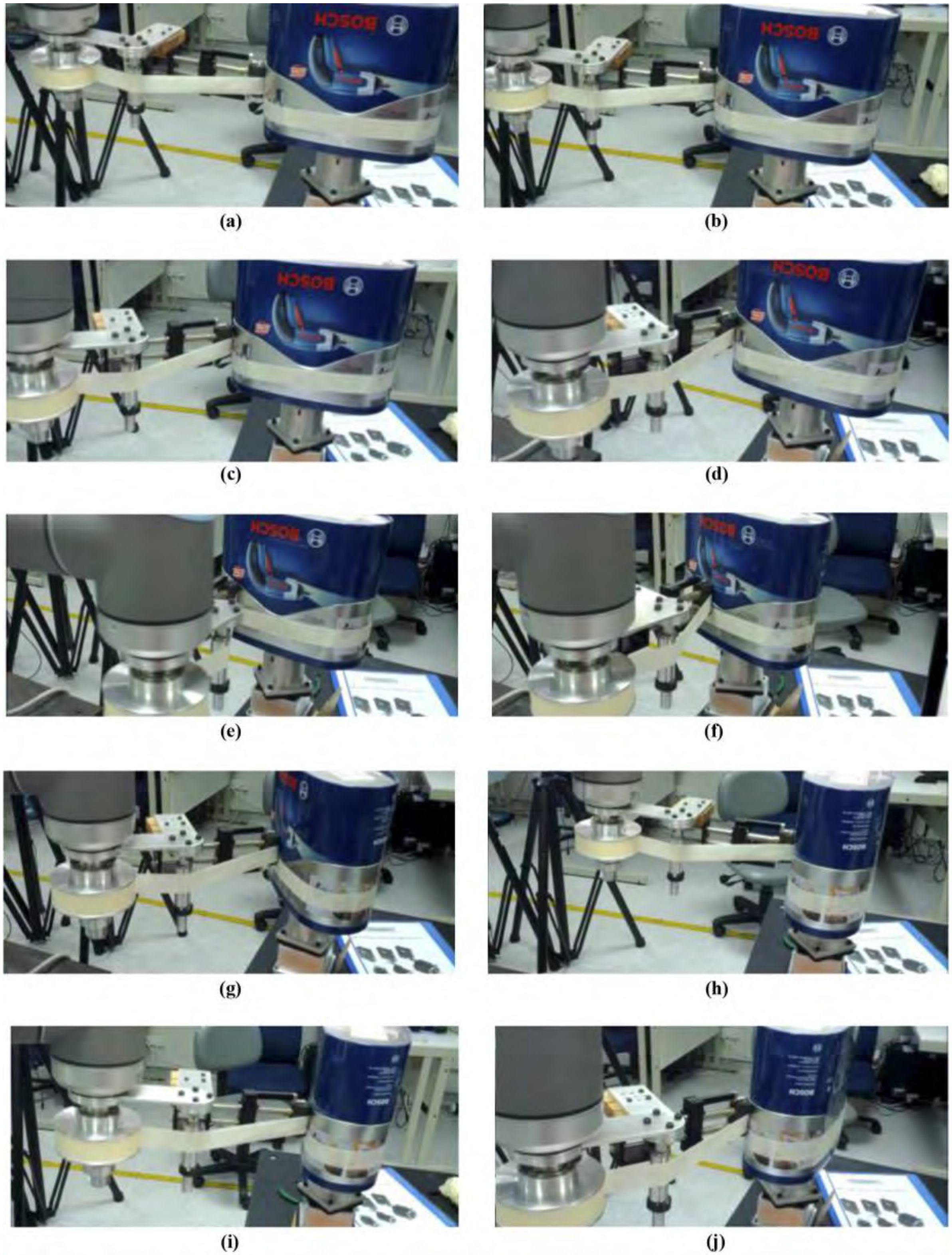
In this cylindrical-like surface taping, more than ten trails have been tested, and results shown that the *repeatability* of the taping is good – *no obvious wrinkle, proper tape overlapping* and no failure in attaching (Figure 17).

This is continuous taping without tape cutting. The taping tool (Figure 4) without cutter is used. While, in many cases with more complex geometry, we need to make the tape cutting to complete the whole process. An example is shown in Figure 18. In this example, the taping starting and end points of the tape segments are manually selected. Manual selection needs experience to guarantee the correct covering. As shown in Figure 18, the adjacent tape segments do not overlap completely because the starting and ending points are not chosen properly. In such case, a simulation before the actual execution is helpful, which will be improved in the future. More detailed information about the cutting can be found in the video attachment.

For taping application, the accuracy requirement is not high, 5 mm error is acceptable so long as the surface covering is satisfied. The error source is mainly from the 3D model error (about 2 mm). Path planning can induce some error, but, because each tape element is short, this error is less significant. For the robotic taping system, the accuracy within 1 mm. Therefore, such system is accurate enough for taping. In terms of repeatability in taping, based on multiple trails, the taping results for each piece is very consistent. This is important to make sure the system is stable in doing the surface covering tasks.

The taping tool is also under further development to make better tape cutting, initial attachment and feedback of errors. With additional distance/contact force feedback, the taping quality can be improved.

Figure 16 Taping process of the automatic robot taping system



Notes: (a) 0s; (b) 0.5s; (c) 1s; (d)1.5s; (e) 2s; (f) 2.5s; (g) 3s; (h) 3.5s; (i) 4s; (j) 4.5s

Figure 17 Taping results for cylindrical-like surface

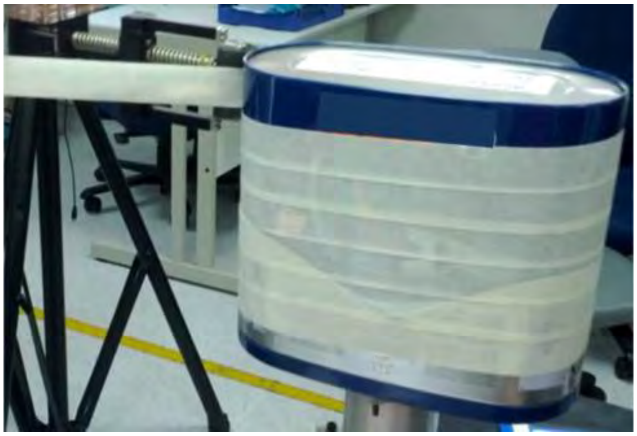
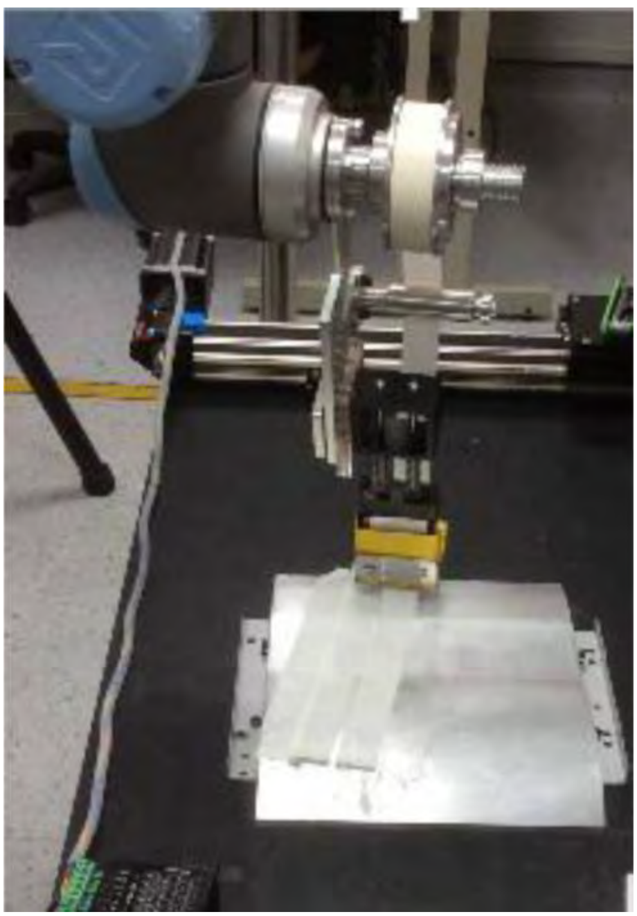


Figure 18 Taping process with tape cutting



For surfaces that need to be taped parts by parts individually, the mechanical parts to be taped may need to be re-located and fixed with differently postures. Further work is needed to have a better description on such problems.

5. Conclusion and discussion

This technical paper discloses the automatic robot taping system and corresponding methods and software package for completing the robotic surface covering using masking tapes. We discuss on the design of the special end-effector for taping. The geometric constraints between the masking tape and the surface are mathematically introduced. Based on the introduced method on taping across the surface from one point to another, the strategies for taping different geometries have been introduced. The path planning ensures that the tape is nicely attached to the surface. This technology is very useful because the taping process is very common in industrial applications such as surface covering before coating of mechanical part for repairing, crack repairing and surface protection. For such taping solutions, the taping tool and the taping software can be combined as a very useful taping package in these industrial applications. Therefore, the taping package is of large potential for commercialization because it can be mounted on any type of robotic arm system for the taping tasks.

- *Taping strategy*: A general method to cover an arbitrary geometric part based on the digital model is almost impossible. For a specific application, the number of parts for taping is limited. Therefore, a more practical method is to apply human heuristic method to assist in building a taping strategy data based. For each part, the experienced workers will advise on the key taping parameters – area segmentation, taping direction, the type of tape, overlap of tape layers, initial points and tape cuttings. With such database, when a part comes for treatment, we will scan the model and do a matching based on the CAD model and apply the path planning following the database and the path planning method.
- *Accuracy*: Taping is a surface covering process where the surface covering method is the most critical. The accuracy is just moderate because the tasks can be completed within the tolerance of a few millimeters. However, to attach the tape on the surface, the taping tool needs to press the tape to the surface and apply some force for the attachment. This can be achieved based on compliant mechanisms on the end-effector. Precise force feedback can be helpful, but it also adds extra costs to the system.
- *Taping speed*: Taping speed for robot is dependent on the strength of the tape. The higher the speed, the larger the tension force on the tape. In surface covering based on taping, the quality is priority instead of speed. Human taping is very slow, but human can handle very complex surface geometry with good quality (taping speed of human is normally several cm/s). It is possible for a robot to make fast taping for simple geometry. However, before the robot can do the job, the taping tools and the path need to be carefully considered to ensure good taping quality.
- *Taping tool*: With compliance mechanism, this tension force also causes pressing of the ending-tool, which need to be considered during the mechanical design and the path planning.

For complex surfaces, parts with grooves for example, the introduced taping tool will not be sufficient. Better assistant devices are needed. In very complex scenarios, the solution is not feasible because in the first place, the 3D model of the grooves will be inaccurate. Meanwhile, the operation of the assistant tools will require a lot of human skills. Therefore, a more proper method is to let robot tape the major part and let worker finish the minor but most challenging parts.

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