Task-Orientated Human-Robot Teleoperation using Wearable Sensors

Qilong Yuan[*], Teoh Yee Seng[#], Qinghua Lu[*], I-Ming Chen[#]

[#]School of Mechanical and Aerospace Engineering, NTU, Singapore.

[*]School of Electro-Mechanical Engineering, Foshan Univ., China

Presented by:

Dr. Qilong Yuan

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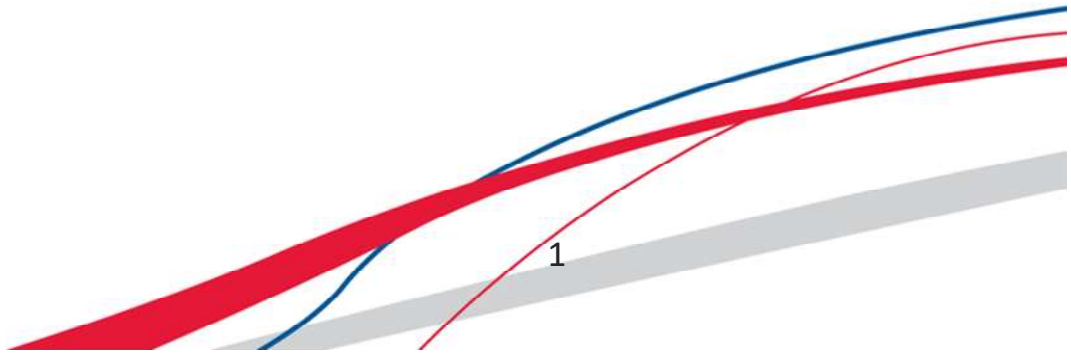
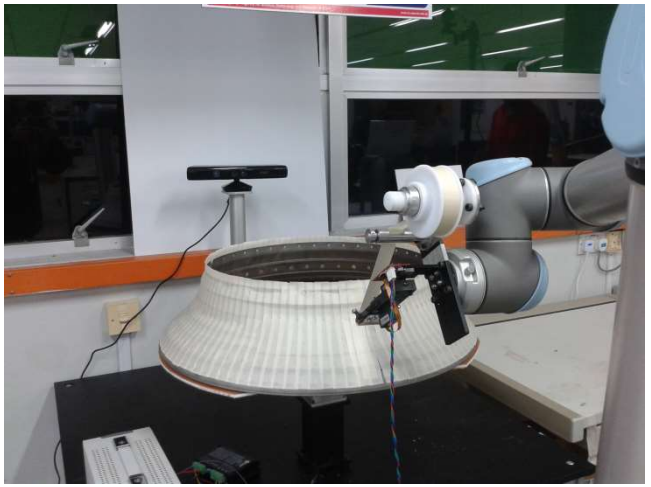


Introduction

- In engine part repairing
  - Surface treatment such as plasma spraying and spray painting are needed
  - Workers need to properly cover the parts using masking tapes for the surface protection.
  - Tedious and arduous manual work.
- Research Objective
  - To develop an automatic robotic system and the corresponding methods to do surface covering process using masking tapes

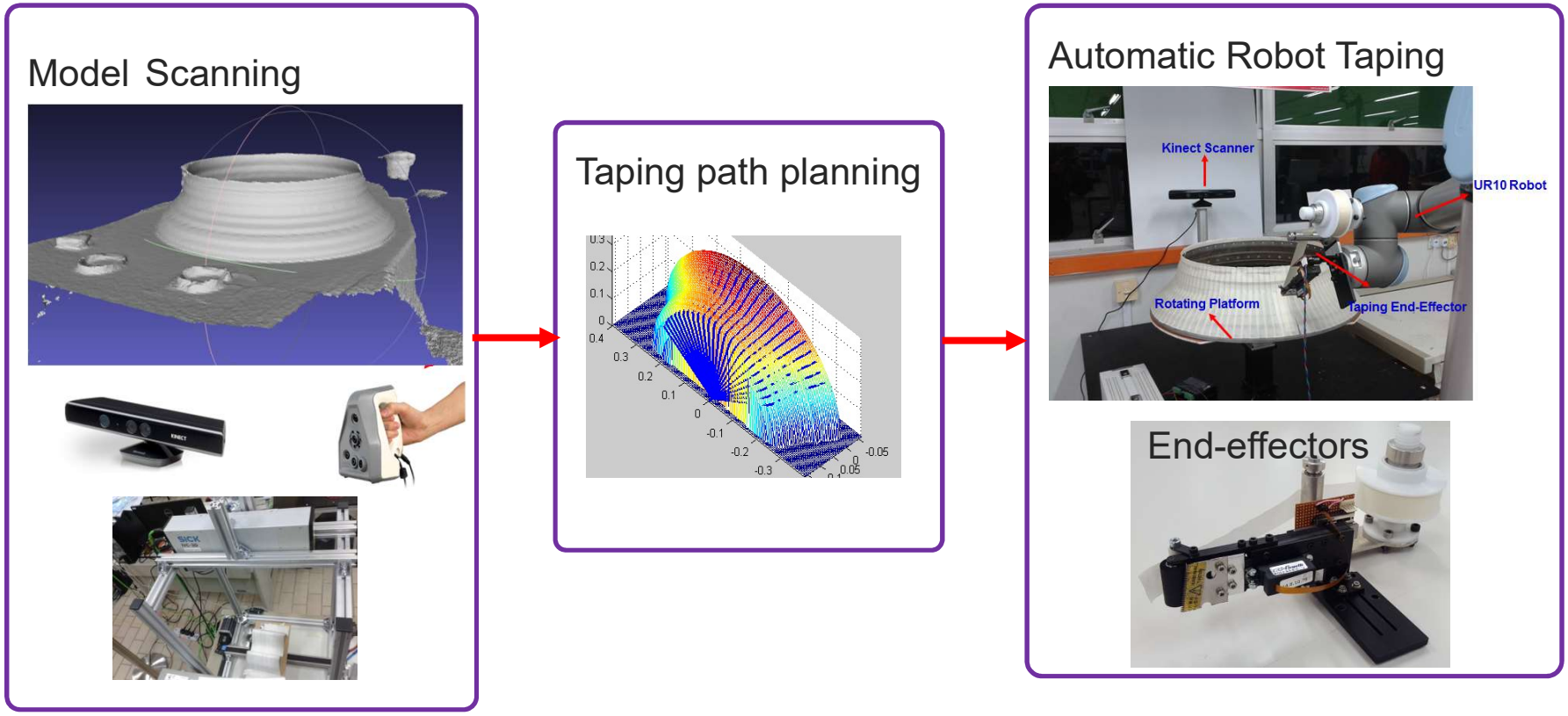
Taping Workpiece Samples

Automatic Taping Solutions



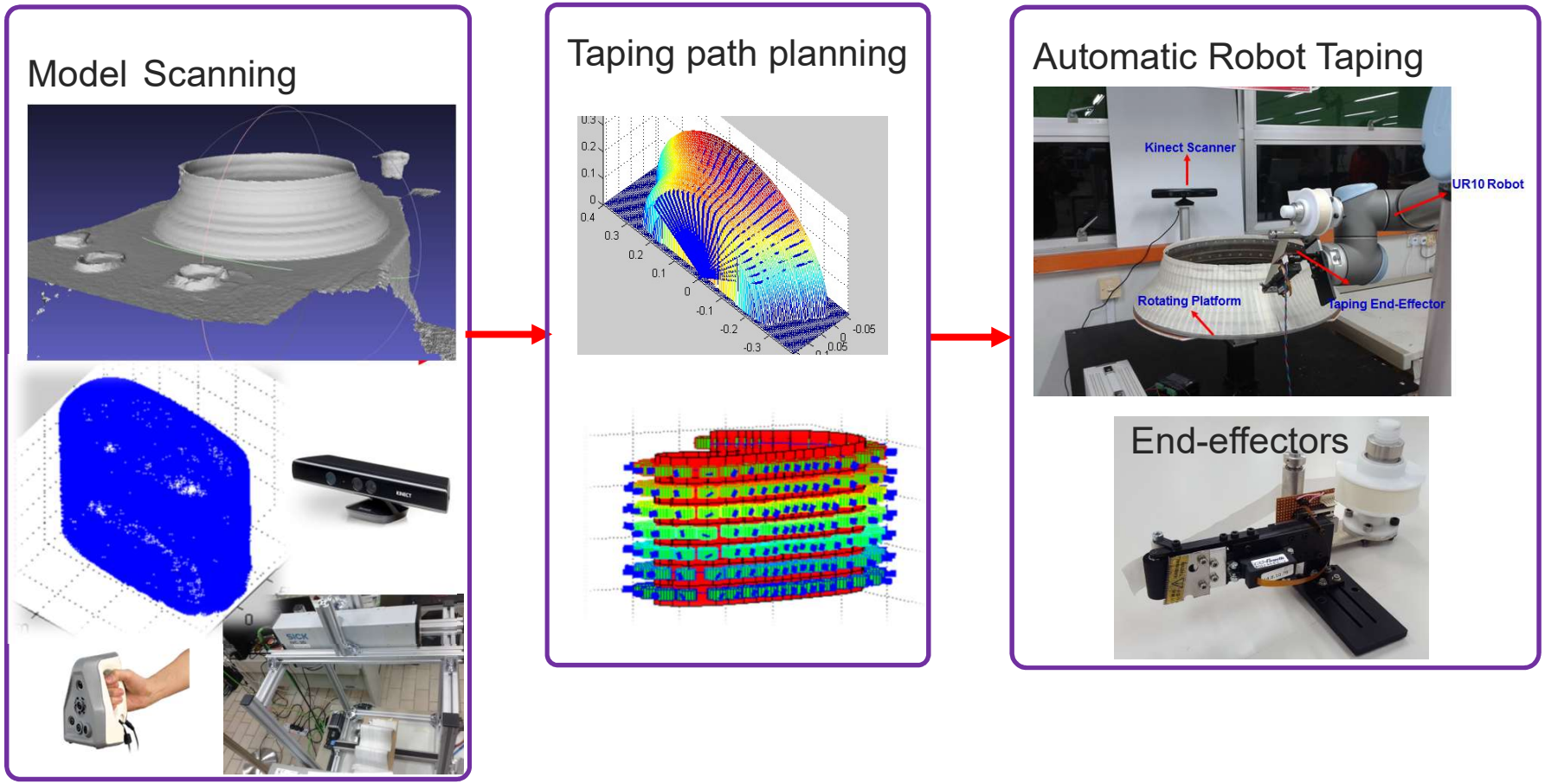
- Existing solutions for objects with simple geometries
- General Solution
  - An automatic system based on a robot manipulator, a rotating platform, a 3D scanner and novel taping end-effectors for taping process.
  - The taping path planning method to cover region of interests is developed for variety of surfaces.

Automatic Robot Taping



- Reconstruction of workpiece model, system coordinate calibration
- Path planning
- Robot execution

Automatic Robot Taping



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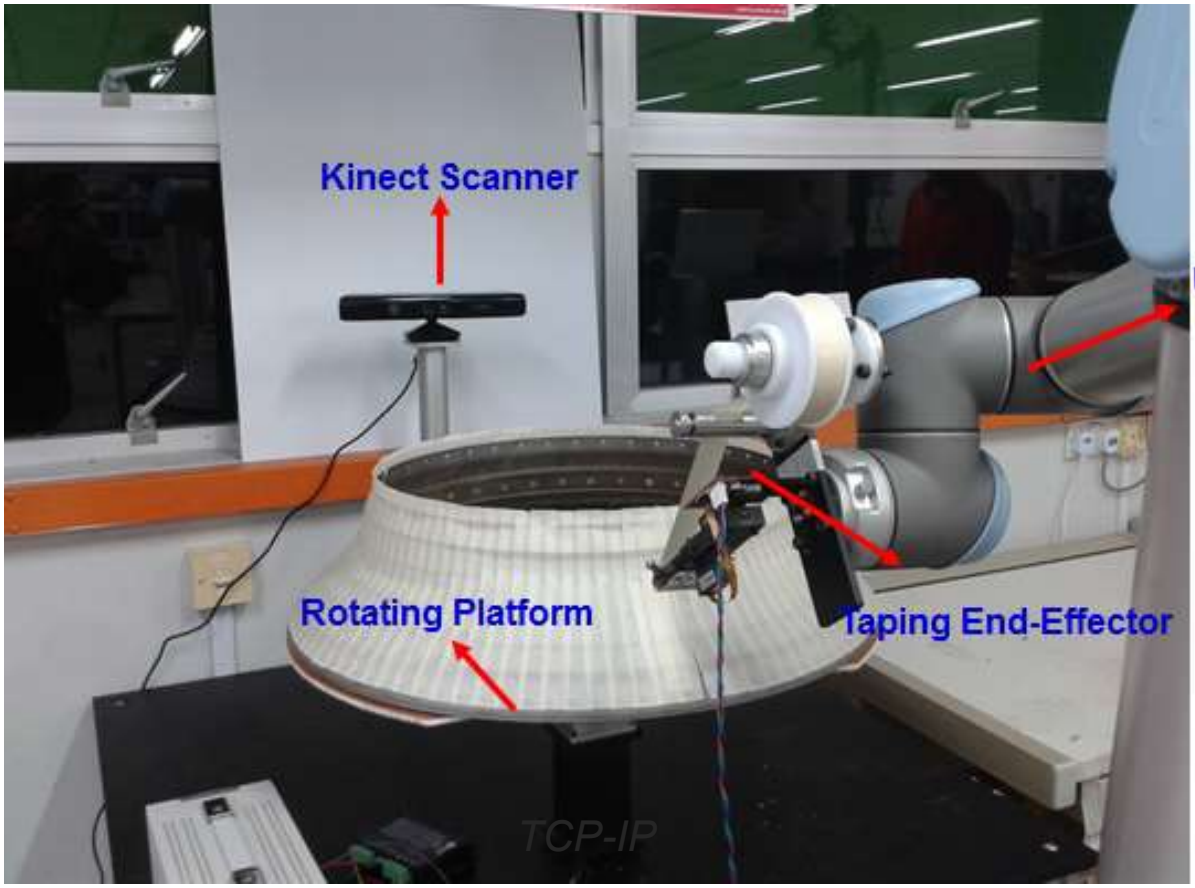
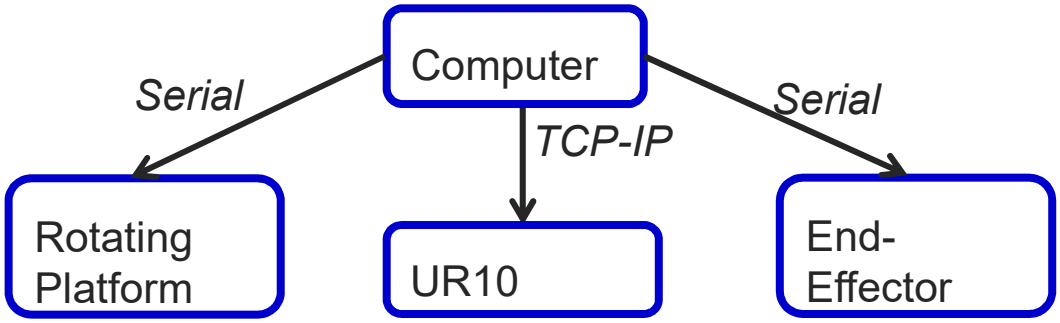
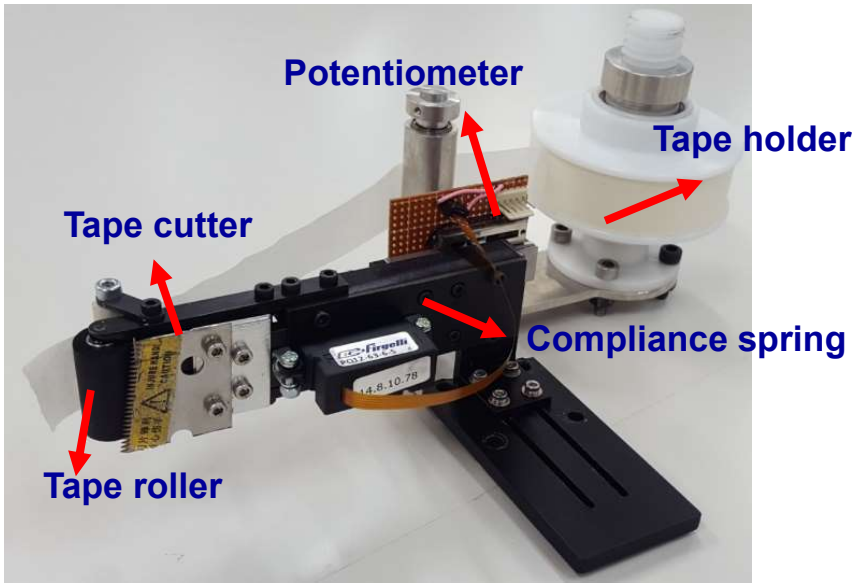
- Robot execution

System Setup





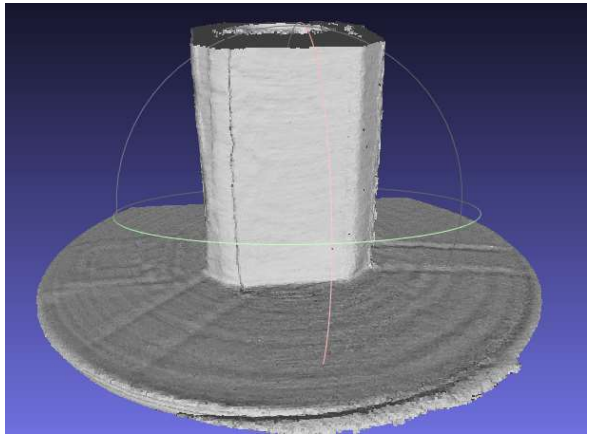
Taping End-Effector Design



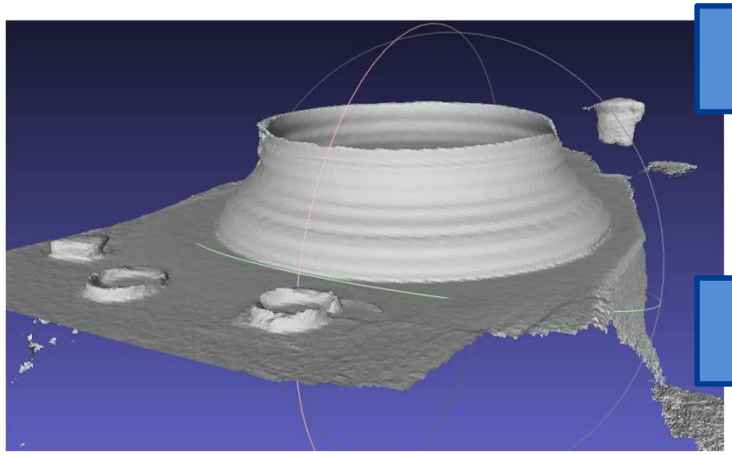
- The taping tool is used as the robot end-effector to handle the tapes and conduct the actual taping process.
  - The **tape holder** is used to hold the masking tapes.
  - The **tape roller** is used to attach tape to surfaces.
  - The **tape cutter** used to separate tape segments.
  - The "**compliance spring**" mechanism with 10 mm compliance at 23 N from the internal extension spring
  - **Linear potentiometer** enables distance/force feedback

Reconstruction of workpiece model

- The object is mounted on the rotating platform.
- A 3D scanner is used to scan the object
  - The result is point cloud data (x,y, and z points on the surfaces)
  - Kinect (2-3mm), Artec Eva (<0.5mm), Sick (~0.5mm).

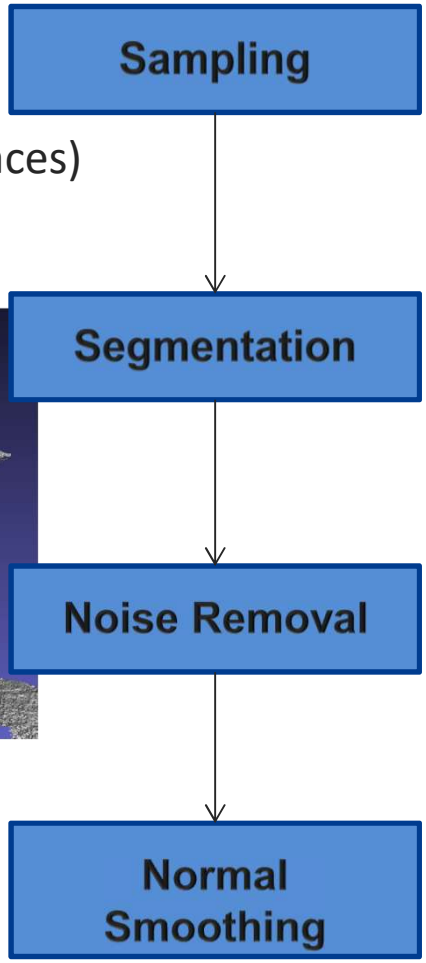


Box Scanning Result

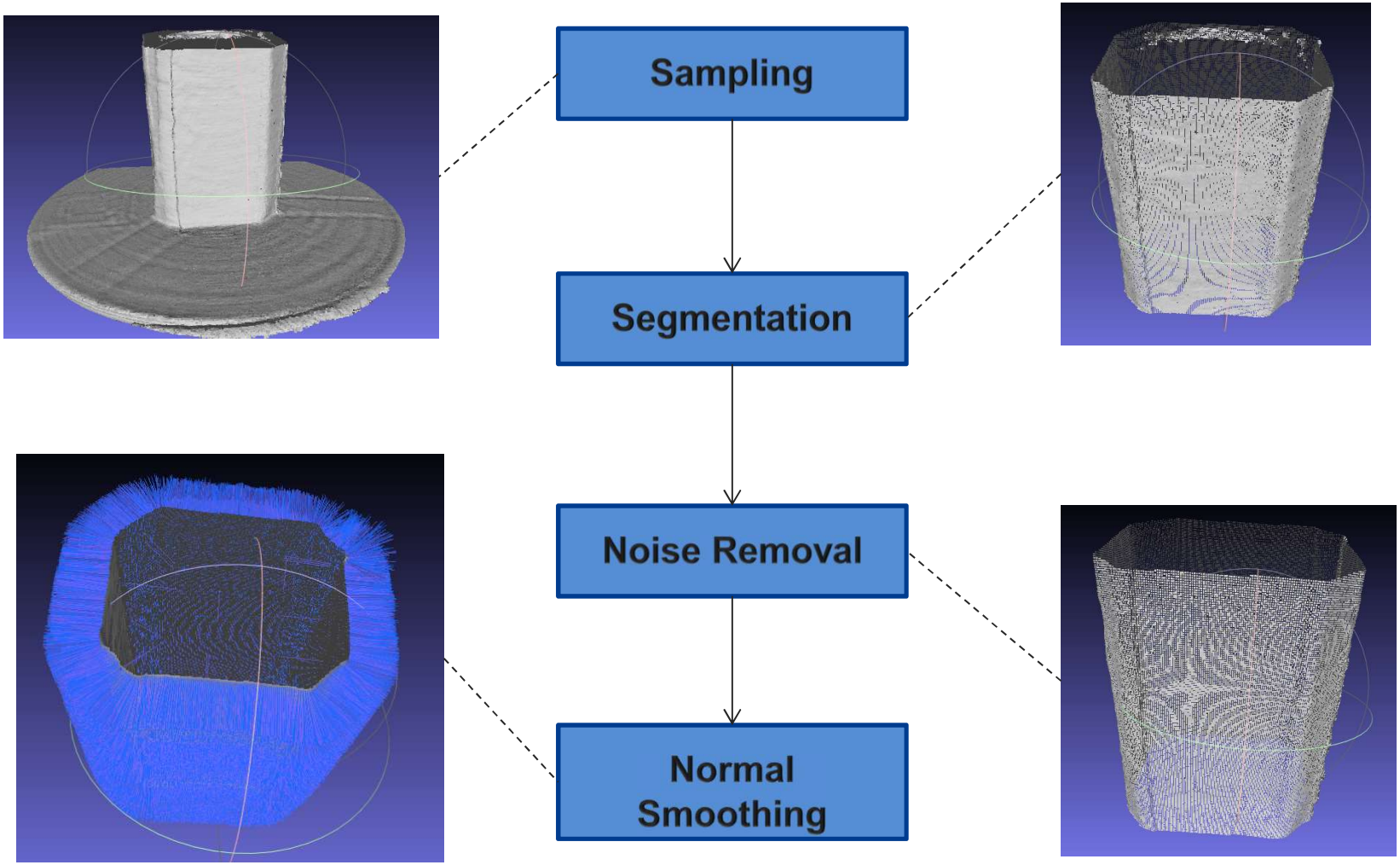


Engine Part Scanning Result

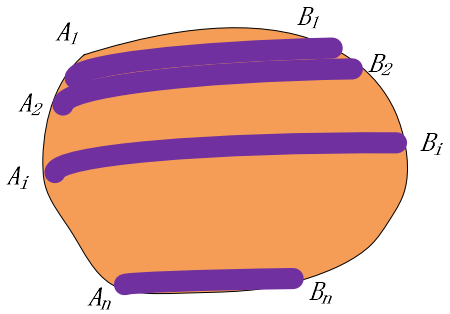
- The scan result: Post processing is required

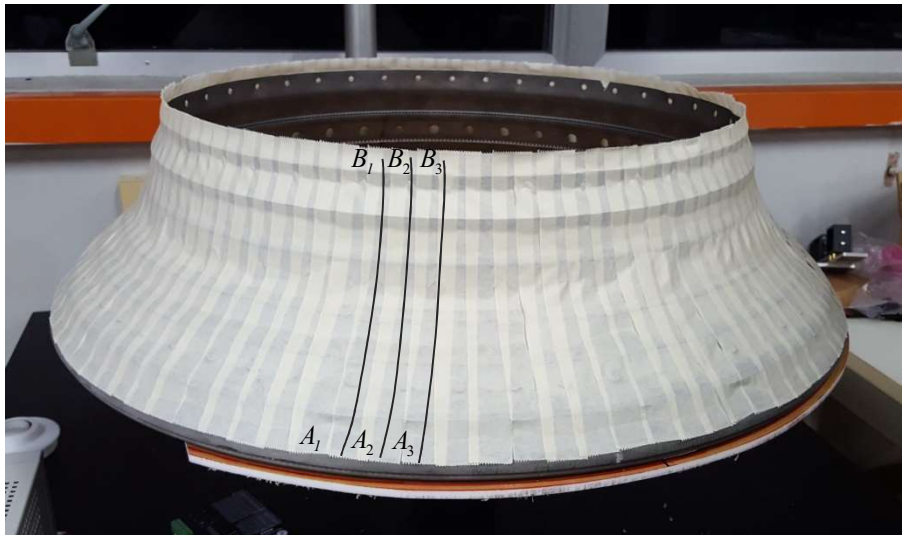


Post-Processing



Surface Covering Methods





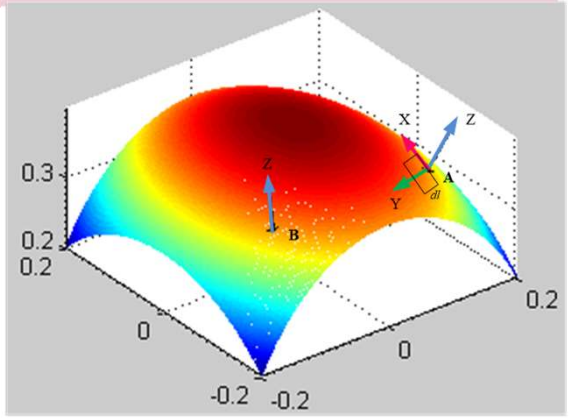
- Covering an area: Separate into sub-surfaces and cover each area applying tape segments in proper direction
  - Major parts have special geometries, flat, cylindrical or rotary surfaces etc.
  - Same type of workpieces have the same surface covering solution, which can be predefined.
  - How does the tape follow the surface for individual tape segment?

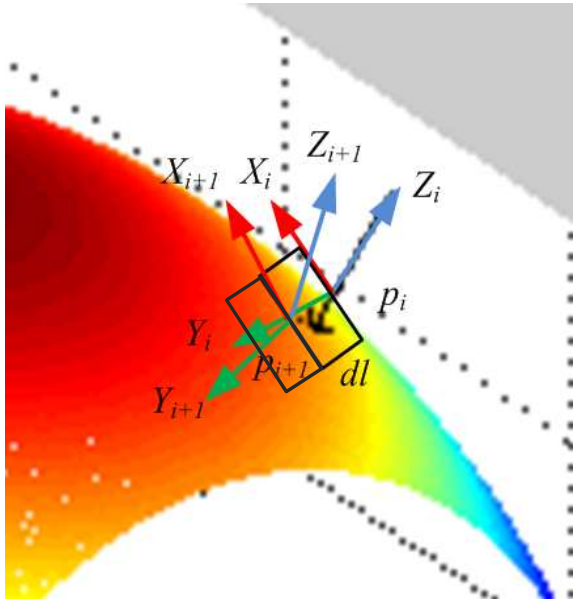
Principle for Point to Point Taping

- Define the tape frame
  - The y axis is the tape heading direction
  - The z axis is the up normal direction, X=Y×Z
- Taping along surfaces
  - Tape following the surface
  - Numerically, given a small taping forward step *dl*, estimate the next taping point,

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

  - Then, project it on surface
  - How to determine where to twist your tape?





Twisting the tape

- The twist axis is not moving, and it is perpendicular to surface normal of the two adjacent small tape element
  - Rotating Axis

$$V_i = \frac{z_i \times z_{i+1}}{\left| z_i \times z_{i+1} \right|}$$

  - Rotating Angle

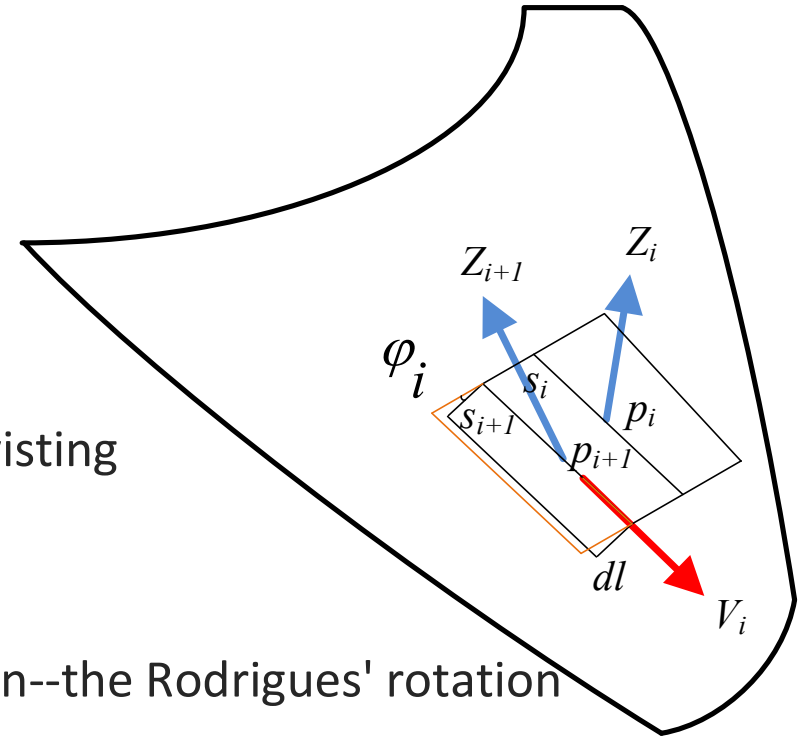
$$\varphi_i = a\cos(z_i \cdot z_{i+1})$$

  - Update the taping direction after twisting

$$y_{i+1} = F(\varphi_i, V_i, y_i)$$

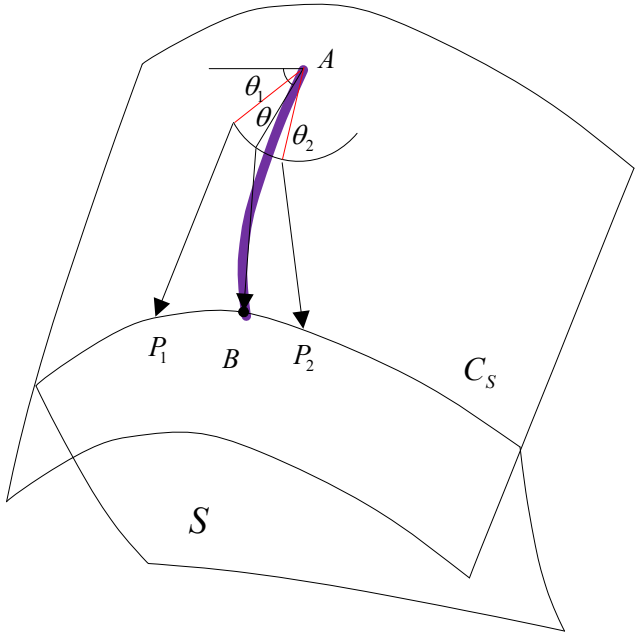
  - *F* denotes the twist mapping function--the Rodrigues' rotation formula

$$y_{i+1} = \cos\varphi_i y_i + \sin\varphi_i (V_i \times y_i) + (1 - \cos\varphi_i)(V_i \cdot y_i) V_i$$



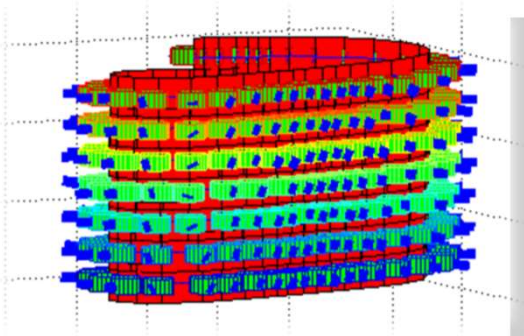
Point to Point Taping

- *Initial Taping Orientation* to make sure the tape reach the target
  - Numerical Solution
- The introduced method match exactly with the geodesic path using the geodesic path algorithm
- Much faster with less computation then the geodesic path algorithm .

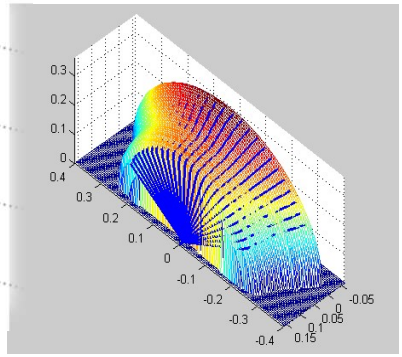


Taping Path Planning

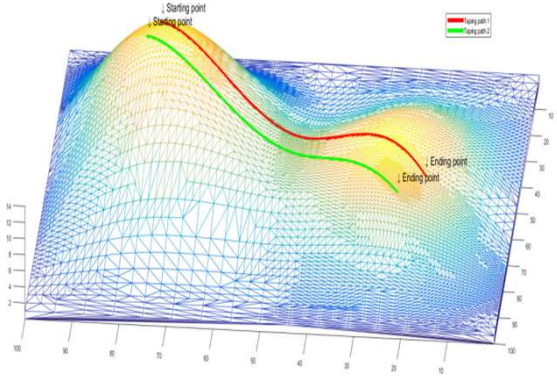
- Taping path planning on the workpiece
  - Cylindrical-like surface (a)
  - Rotational Symmetrical surfaces (b)
  - Freeform surface (including flat surfaces) with no grooves (c)
  - Surfaces with grooves. (d)



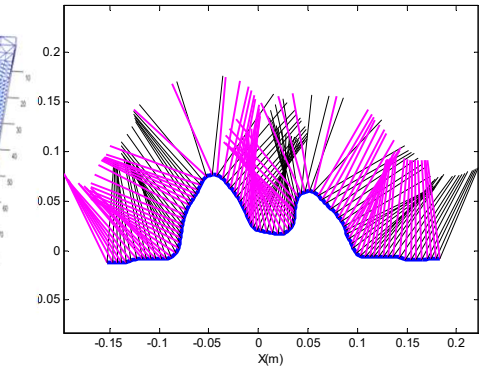
(a)



(b)



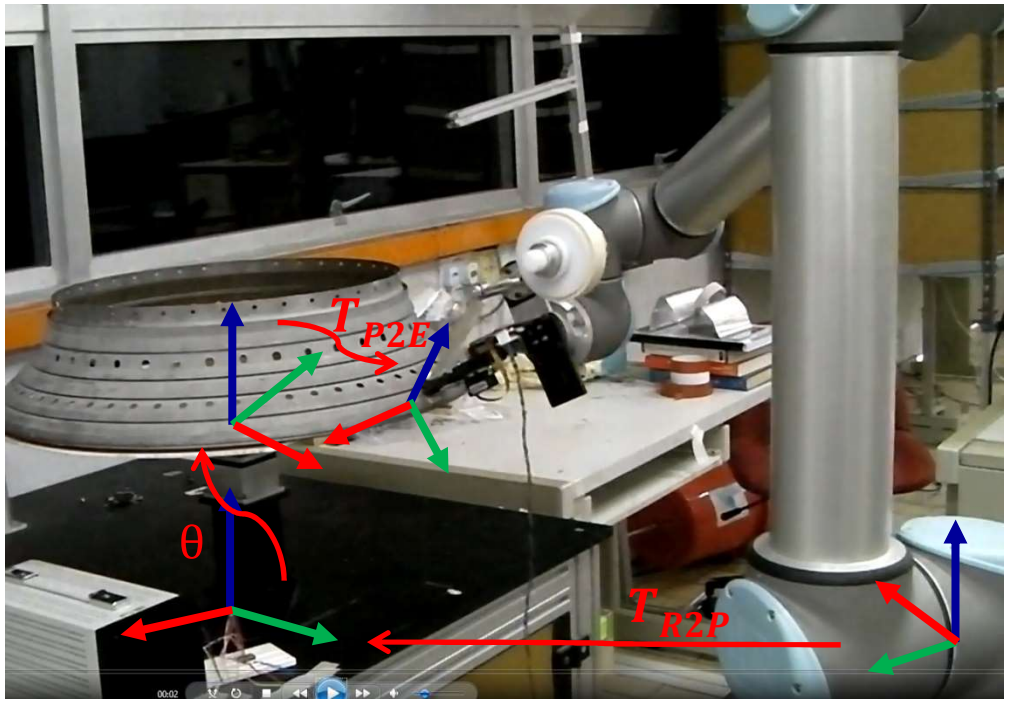
(c)



(d)

Robot Platform Path Generation

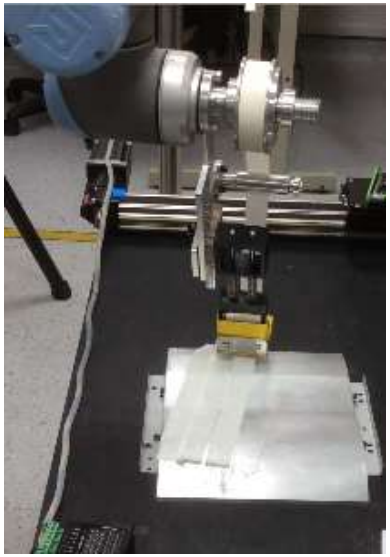
- The rotating platform collaborates with robot manipulator
- At a time t, calculate the posture of the end-effector
  - The rotating angel for the rotating platform, θ
  - The target posture of the end-effector with respect to the platform T_{R2P}
  - The coordinate mapping between the robot bask and the platform base T_{R2P}, which is calibration initially.



Robotic Taping Experiments (1)

- Preliminary taping tests on
  - Cylindrical like surface (see Figure (i))
  - Freeform surface taping (see Figure (ii))
  - Grooves surface taping (see Figure (iii))

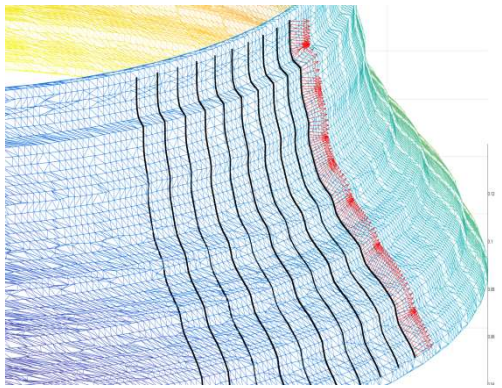
(i)



(ii)

(iii)

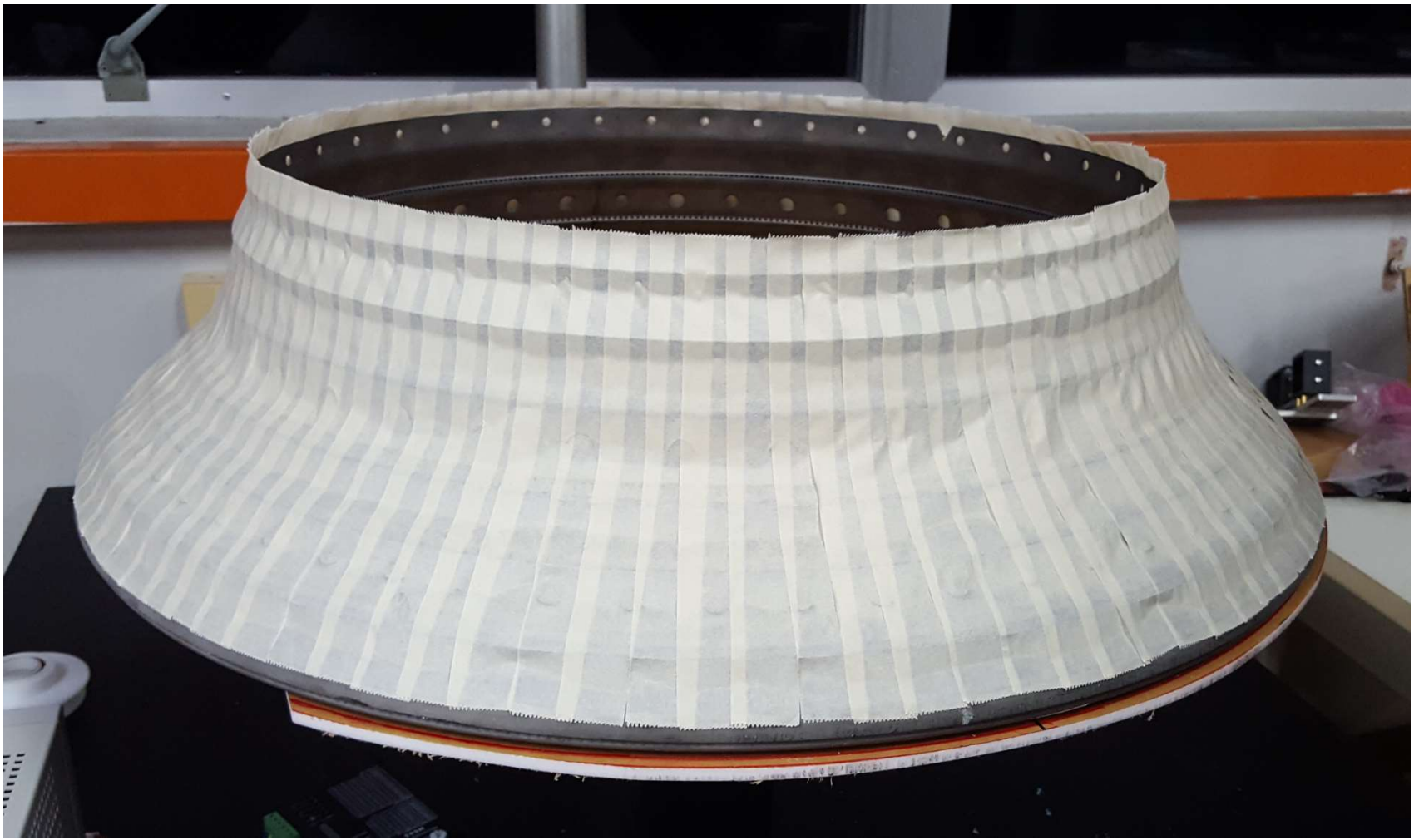
Robotic Taping Experiments (2)



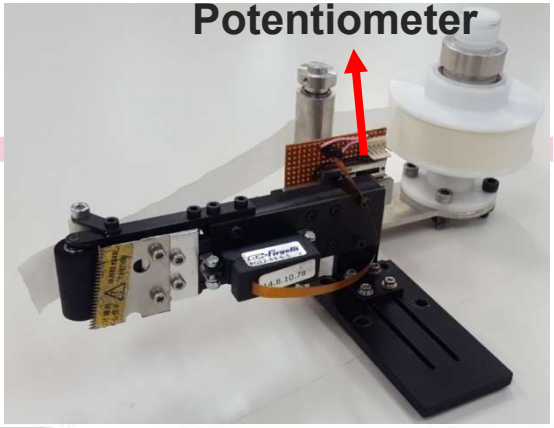
- Taping an engine part
  - Overlapping of tape (10%)
  - **Taping speed:** 1.6m/min
  - 11 mins, tape length 18 meter, area 7000(cm2)
  - With force feedback , the system can attach the tape properly along the entire surface.

Failure while no feedback

Robotic Taping Experiments (2)



Force Feedback



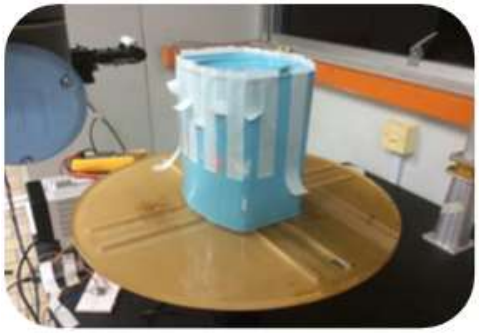
- Force feedback based on linear distant sensors
  - *Define the force range:*

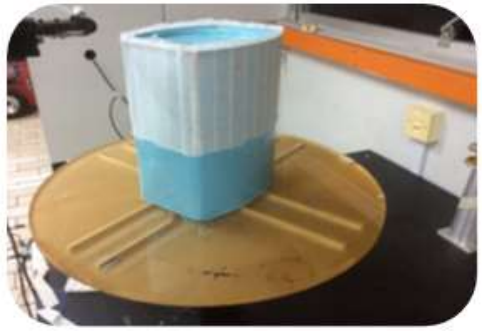
    $F_{min} < F < Fmax$
  - **Loop:**
  - If *Fmin < F < Fmax*

    Go to Next
  - If *F< Fmin*

    $d_n = d_n + 0.05$
  - Else if *F > Fmax*

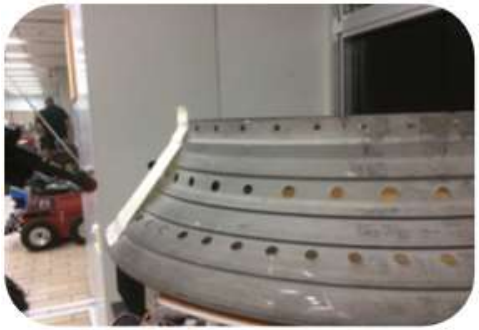
    $d_n = d_n - 0.05$
  - **Go to Loop**
  - **Next:** Go to next point

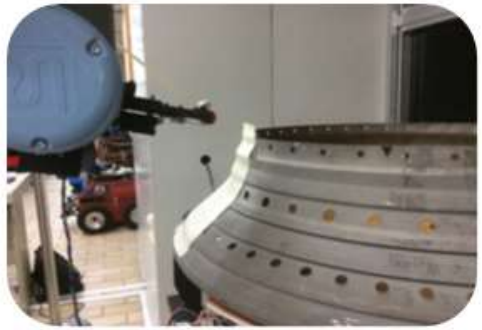




No Force Feedback

With Force Feedback

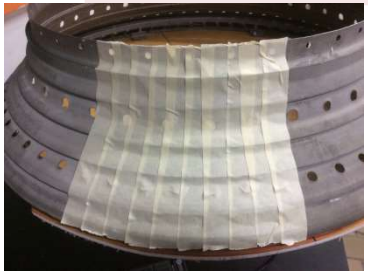


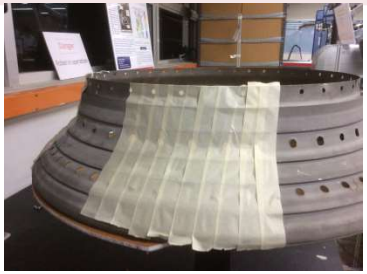


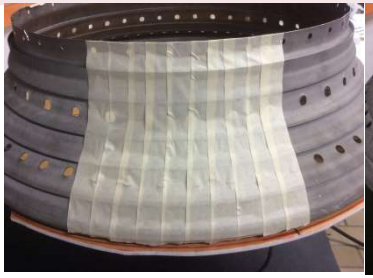
Competition: Robot VS Human

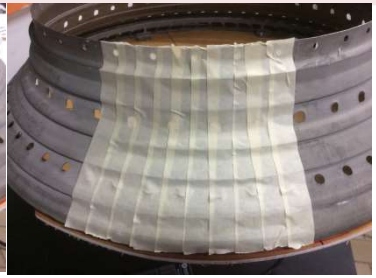
Inner liner taping: Comparison between human operator and robot

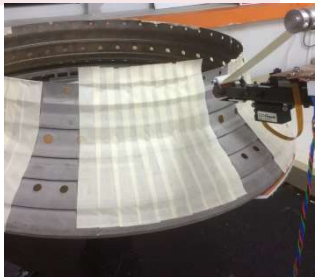
Operator	Time	Tape Length	Area	Quality (Overlap, wrinkle)
No. 1	1m 56s	1.9m	350cm^2	Uneven, Wrinkle
No. 2	1m 39s			Uneven, Wrinkle
No. 3	2m 41s			Uneven, Wrinkle
No. 4	2m 12s			Uneven, Wrinkle
Robot Taper	1m			Even overlap, Flat
Remarks: The competition is based on taping the inner liner with 10 tape segments. Four people participate in the challenge with robot.				


Human 1


Human 2


Human 3


Human 4


Robot Taper

And the winner is…

Competition: Robot VS Human

- Volunteer subjects feel difficult in taping
  - Uneasy to maintain even overlapping
  - Incremental errors in orientation
  - Wrinkle happens very often
  - Tedious and arduous
- Competition
  - Robot can cover the majority of the parts for the engine repairing
  - Robot is faster
  - Human is more flexible taping tiny features.
  - Deal to size of the taping rollers and surface geometry constraints, taping tiny grooves on the surfaces is not available.
  - Robot can do the major job, and leave tiny difficult parts to human

Thank You !

Email: MICHEN@ntu.edu.sg