

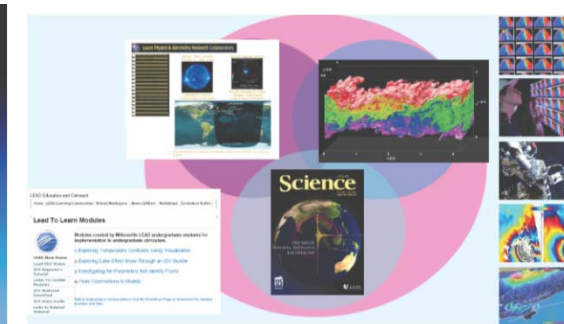
Industrial Automation in the Information Era

Ning Xi

席宁

Emerging Technologies Institute
Faculty of Engineering
The University of Hong Kong
Hong Kong, China

Cyber Infrastructure



Human/
Computer
Interface

Humans



Cyber-Physical-Human System

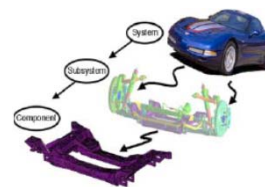
logistics



services



manufacturing

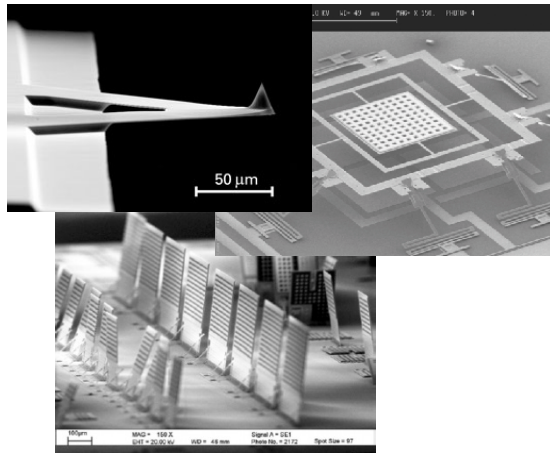


urban area



Physical Systems

Development of Automation Technology

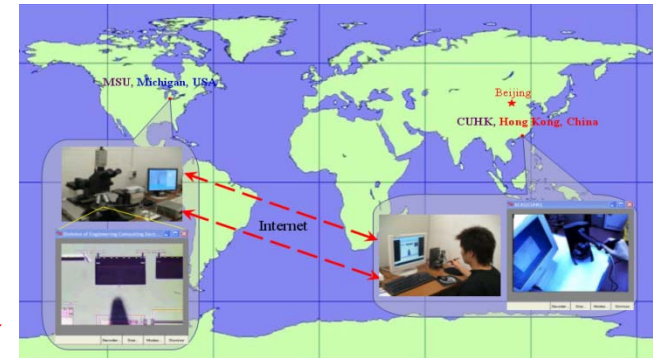


Micro/Nano Robots and Automation

Nano Technology

Scale (m)
 10^{-n}

Challenges



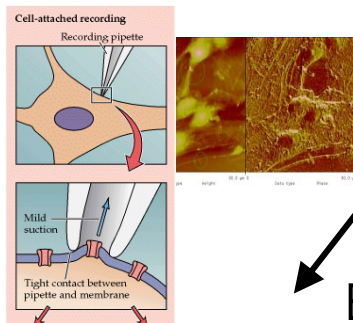
Ultra Robots and Automation

Distance (Km)



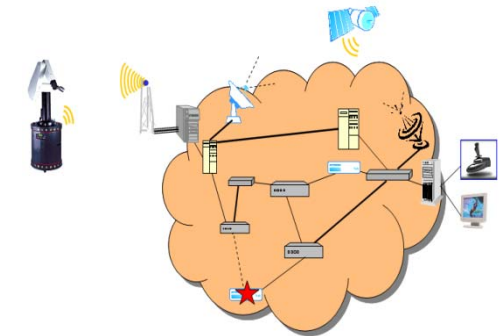
Biomedical Technology

Information Technology



In-Situ Robot & Automation

Environment



Tele Robot & Automation

Intelligent Robots for Industrial Automation

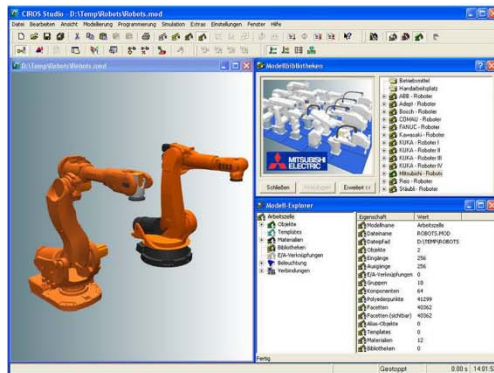
- Friendly

New Critical Technologies:

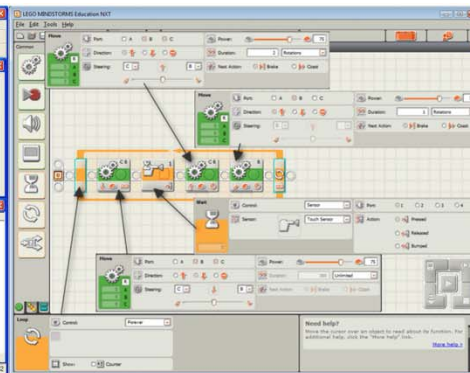
- Robot programming
- Robot calibration
- Robots Integration with sensors

➤ Accuracy

Existed Robot Programming Methods



(a) Specific language



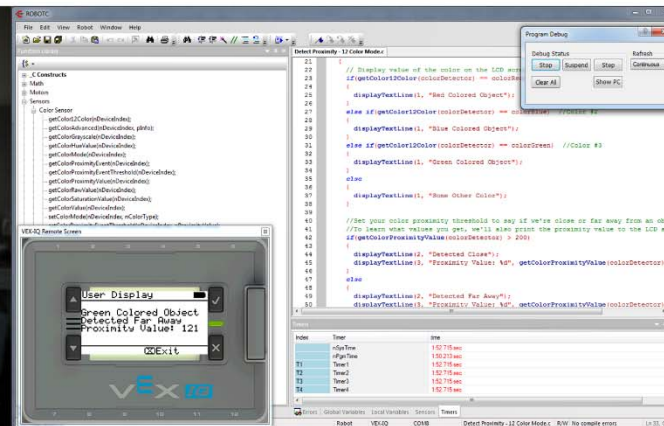
(b) Graphical language



(c) Programming by Demonstration

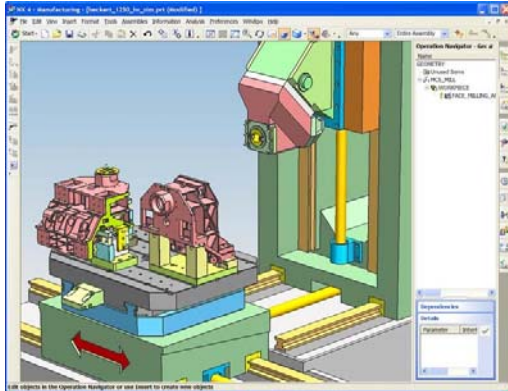


(d) Guiding

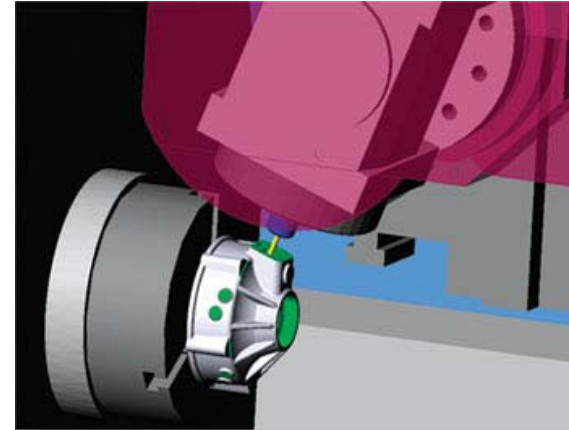


(e) Generic language

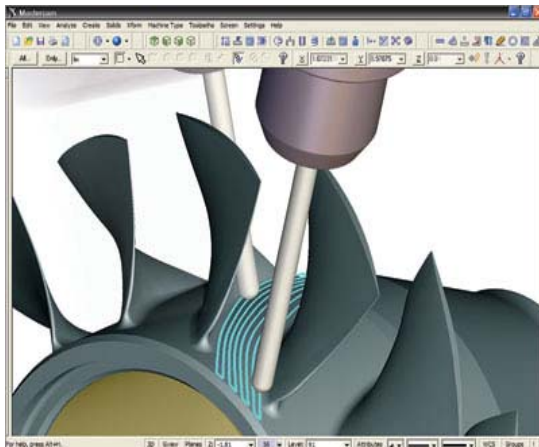
CAD-Guided Robot Programming



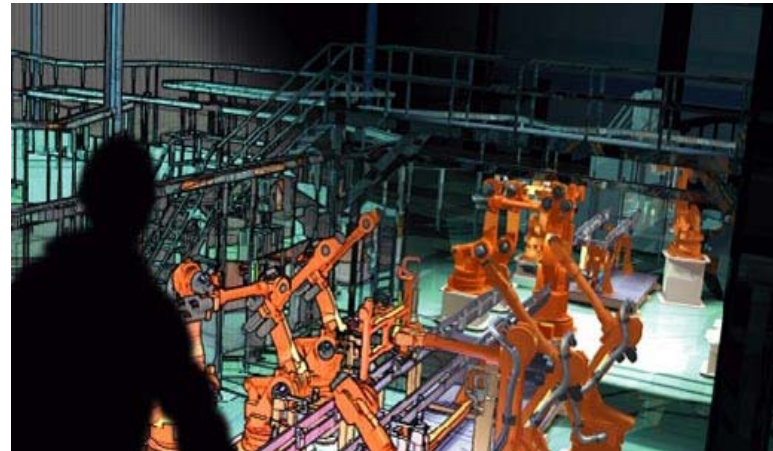
Design and Modeling



Robot/CMM Offline Programming

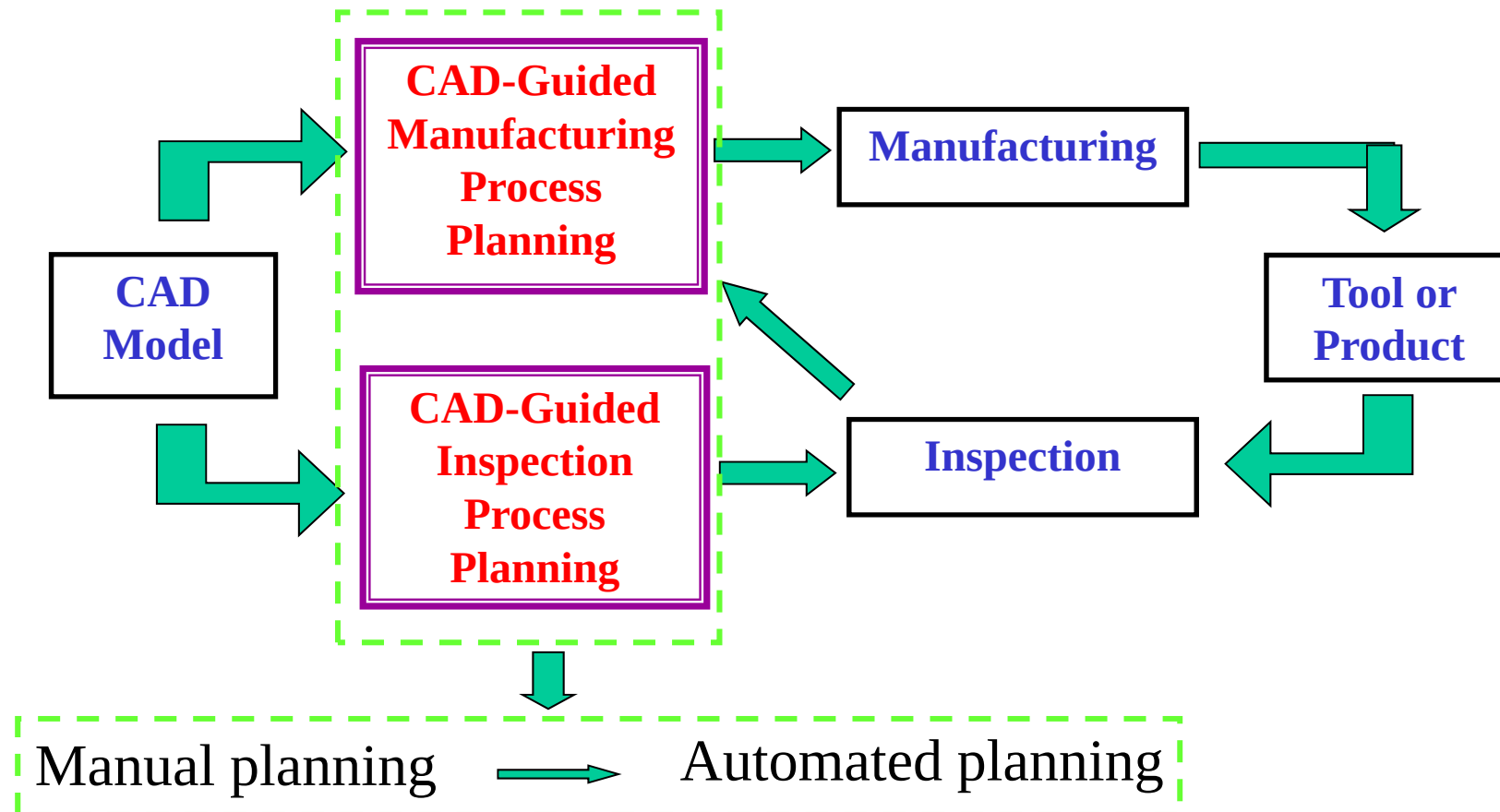


Tool Planning



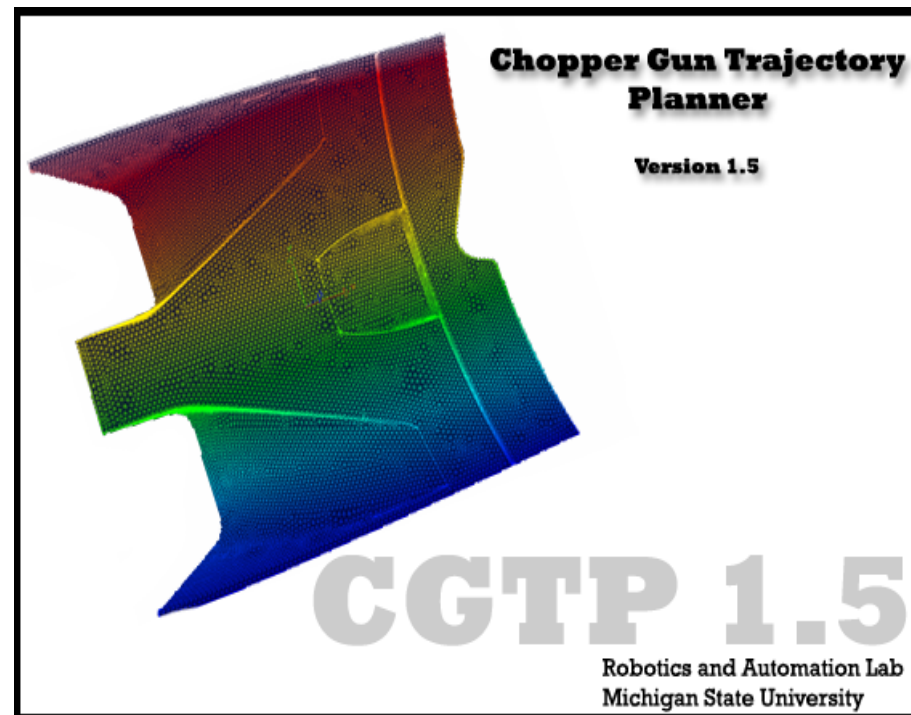
System Simulation

CAD-Guided Process Planning



CAD Guided Tool Planner CGTP Software

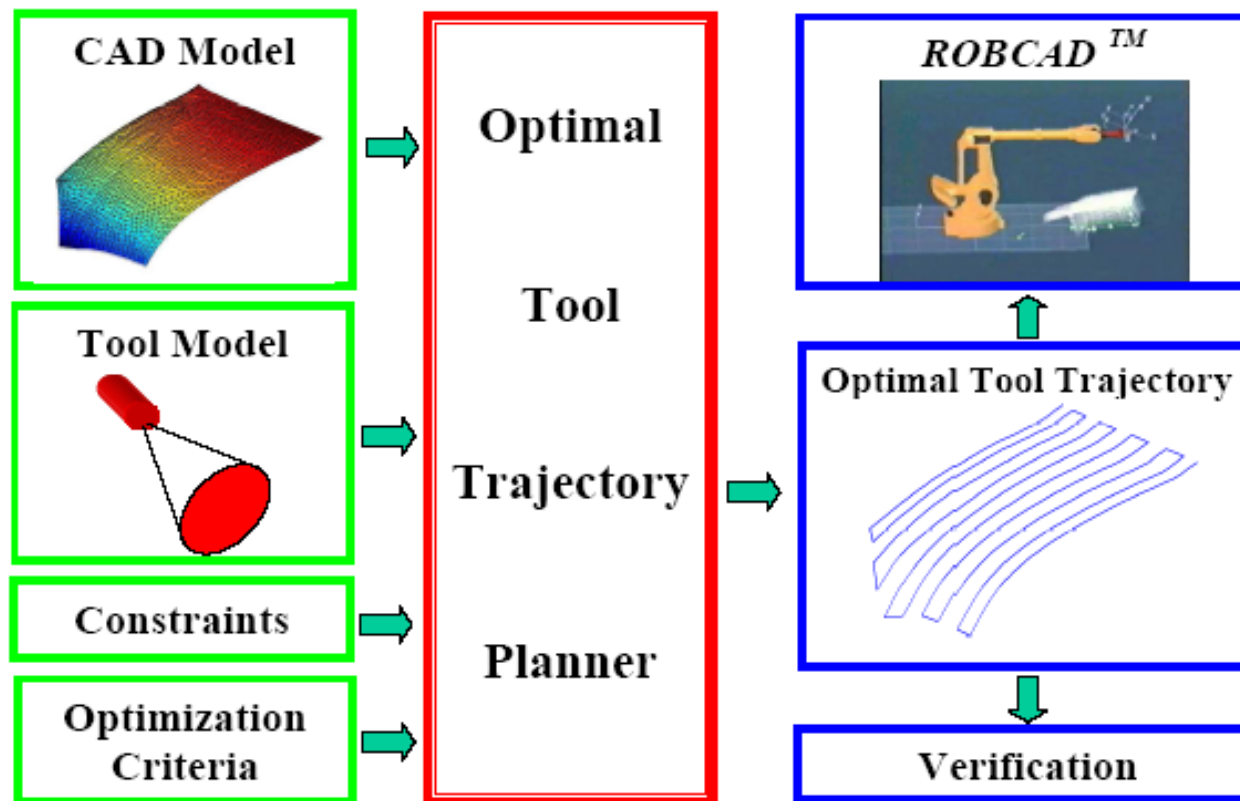
1. Part manipulation
2. Robot trajectory generation
3. Robot gun point manipulation
4. Robot path manipulation
5. Area density simulation



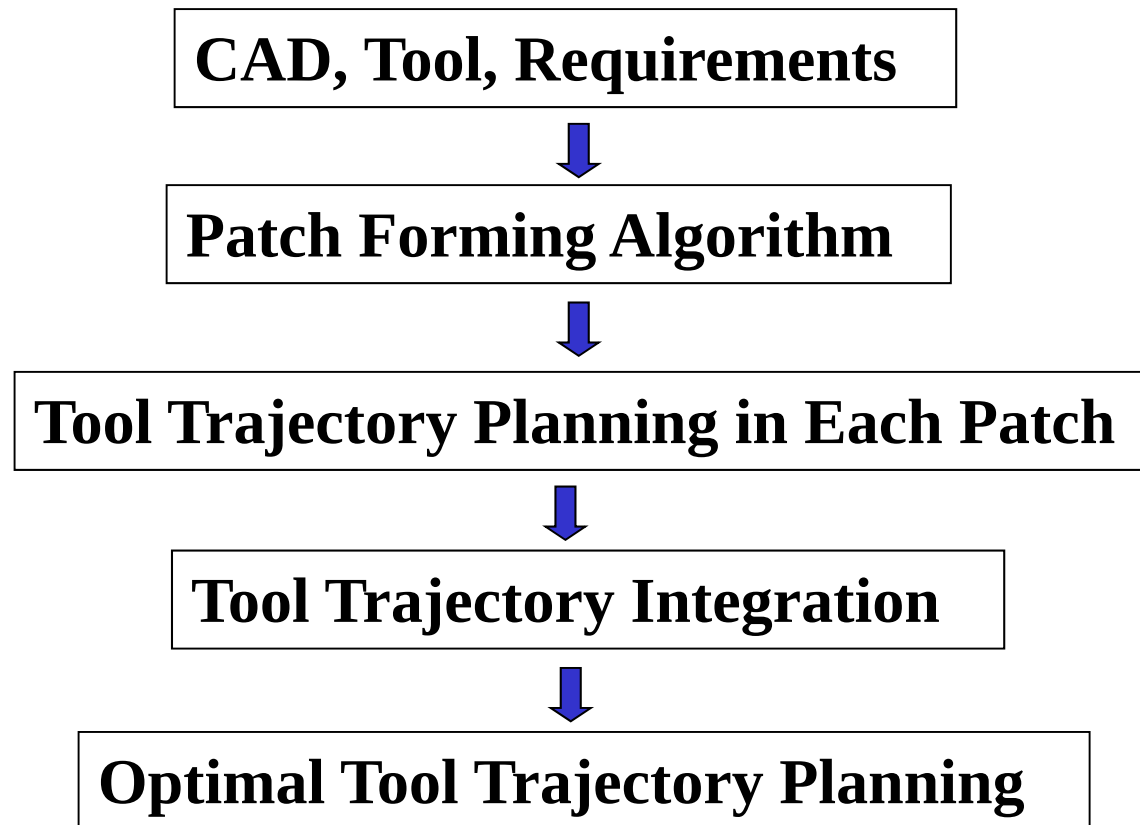
3D Printing Auto Parts

Preforming of
A Pickup Truck Box

CAD-Guided Chopper Gun Trajectory Planning System



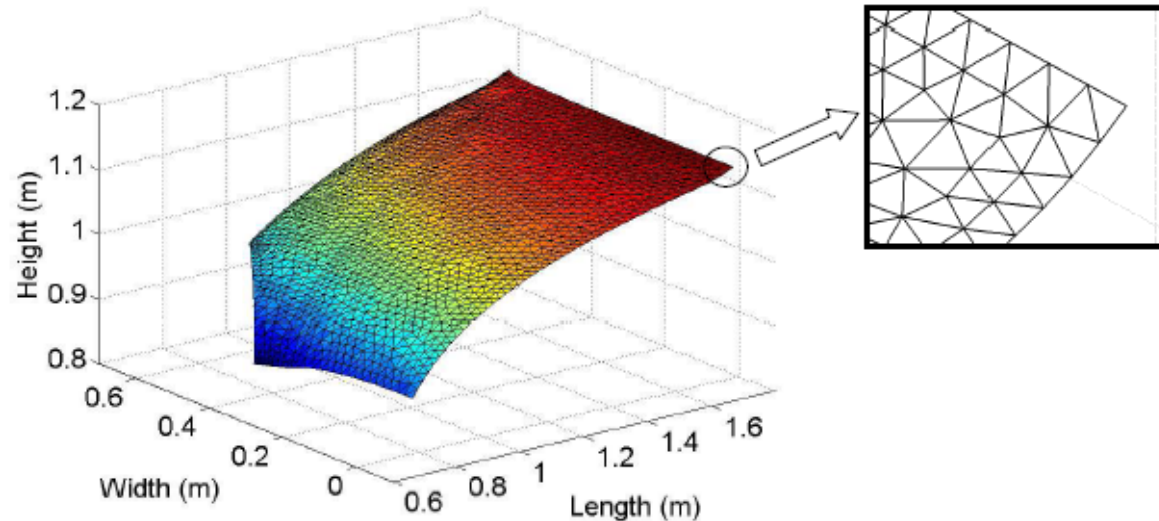
Automated Tool Path Planning



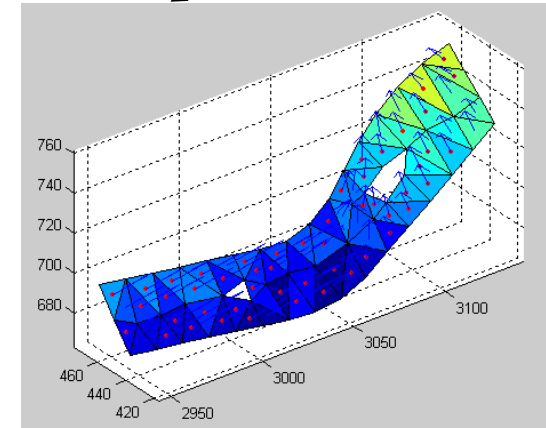
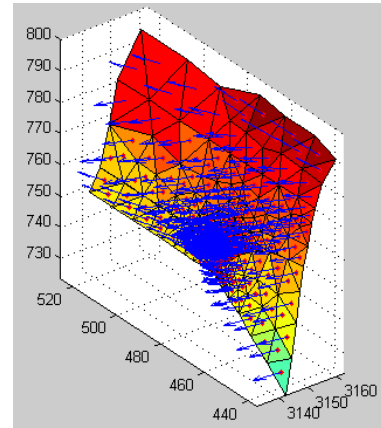
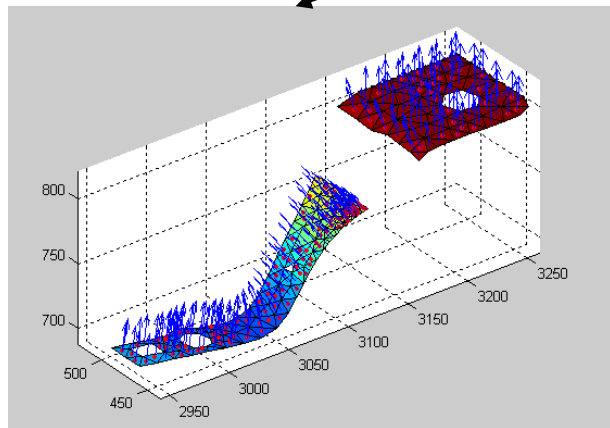
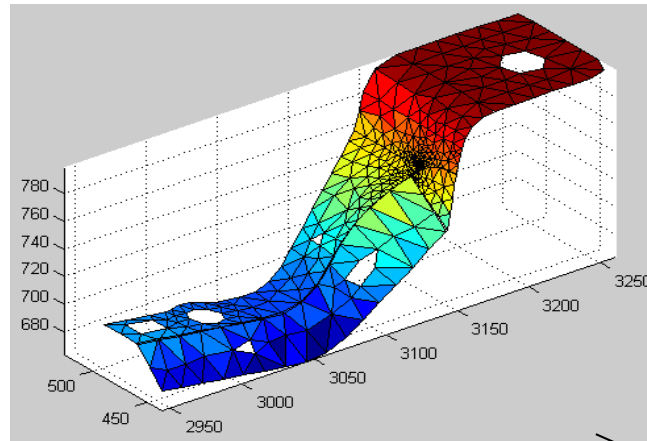
Mathematic Representation of a CAD Model

Mathematic representation of a CAD Model

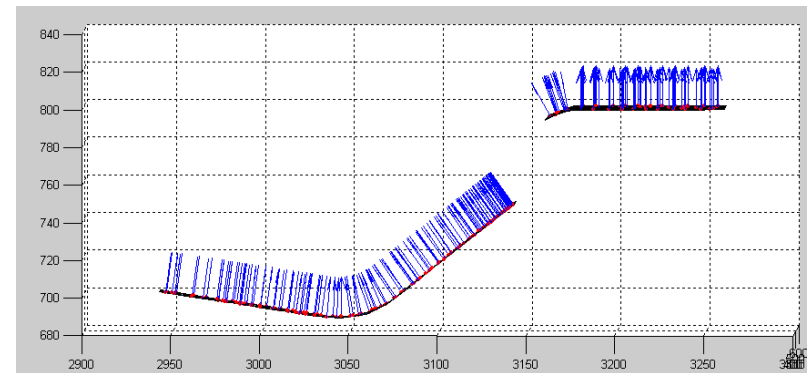
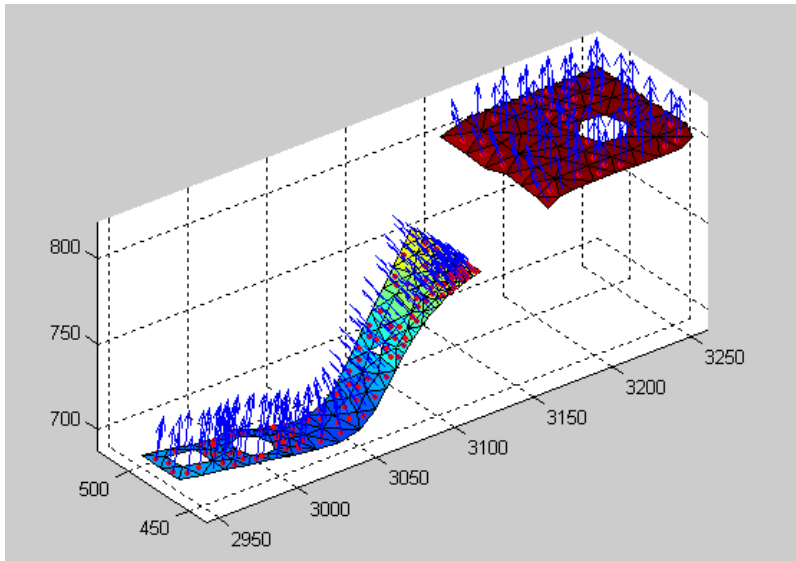
$$M = \{T_i; i = 1, 2 \dots N\}$$



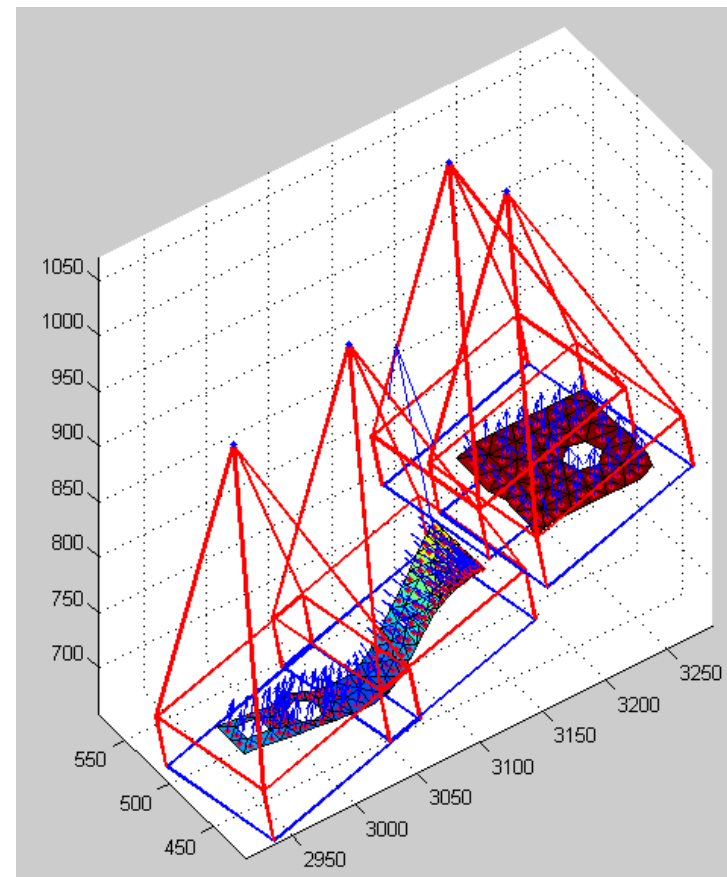
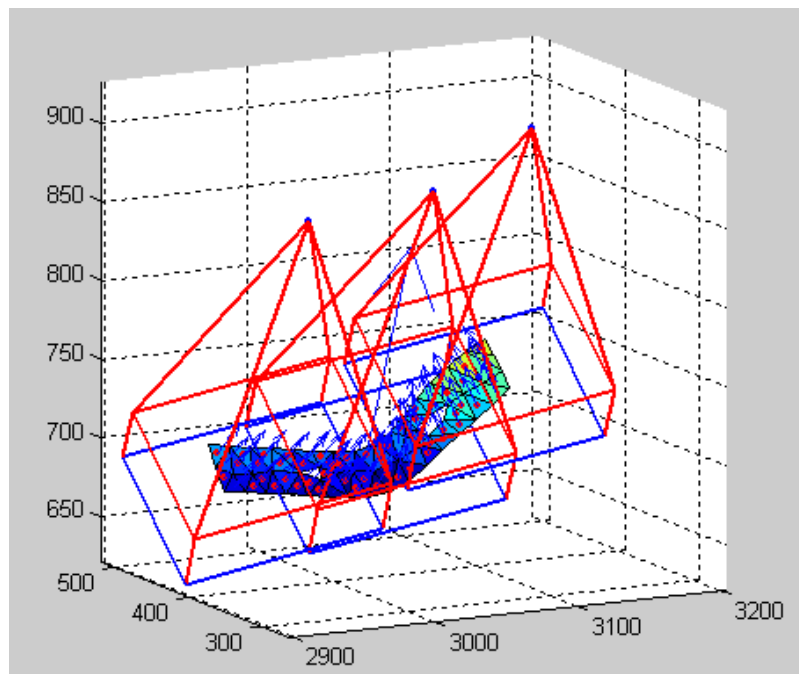
Partition of Patches using Average Triangle Norms



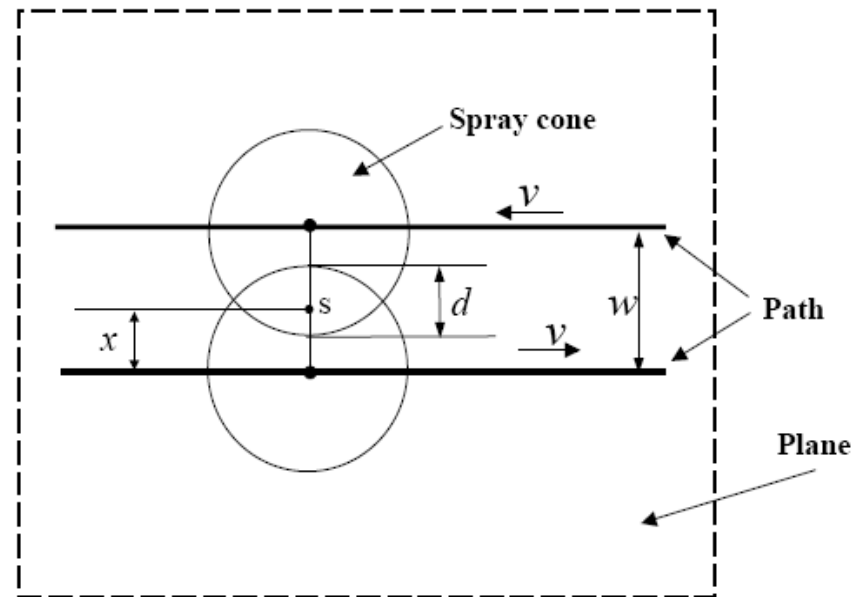
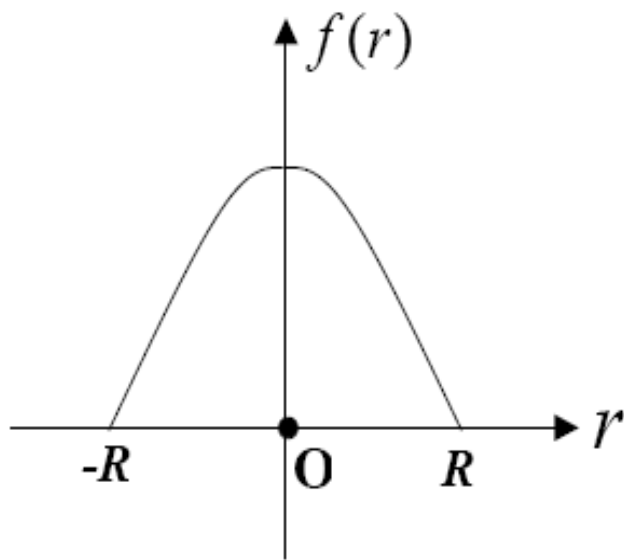
Clustering Triangles by Norm



Bounding Box and Gun Point Generation

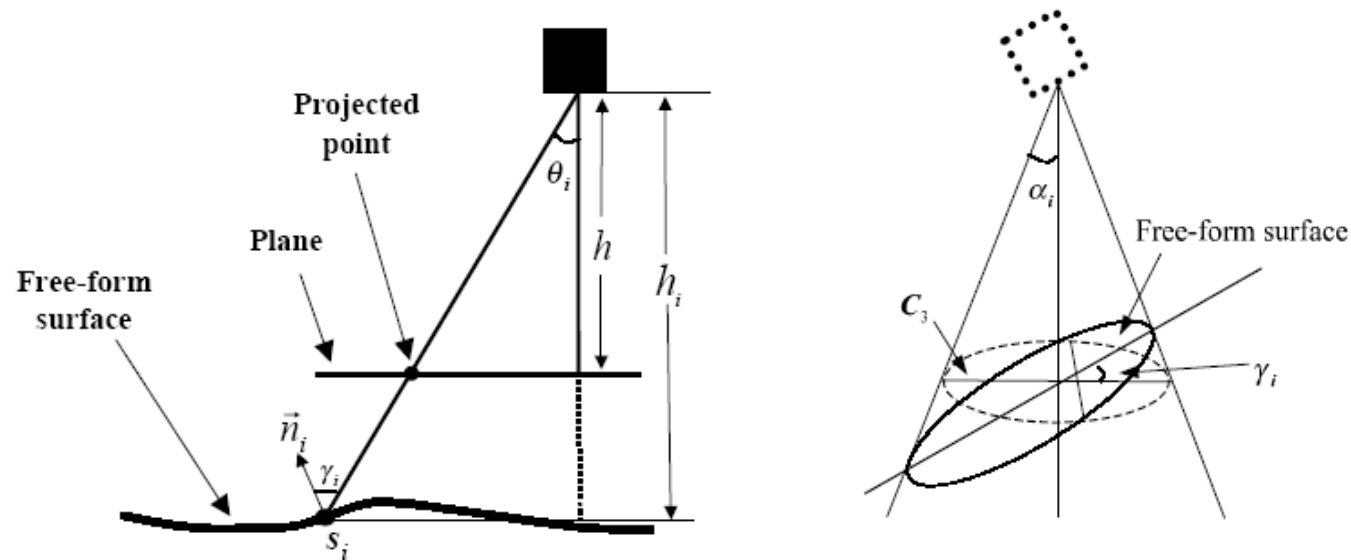


Tool Model and Task Constraints



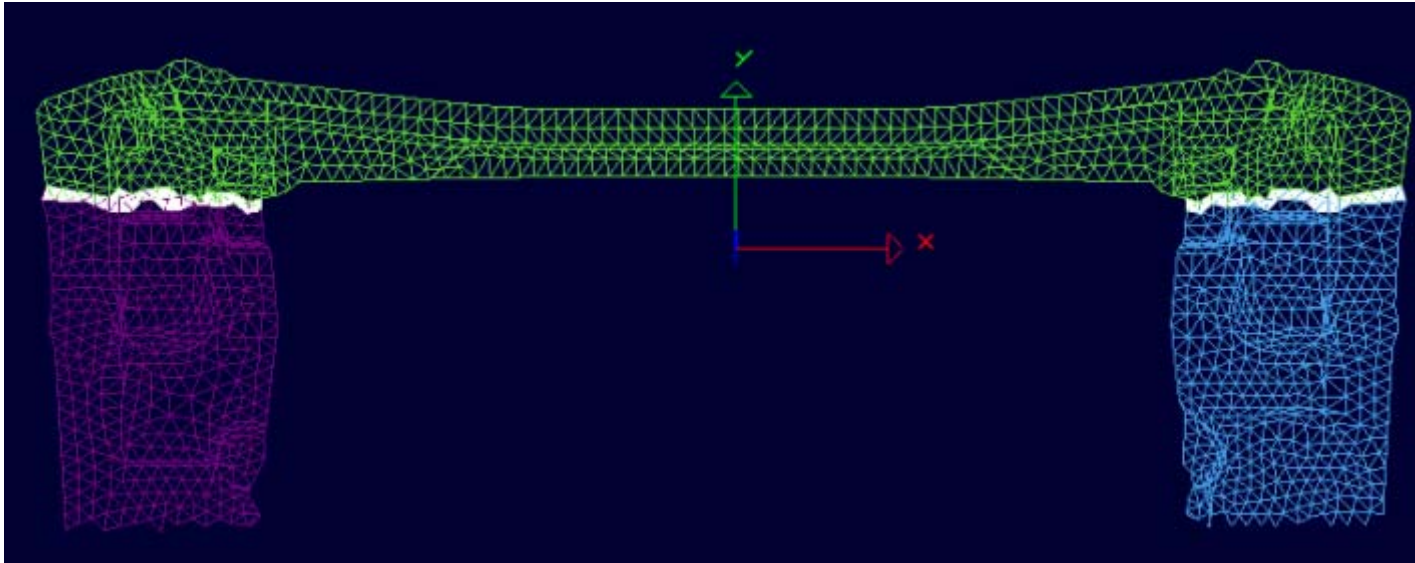
$$\bar{q} = \int_0^t f(r(t))dt$$

Optimization on a Freeform Surface

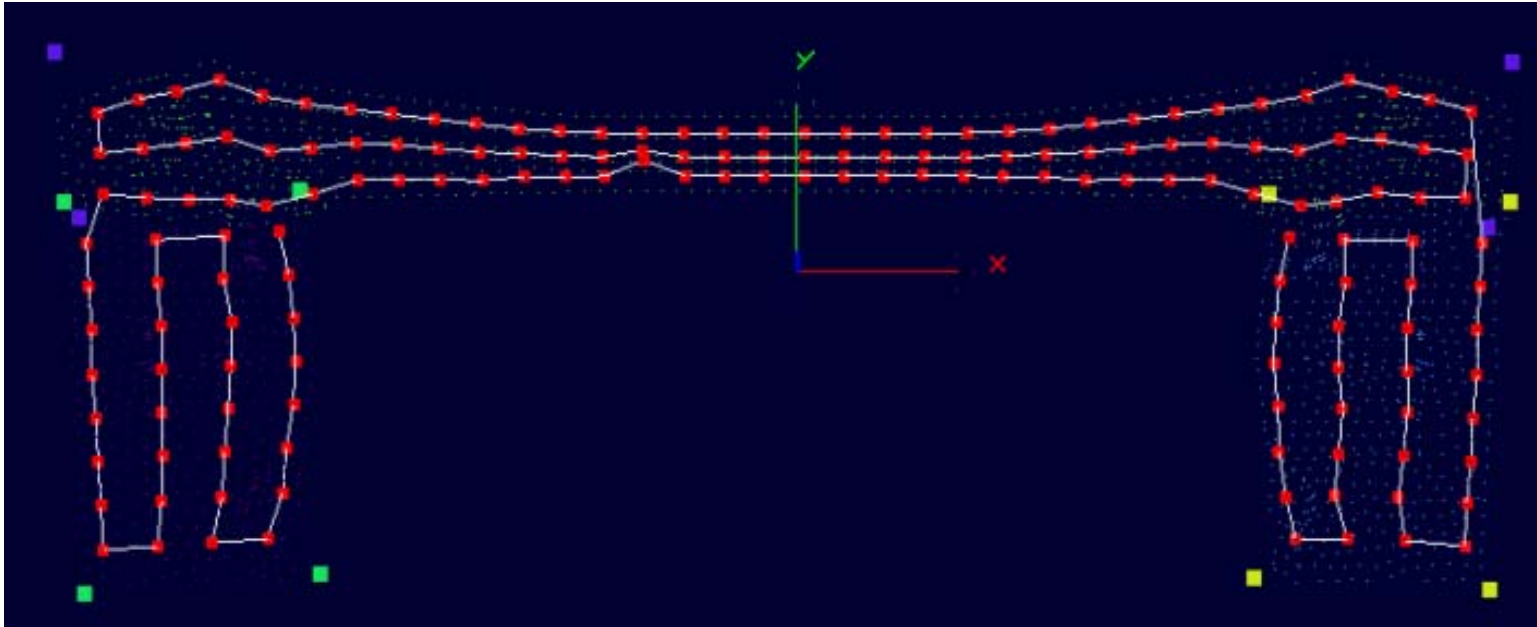


$$q_s = \bar{q} \left(\frac{h}{l_i} \right)^2 \frac{\cos \gamma_i}{\cos^3 \theta_i}$$

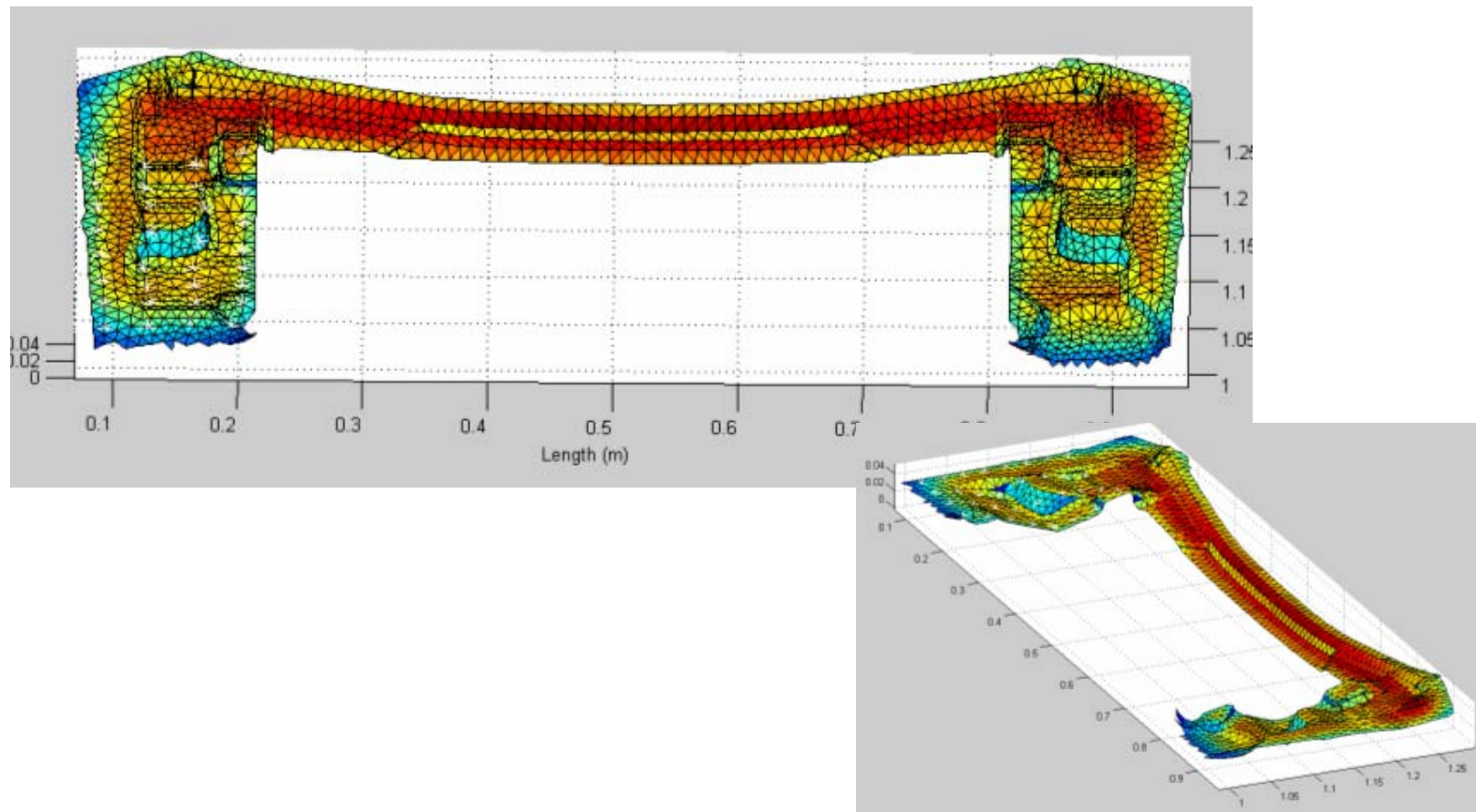
Manipulation of a CAD Model



Robot Trajectory Simulation



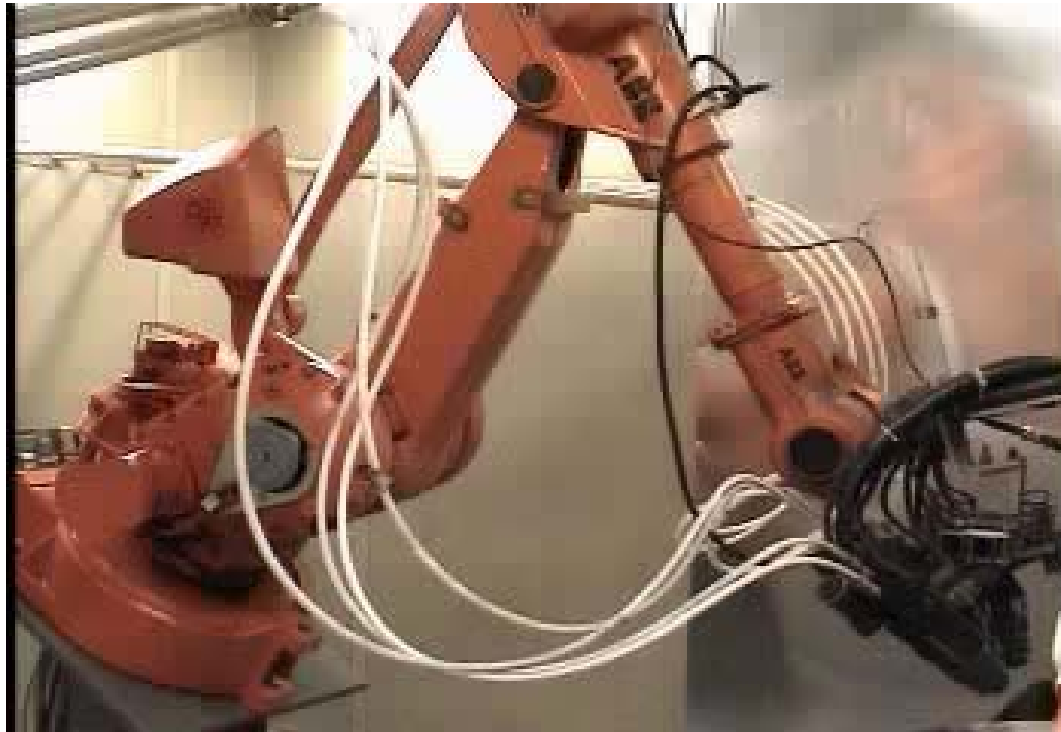
Robot Trajectory Verification



Automotive Spray Painting



3D Printing Tools



Automatic Programming in Robotic Polishing



Applications in Home Appliance Polishing

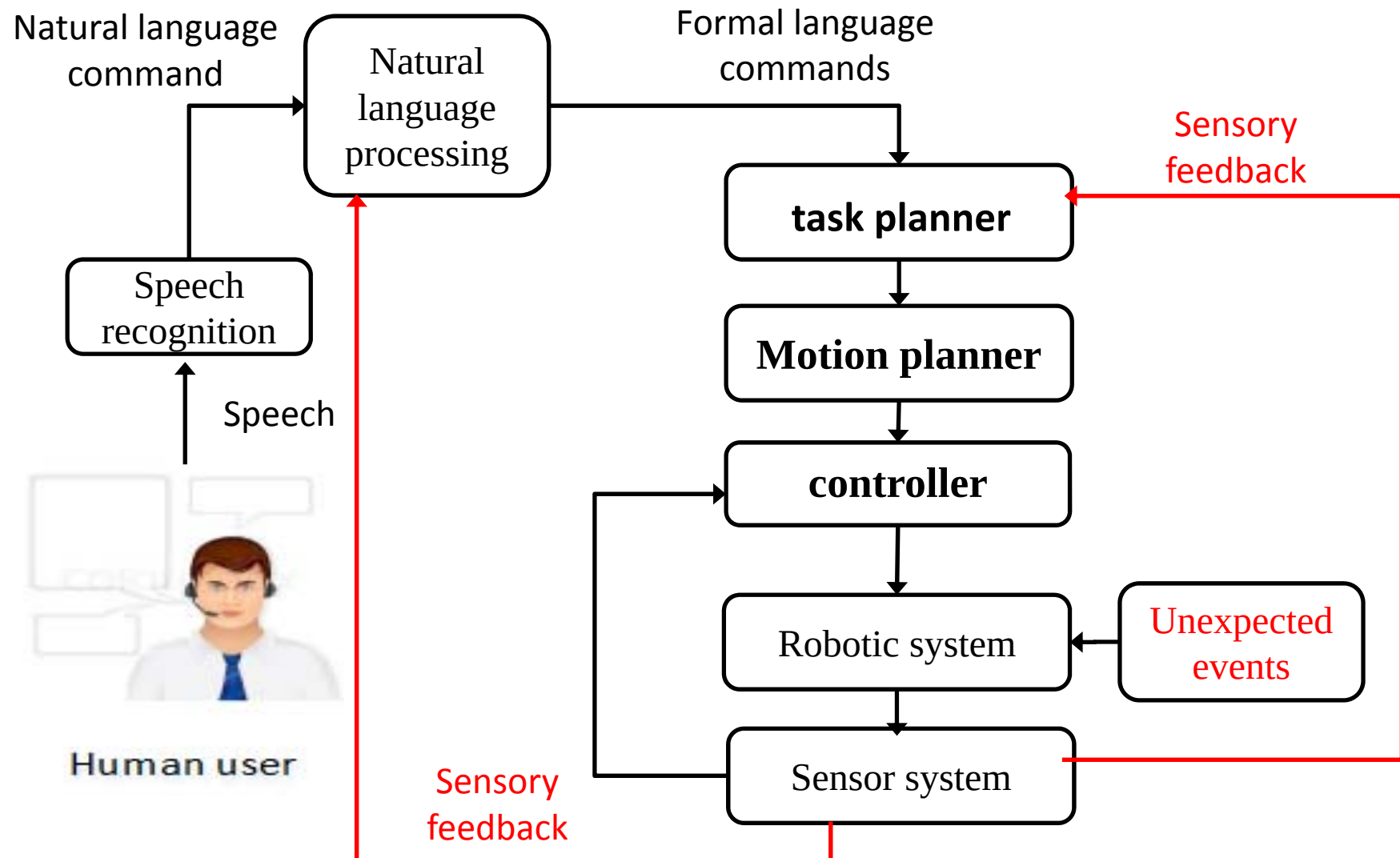


Natural Language based Programming and Control

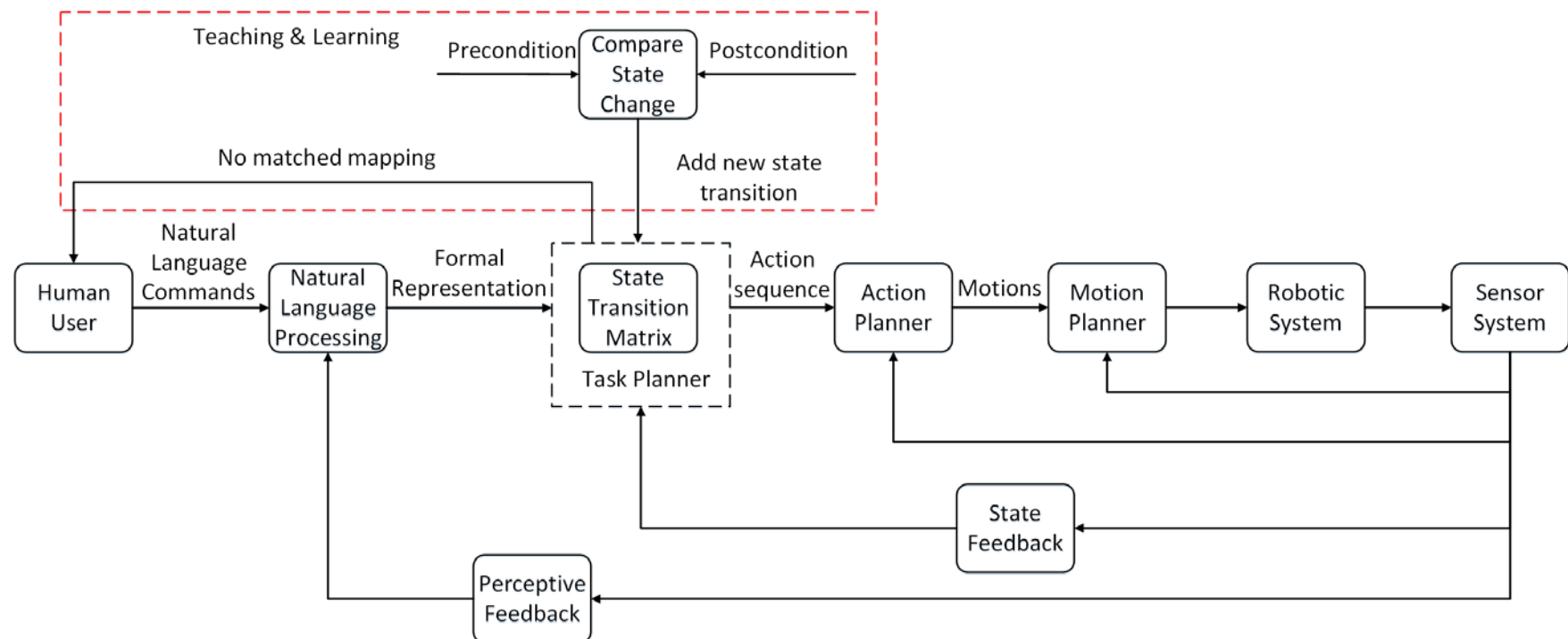
- Easy to program difficult tasks
- Less or even no training for users
- Natural language is convenient



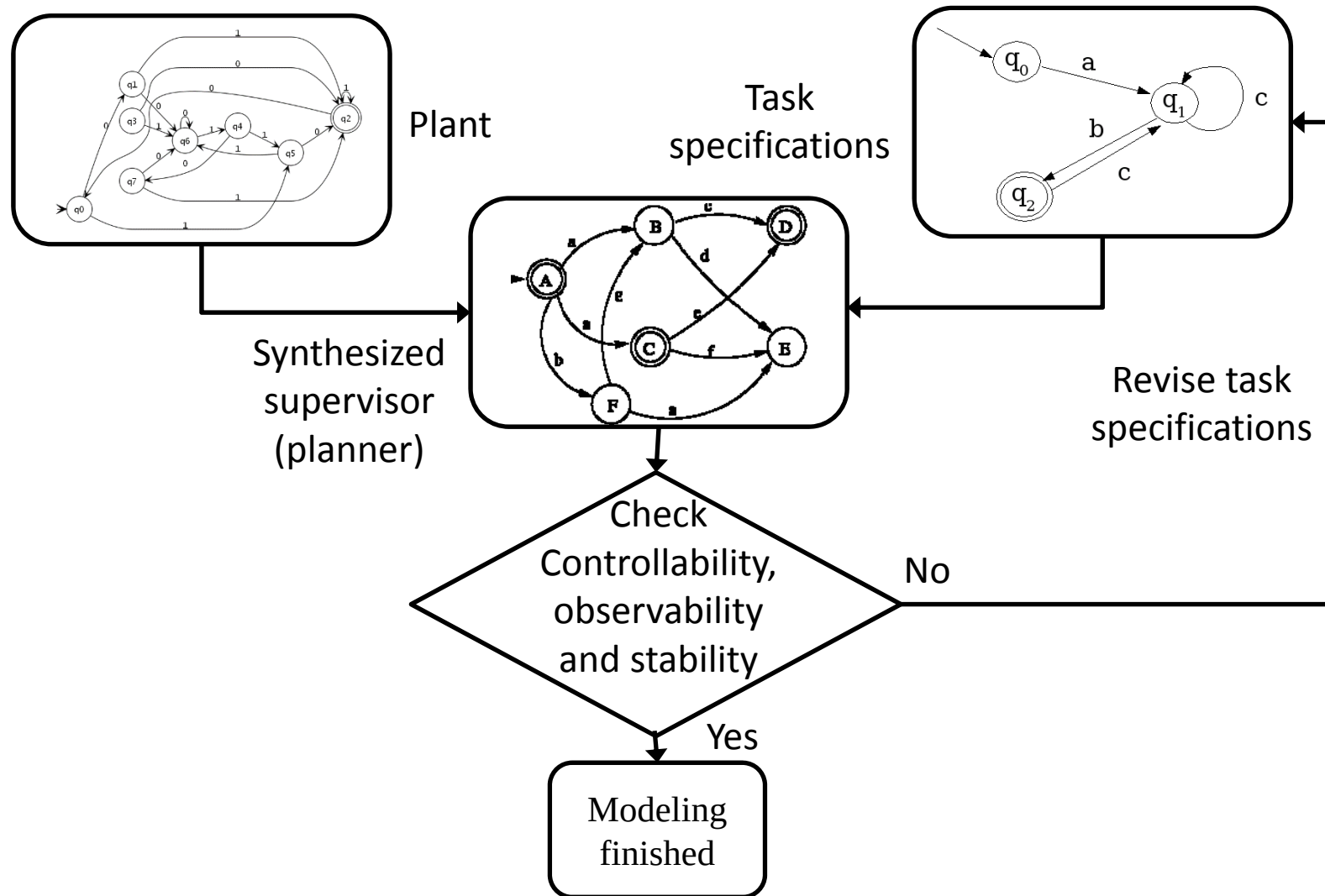
Natural Language based Control/Programming



Natural Language based Control/Programming Framework



Natural Language based Control/Programming



Natural Language based Control: Analysis

➤ **Controllability:** $\bar{K}\Sigma_{uc} \cap L \subseteq \bar{K}$

➤ **Lyapunov Stability:**

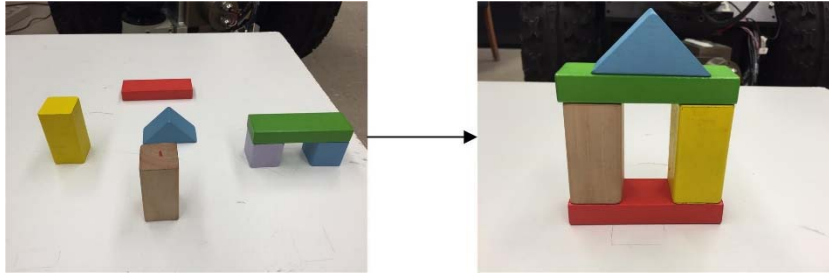
- A closed invariant set X_m is said to be asymptotically stable in the sense of Lyapunov w.r.t. E_a , in a sufficiently small neighbourhood $N(X_m;r)$ of the set X_m , if it is necessary and sufficient to find a functional which satisfies the following four conditions:
 1. For an arbitrary small $c_1>0$, a $c_2>0$ can be found in such a way that $V(x) > c_2$ for x in $N(X_m;r)$ and $d(x,X_m) > c_1$
 2. For an arbitrary small $c_3>0$, a $c_4>0$ can be found in such a way that $V(x) \leq c_4$ for x in $N(X_m;r)$ and $d(x,X_m) < c_3$
 3. $V(X(x_0,E_k,k))$ is a nonincreasing function.
 4. As k goes to infinity, $V(X(x_0,E_k,k))$ converges to 0.

$$V(x) = \rho(q, q_m) = \inf\{n : \xi(s, q) = q_m, s = \sigma_1\sigma_2\ldots\sigma_n, \sigma_i \in \Sigma\}$$

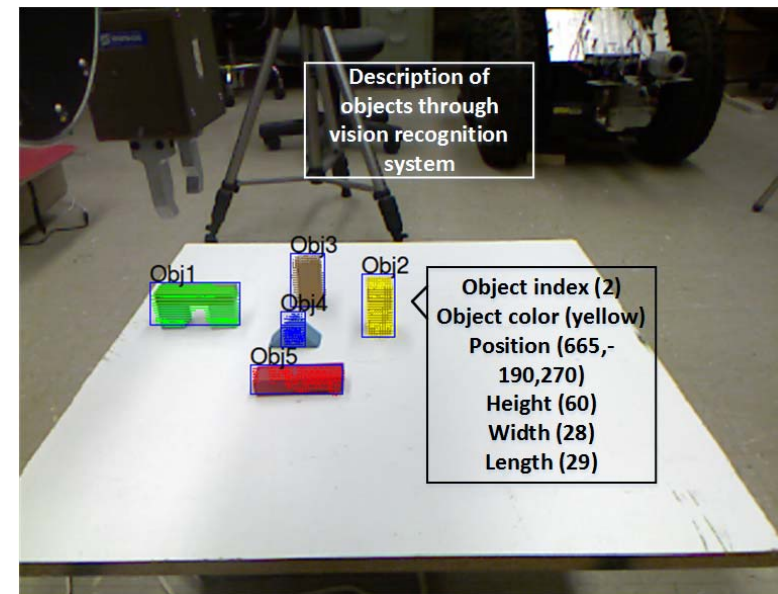
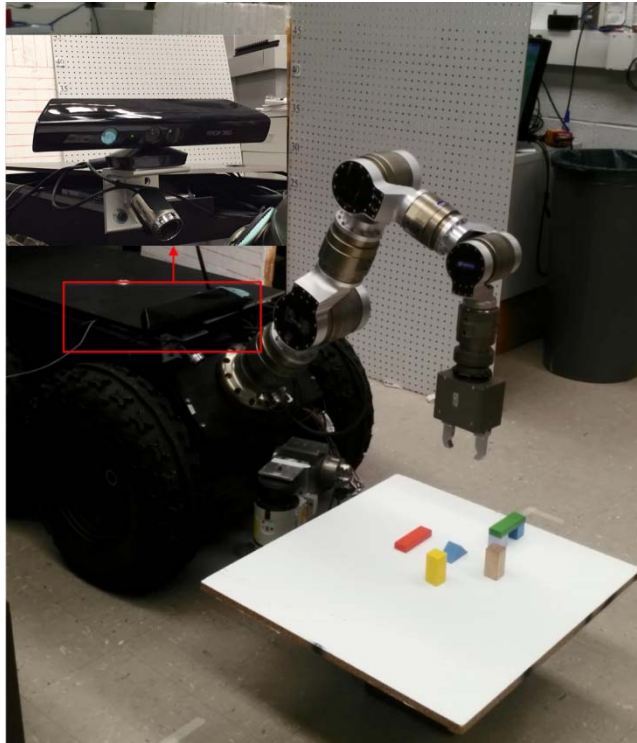
Natural Language based Control : Experiments



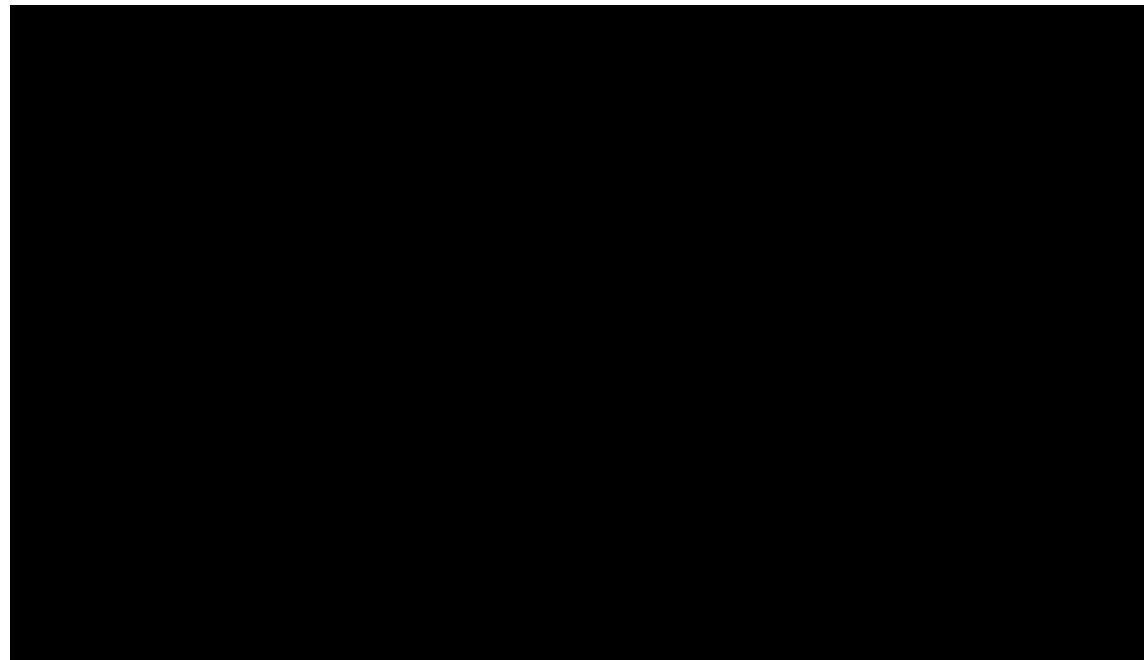
NL Robot Programming : Experiment



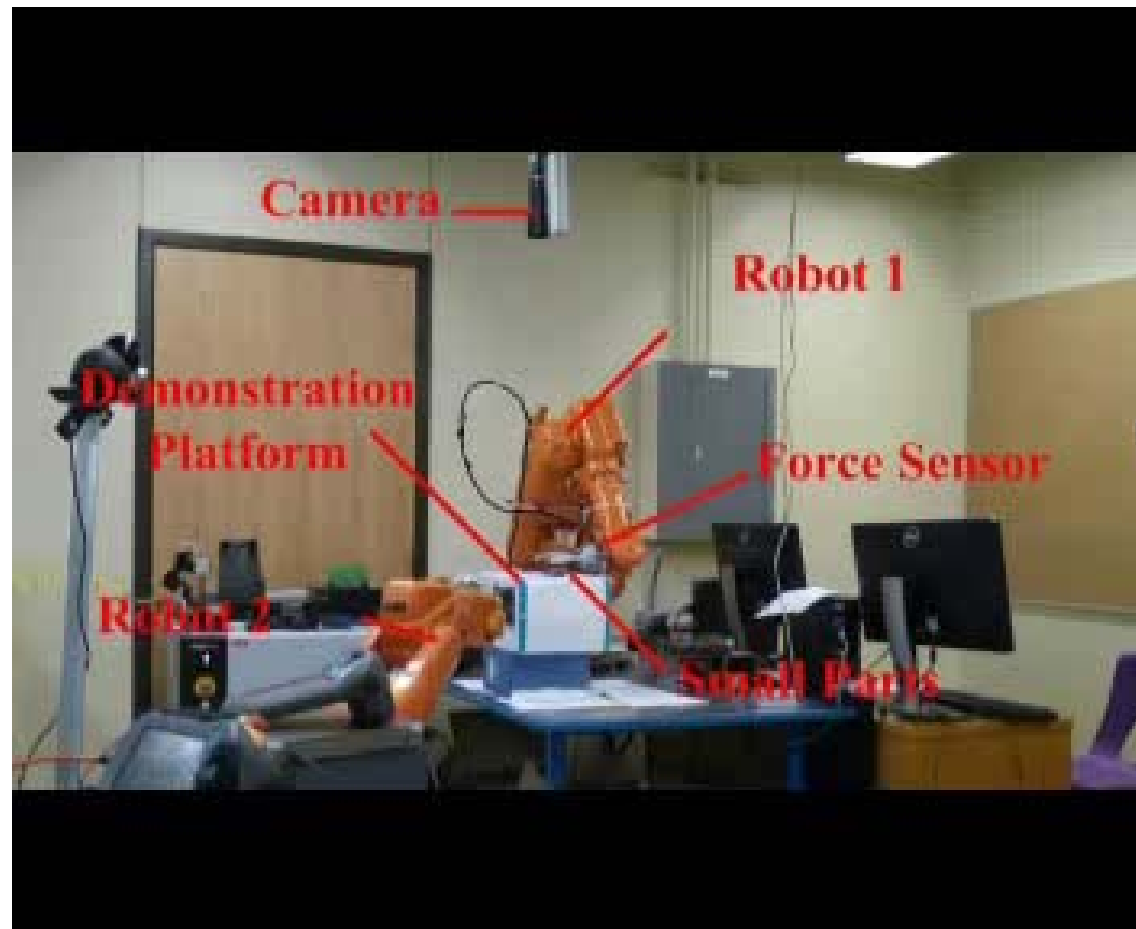
The grey and yellow parts above the red workpiece. The green workpiece is above the grey and yellow parts. The grey workpiece is left of the yellow one. The blue workpiece is above the green one.



NL Programming : Experiments



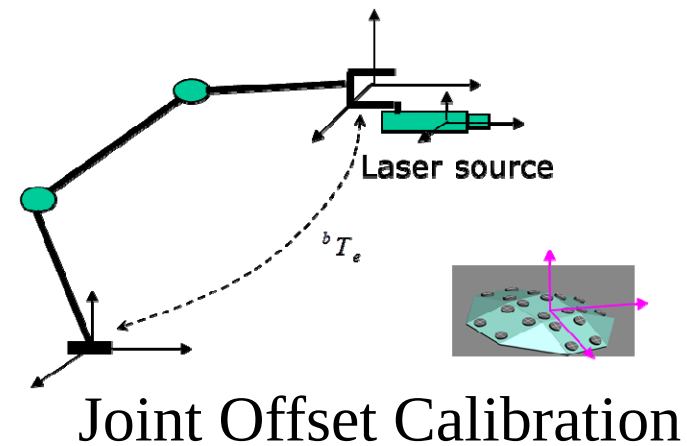
Robot Programming by Demonstrations



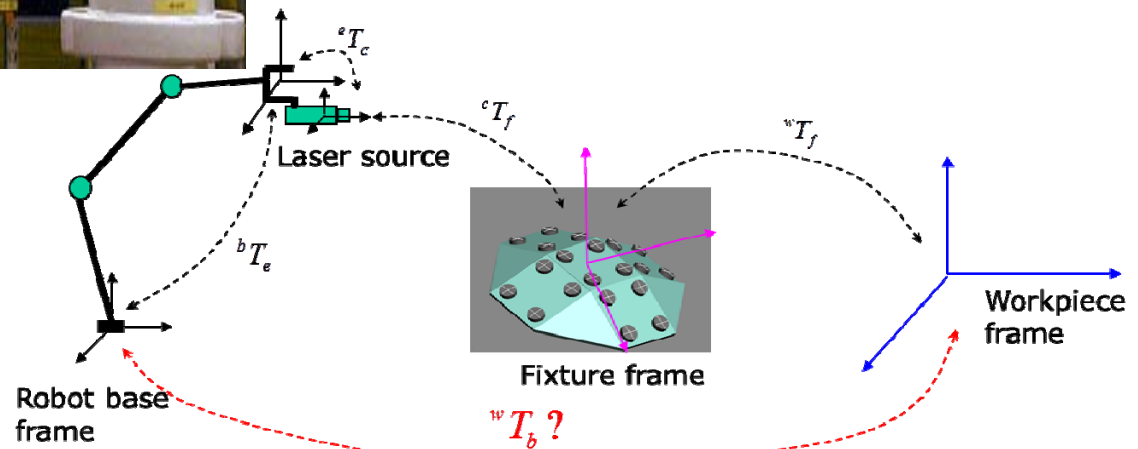
Natural Language Control of Telerobotic Operations



Reducing Setup Time by Automated Calibration



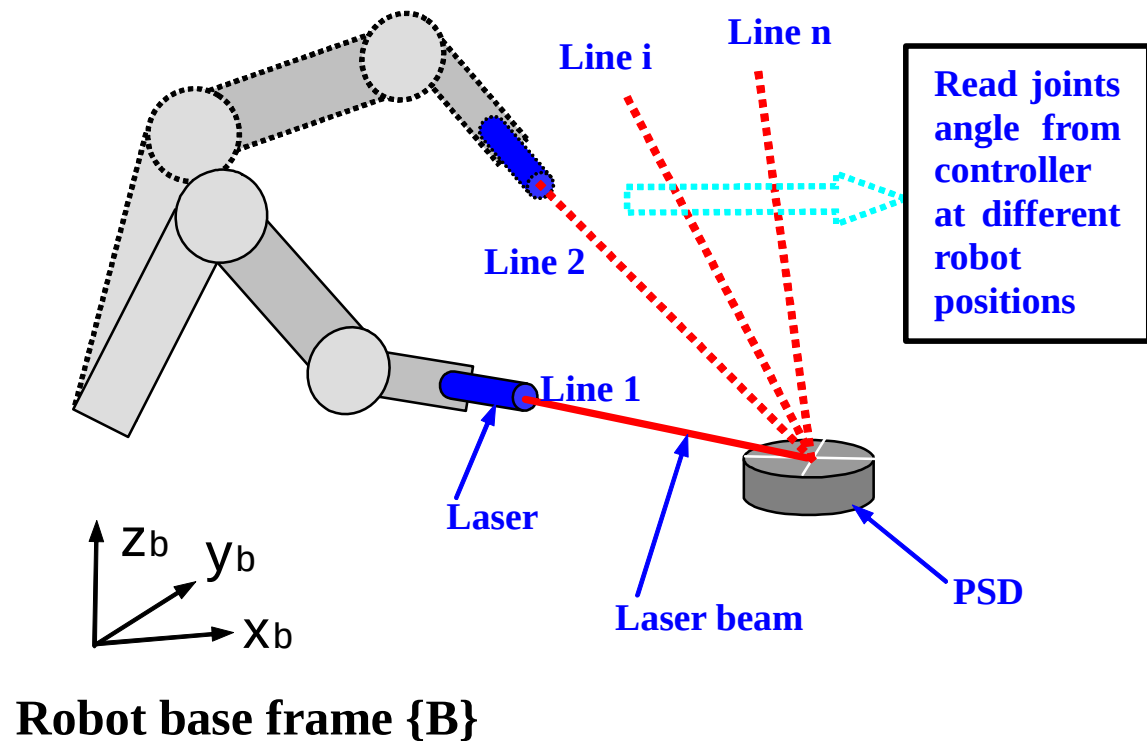
Workspace Calibration



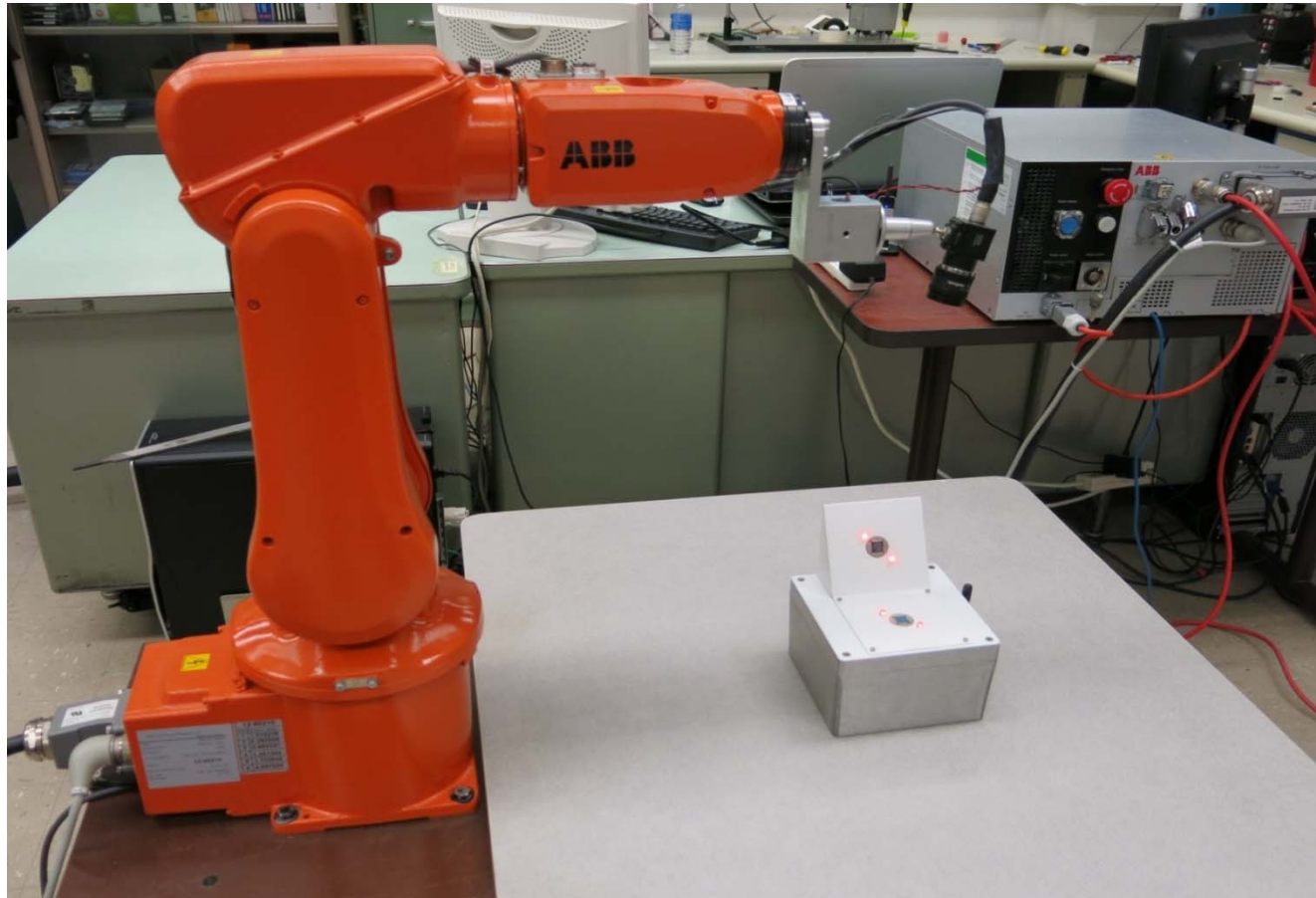
Line-based Calibration Method

- **Rapid calibration using virtual lines and a single point constraint**

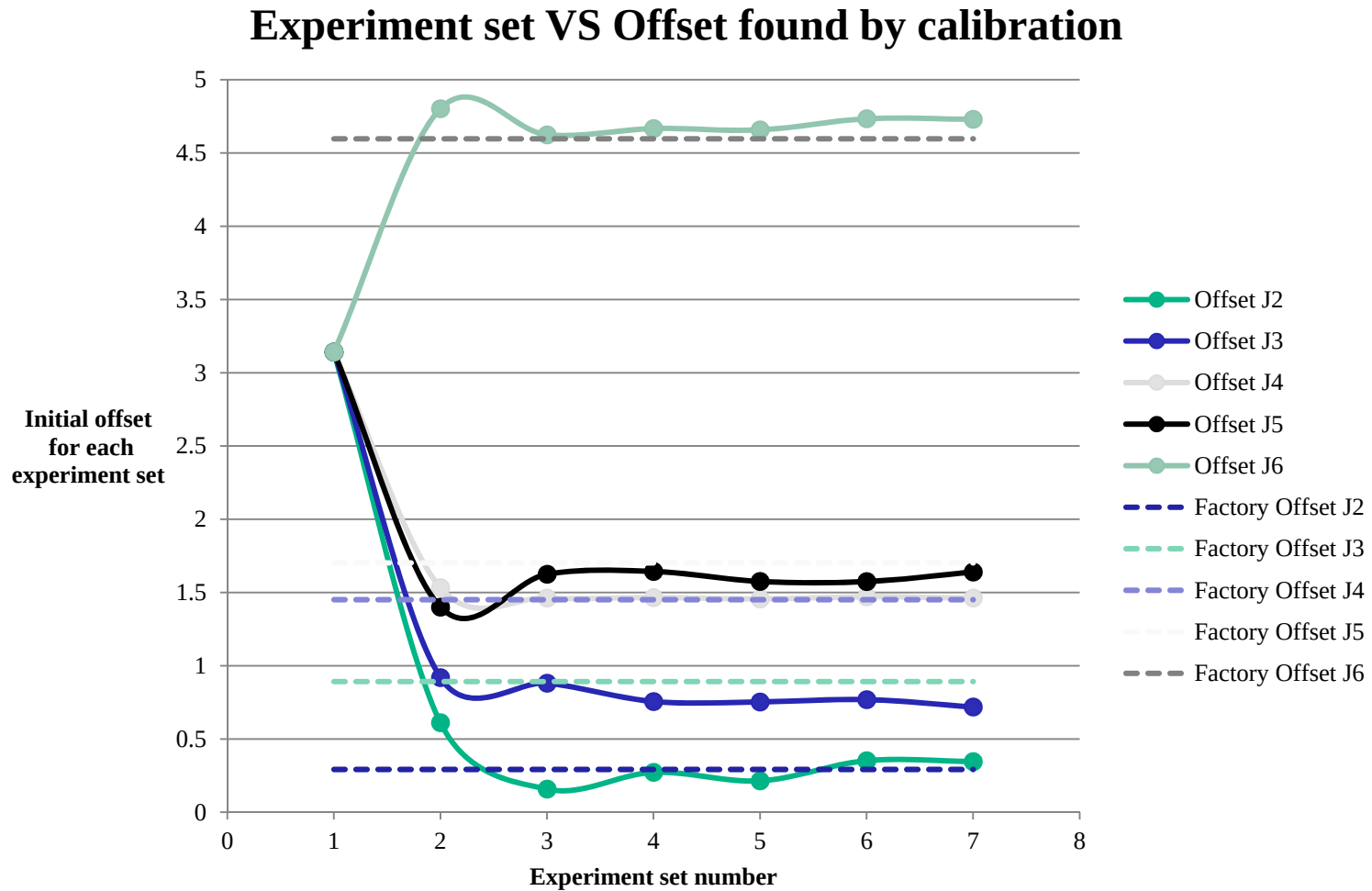
- ✓ One PSD is used
- ✓ The coordinates of PSD are unknown
- ✓ Multiple robot positions are used
- ✓ The process is automated Based on visual and PSD feedback



Automated Calibration System



Experimental Results on Joint Offset Calibration



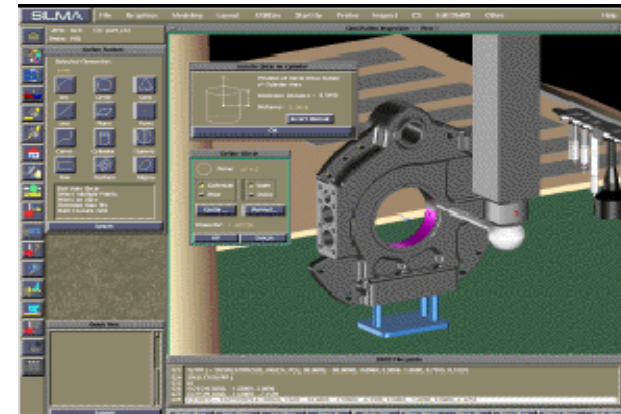
Integration of Robots and Sensors for Automated Surface Inspection



The backside of truck door panel,
1624-7840477-AH



Brown & Sharpe, Tesa Micro-Hite 3D

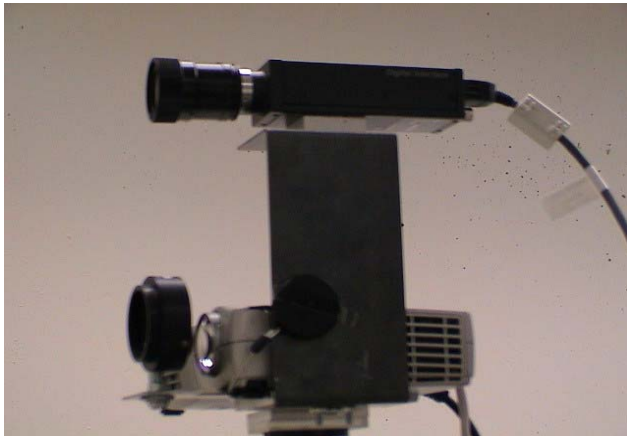


Offline Programming of a CMM

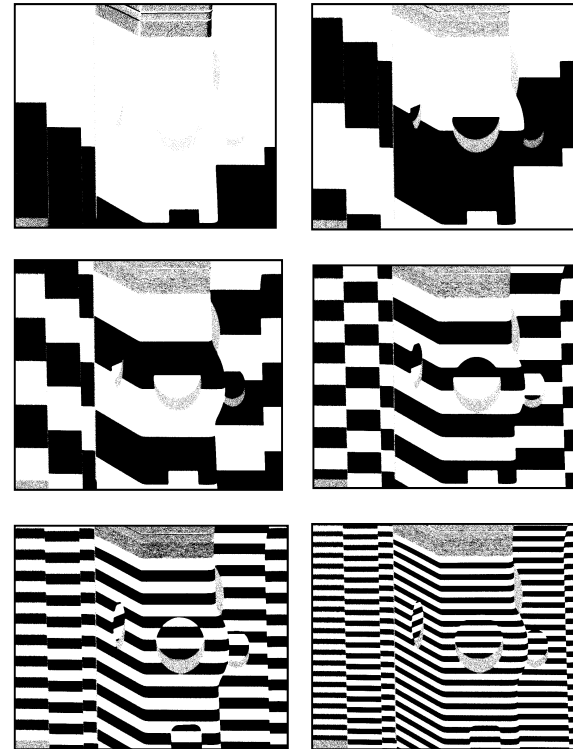
Robotic Areal Sensing system for 3D shape inspection



High Speed Area Sensor

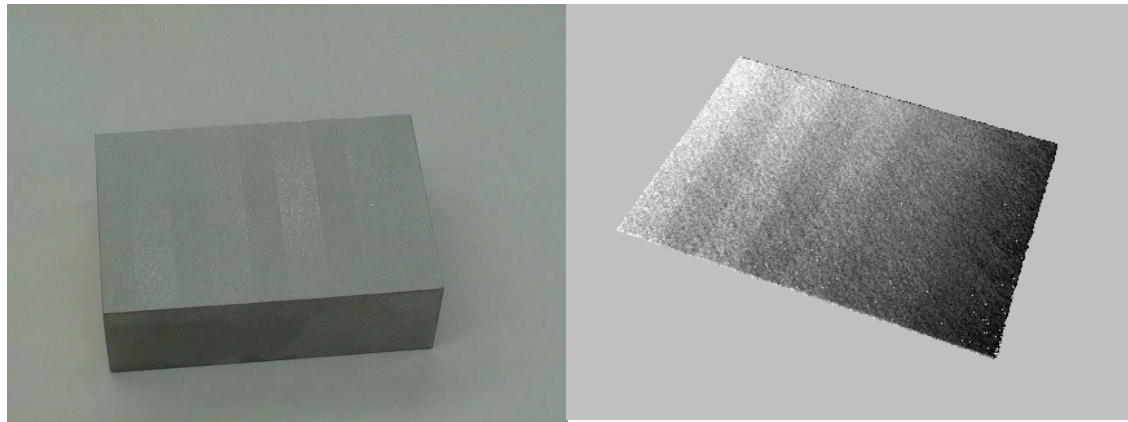


A DLP-based Area Sensor
Prototype



Retrieve 3D Shape from stripe
deformation

Measurement Precision Analysis



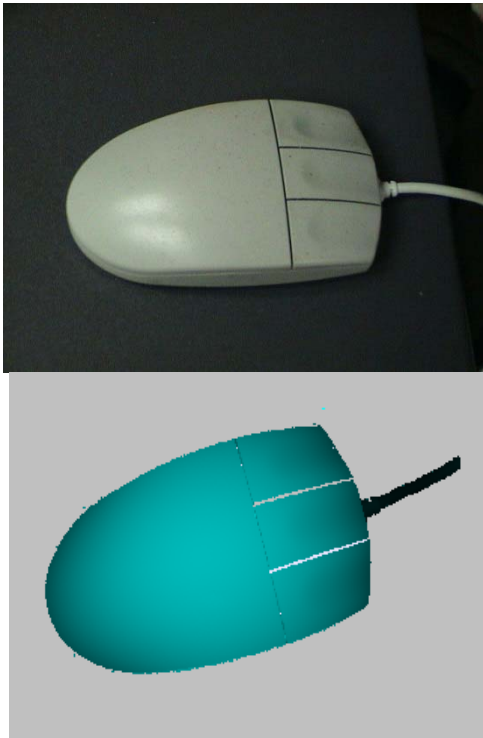
Measurement Precision:

4 slots gauge, from left to right: 32 μ ms, 24 μ ms, 14 μ ms, 8 μ ms

Measurement Error:

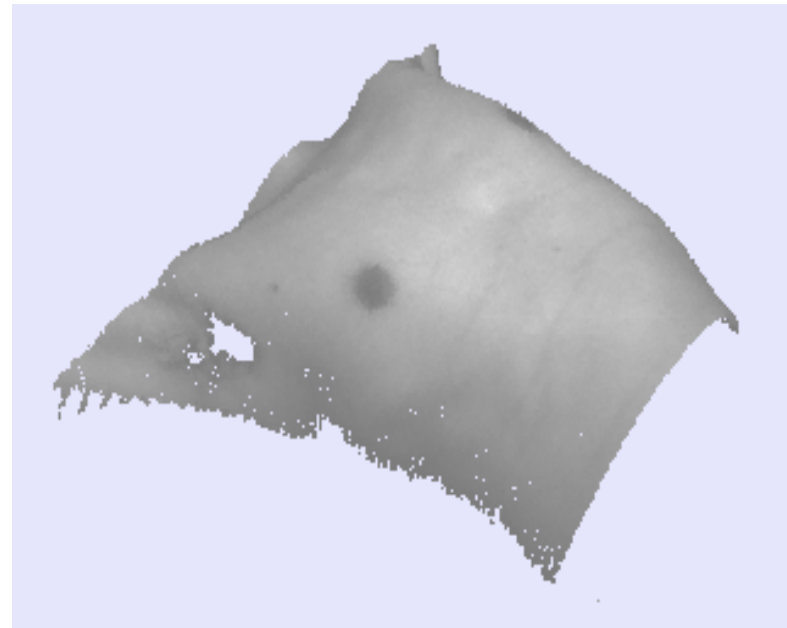
Mean = 0.0018mm, STD = 0.0261 mm

Measurement using the Area Sensor



Computer Mouse,

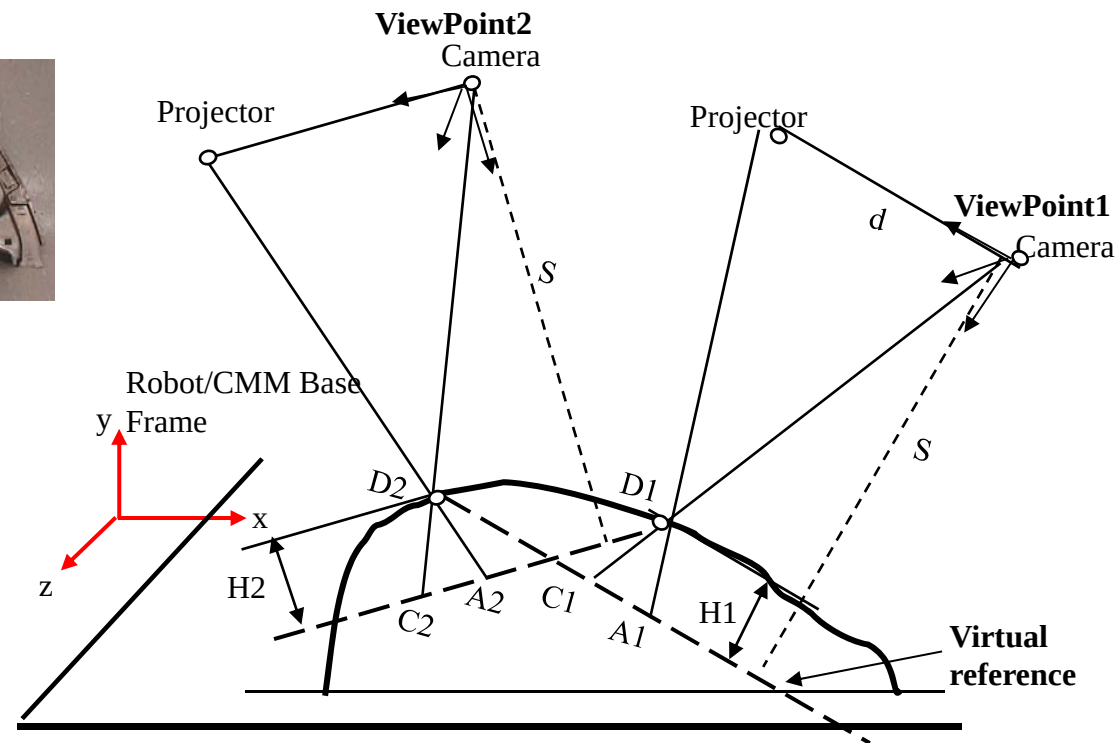
21,235 points obtained in 5 seconds



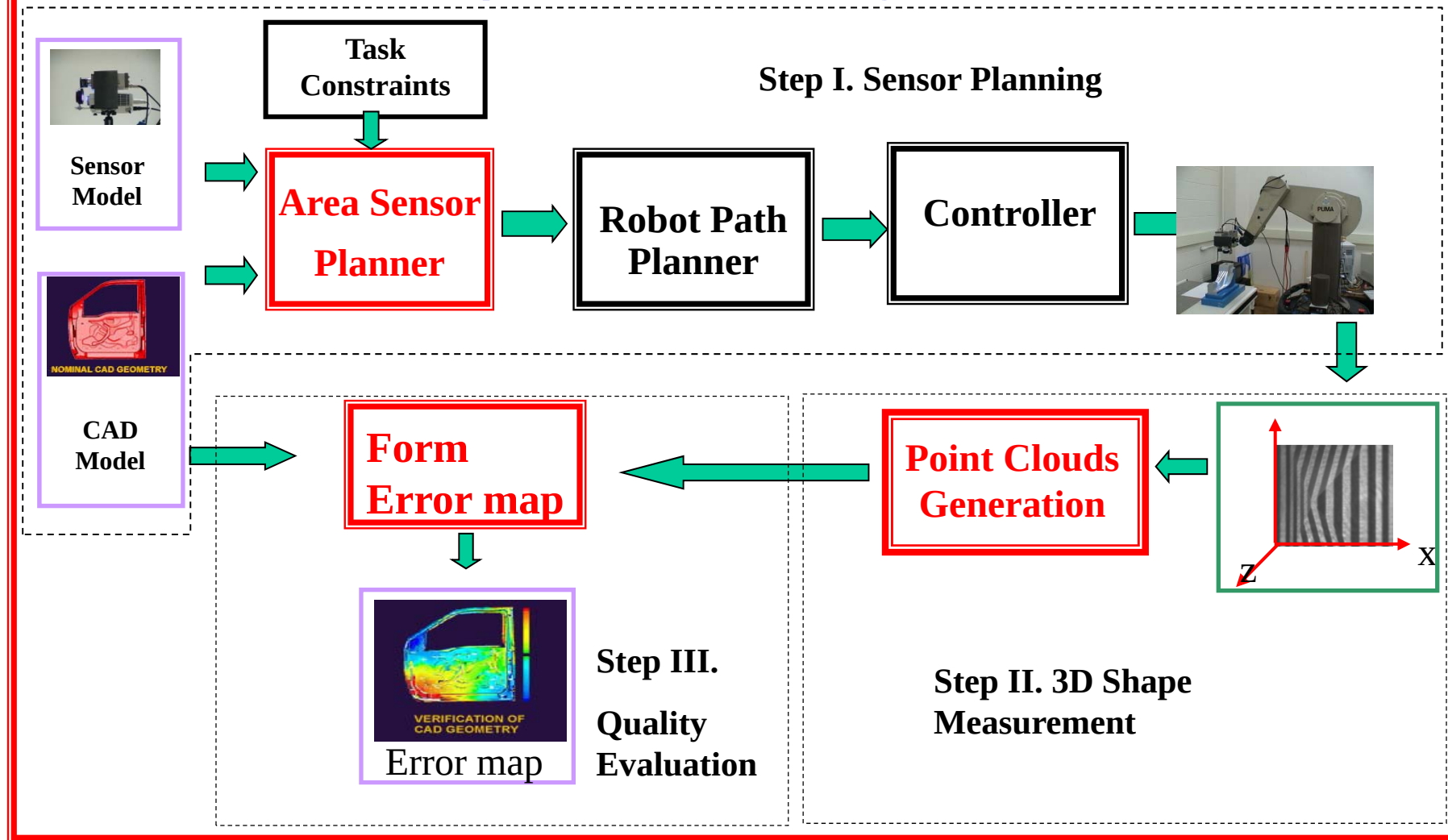
Man Chest,

142,235 points obtained in 52 seconds

Sensor Planning for an Automated Inspection System



An Automated Dimensional Inspection System



Area Sensor Planning

-- Task Constraints --

Projector constraints:

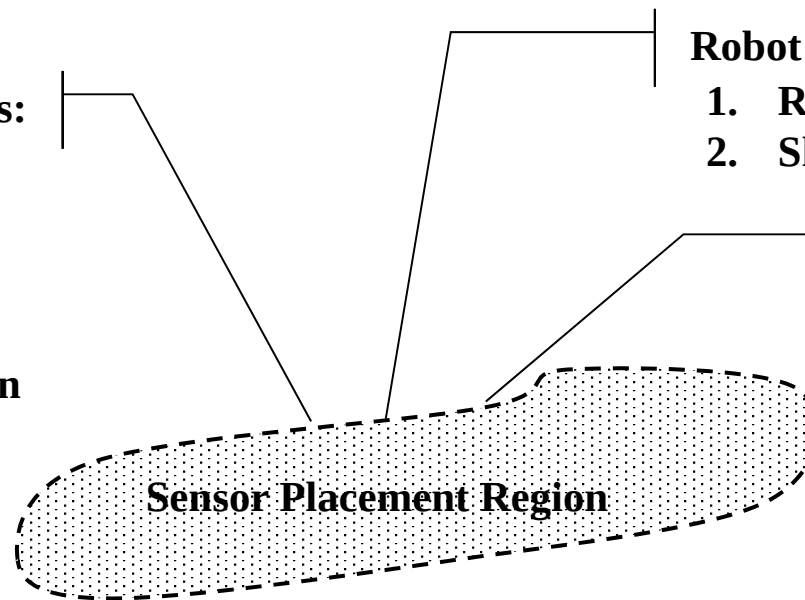
1. Resolution
2. Field of View
3. Shadow
4. Focus
5. Light reflection

Robot constraints:

1. Reachability
2. Shortest path

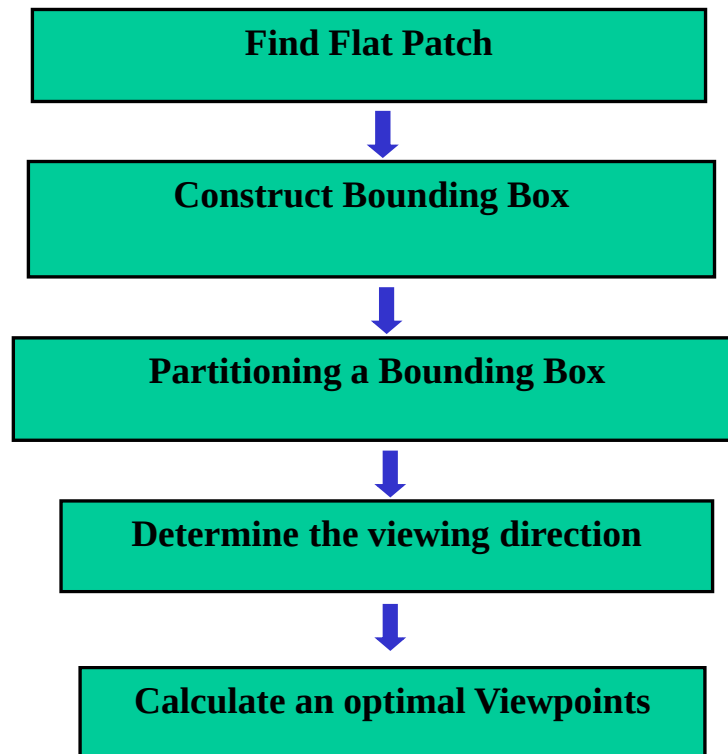
Camera constraints:

1. Resolution
2. Field of View
3. Visibility
4. Focus
5. Light reflection

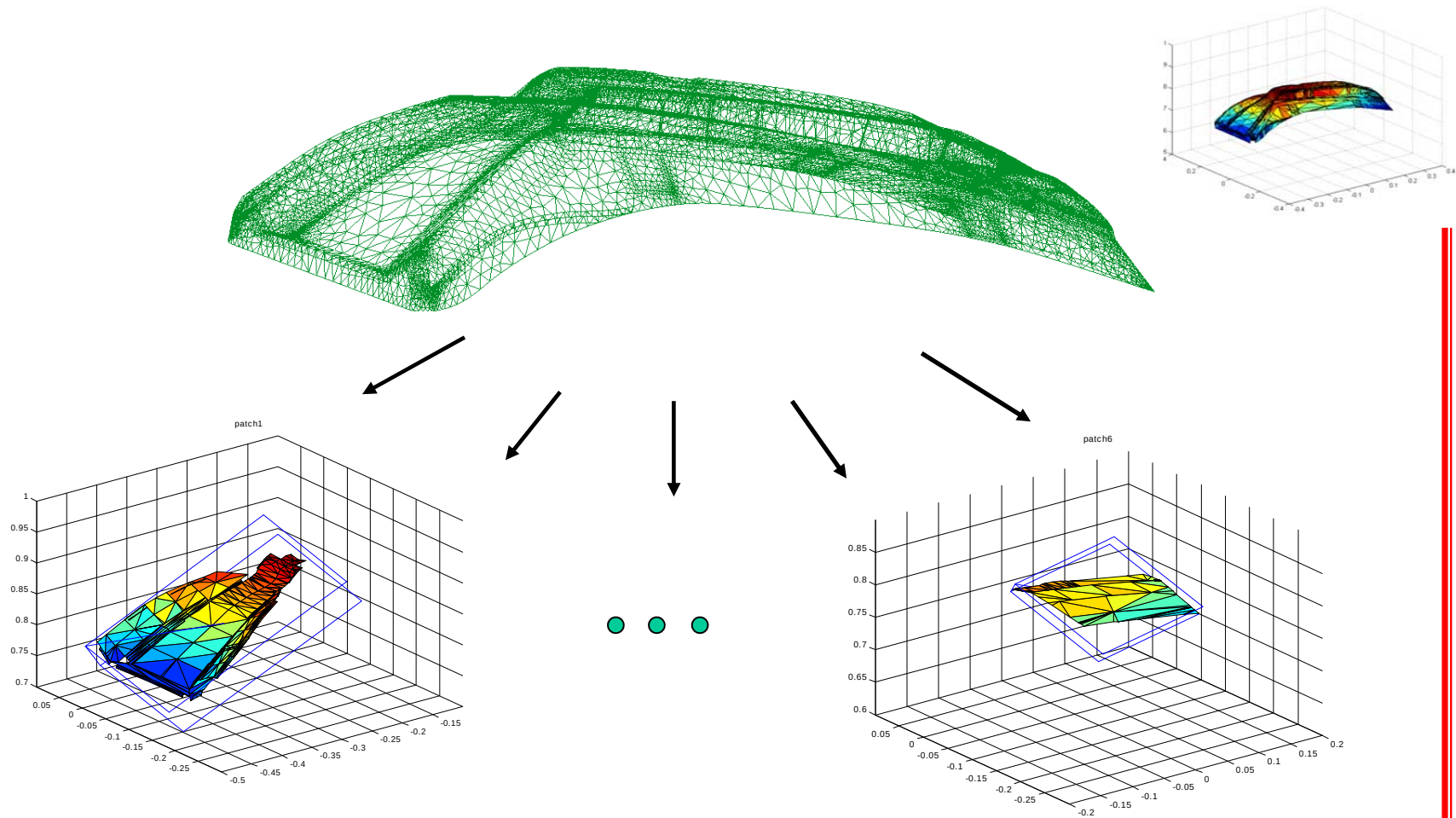


Object

Flow Chart of a CAD-based Area Sensor Planning Algorithm

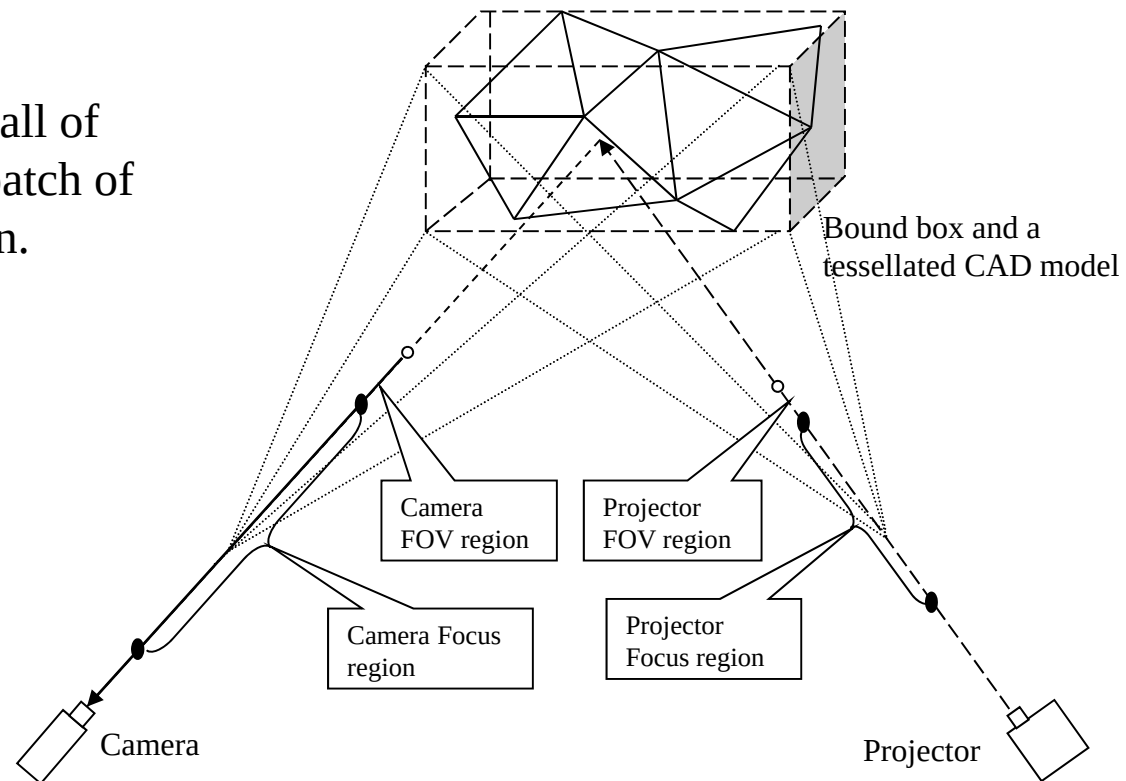


Patch Determination

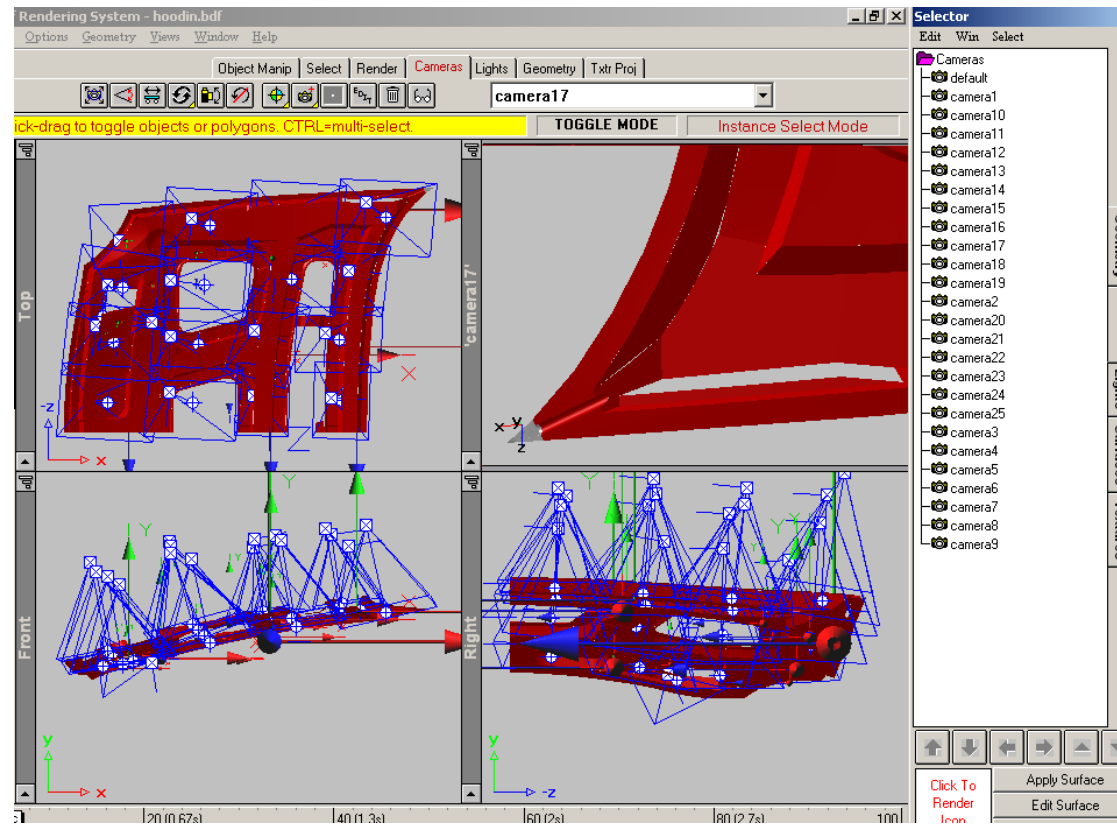


Bounding Box Method

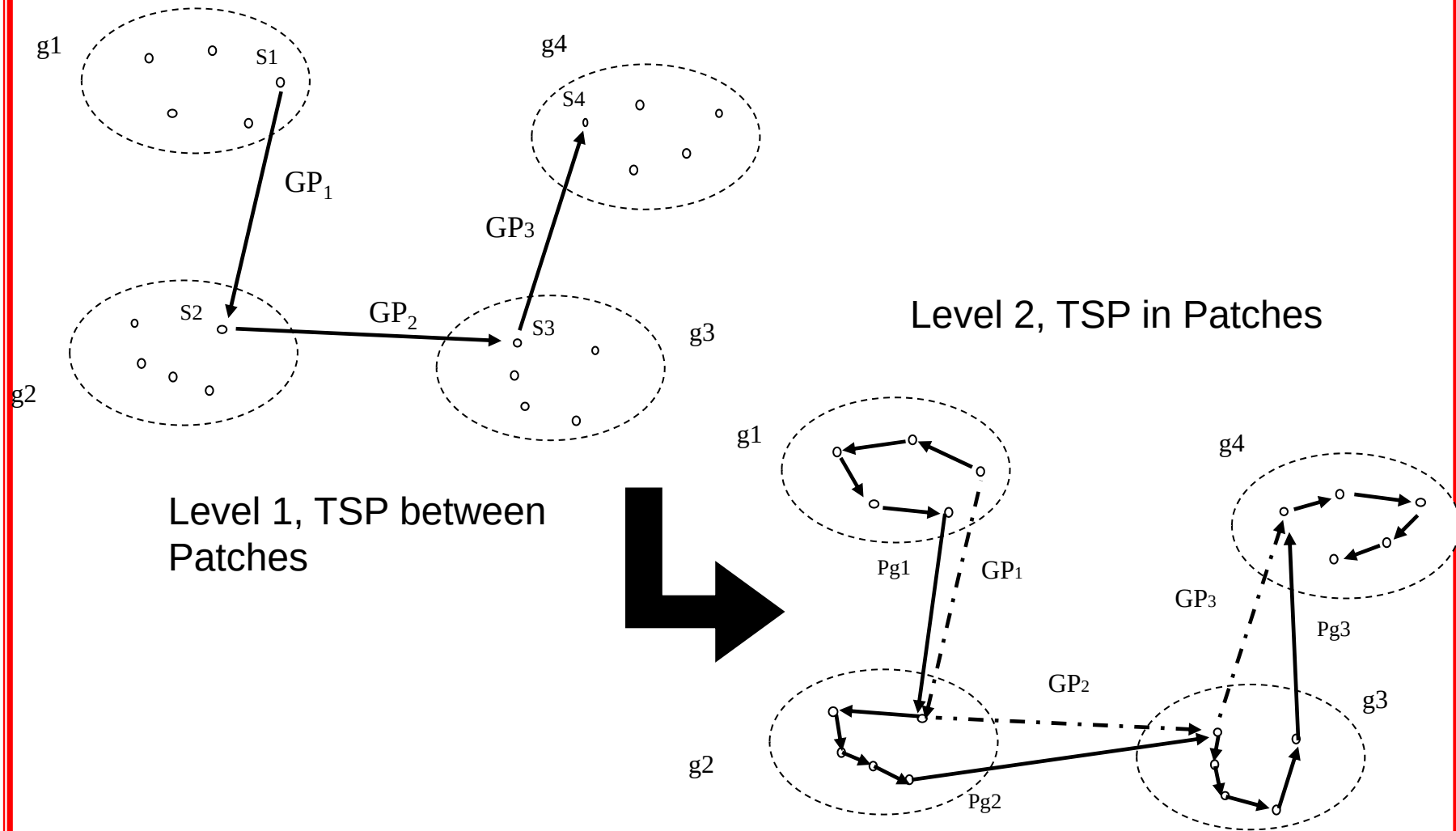
Bounding Box integrates all of the constraints to hold a patch of CAD model for inspection.



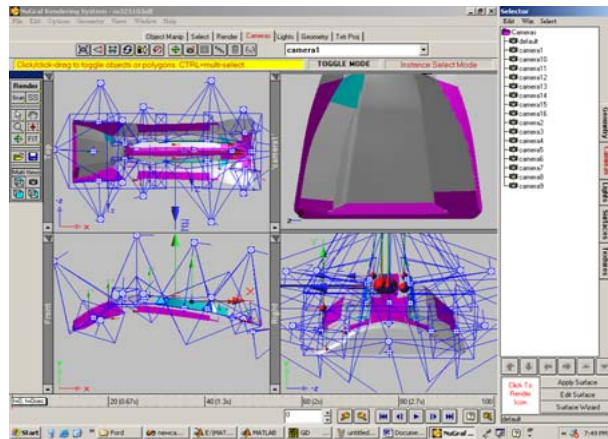
Bounding Box and Viewpoints Generation



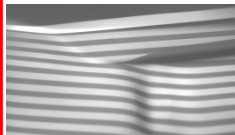
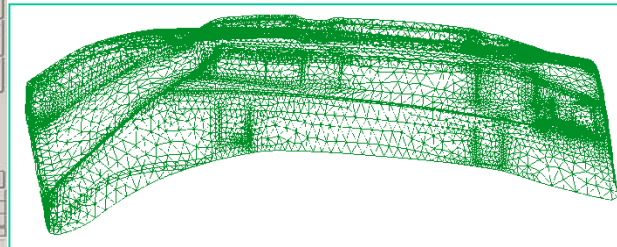
Two-Level TSP Algorithm



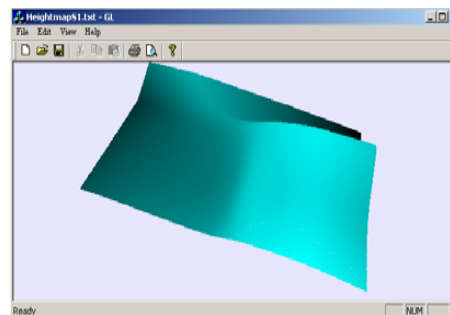
3D Surface Measurement System



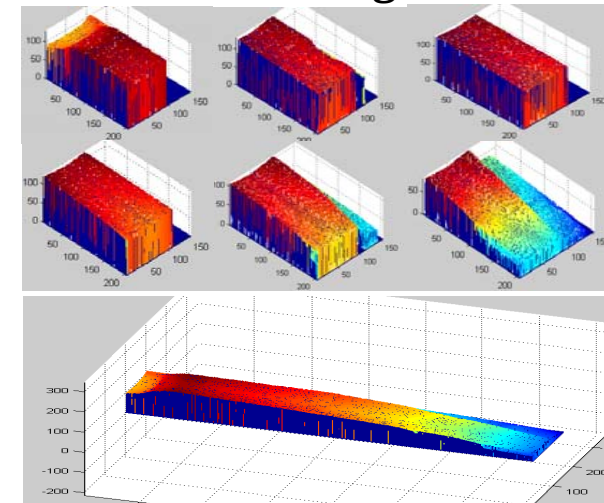
Sensor Planning



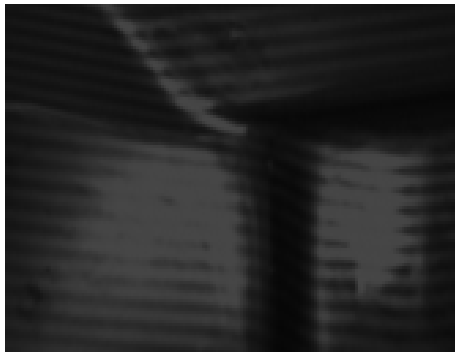
3D shape measurement



Point Cloud Registration



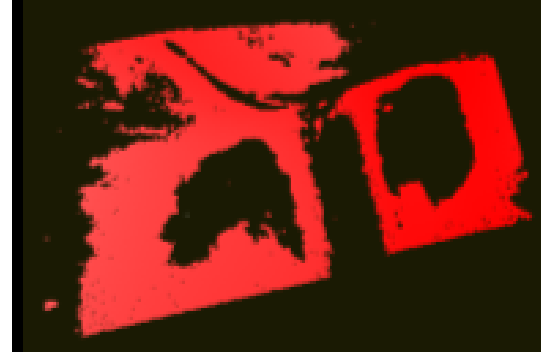
Defects in Point Clouds



(a)

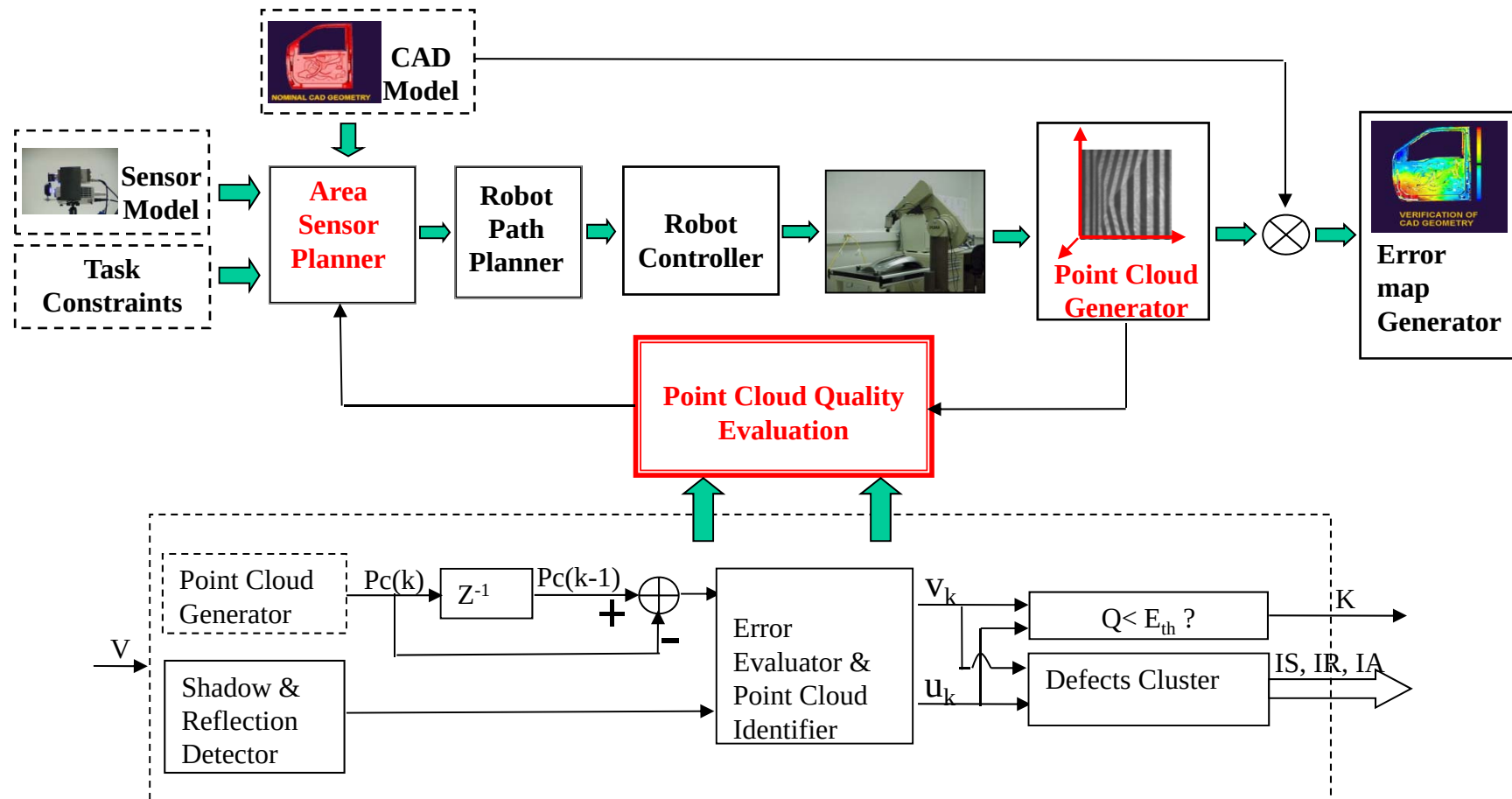


(b)



(c)

Feedback Design of the Automated Dimensional Inspection System

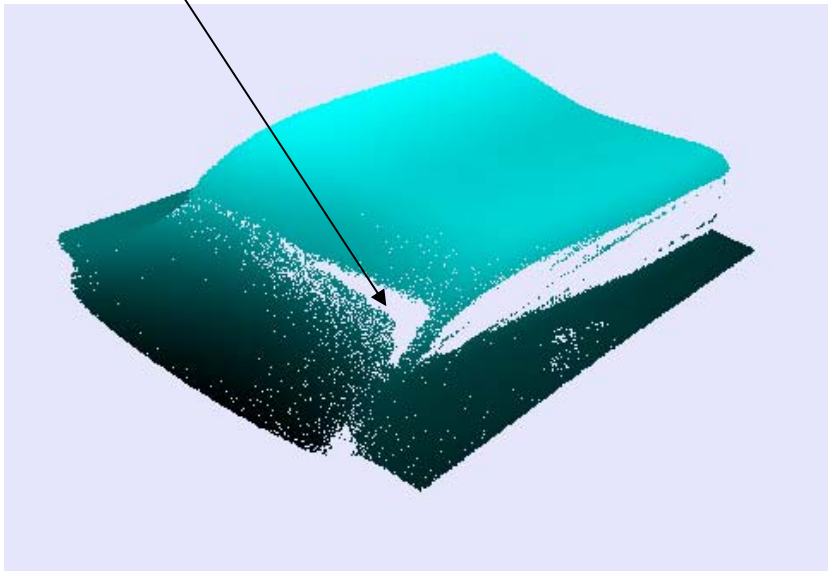


Automated Dimensional Inspection System

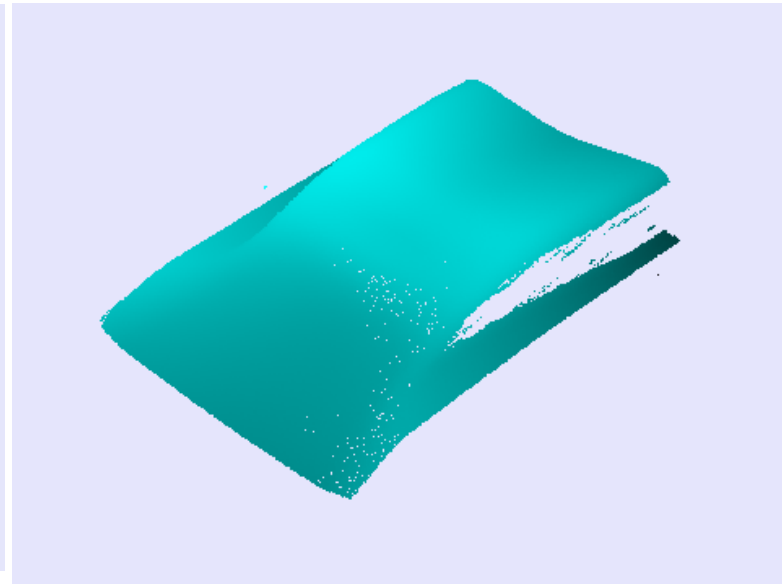
**CAD-Guided Sensor Planning for
Surface Inspection in Manufacturing**

Point Clouds Measured in Feedback

A hole caused by shadow

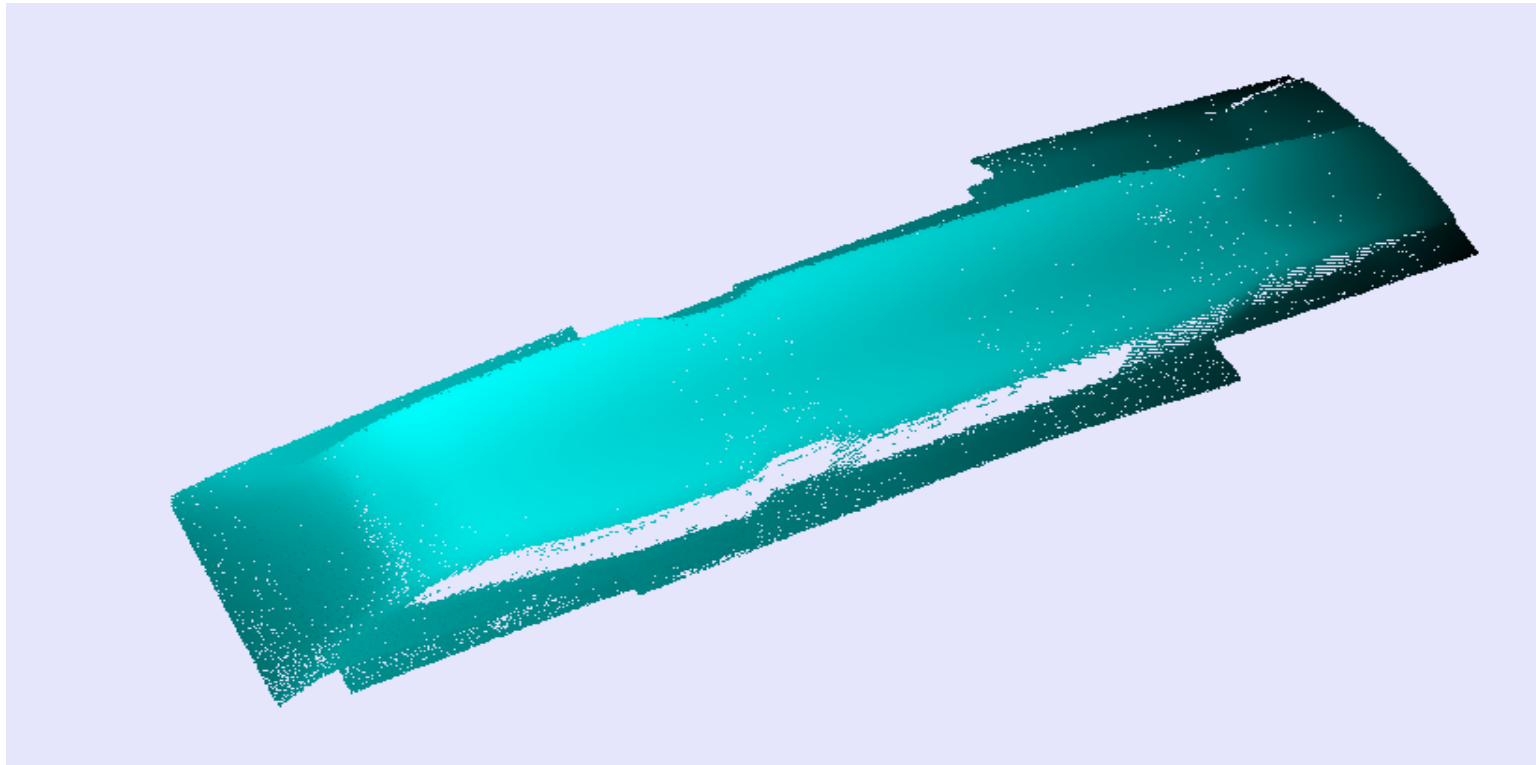


Cloud measured on view 1

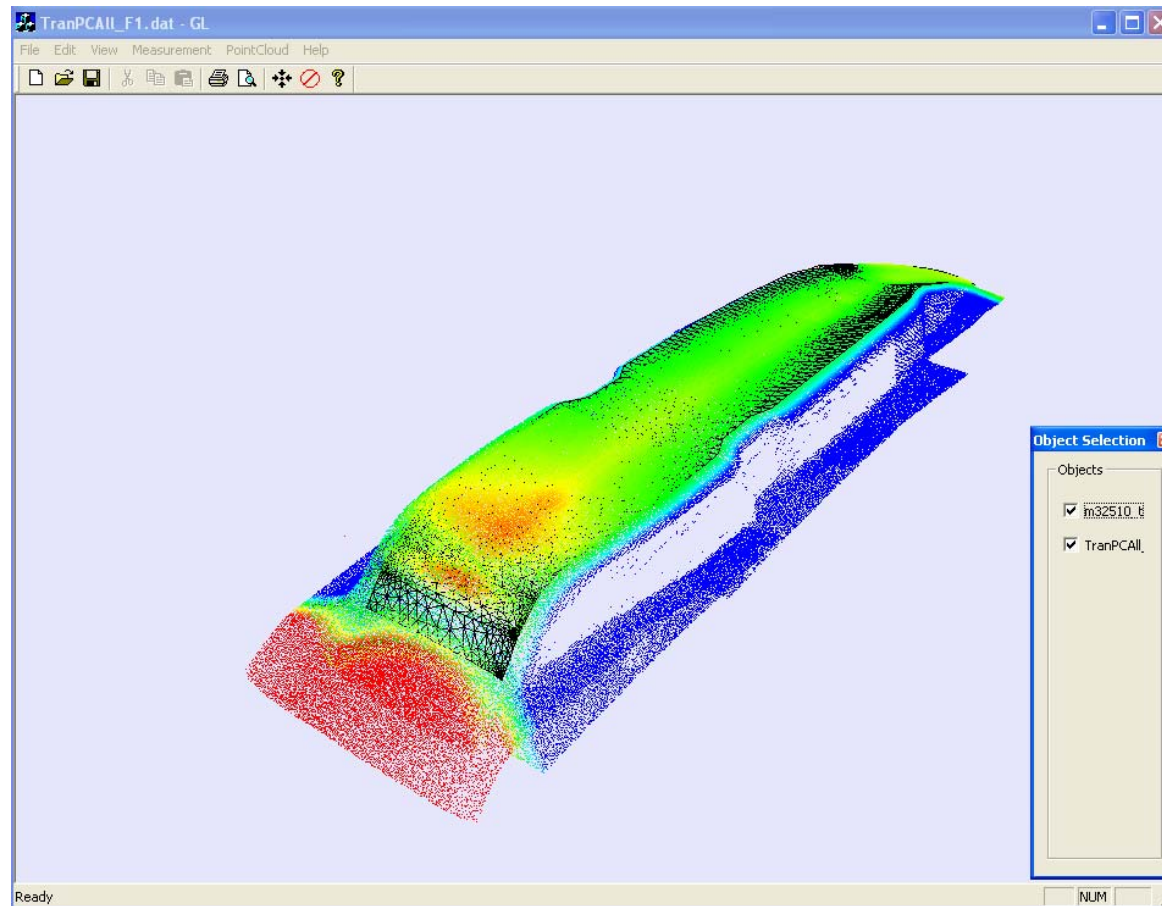


Cloud measured on view 5
(Viewpoint generated in feedback)

Registration of Point Clouds



Part Error Map



Automatic Inspection of High Speed Train



Surface Characterization

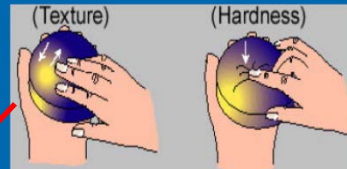
Surface measurement & evaluation

Surface features extraction

Characterization



Professional inspector



Tactile/force perception

H_p

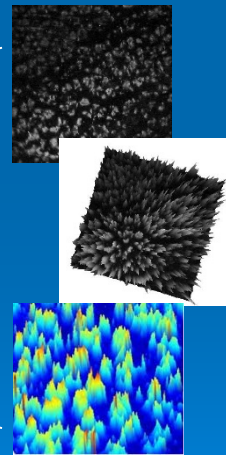
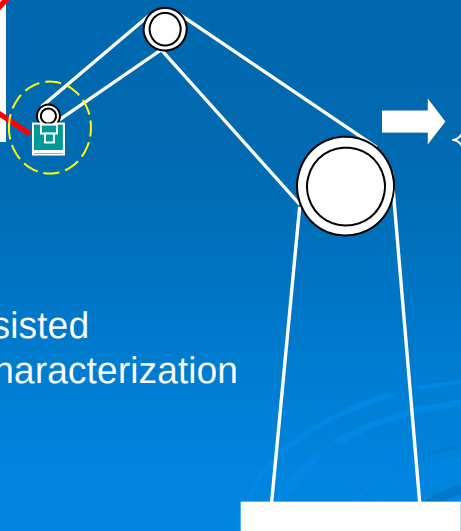
Spectral histograms,
Wavelet,
Markov Random Fields,
Neural Network,
Autoregressive Random Fields,
... ..

Correlation

Quantified characteristics



Robot assisted
surface characterization



Texture pattern

H_w

Roughness
and Friction

$$R_q = \sqrt{\frac{1}{L} \int_0^L |Y^2(x)| dx}$$

H_r

Stiffness $\frac{F}{d}$

H_s

Impedance $\frac{F}{v}$

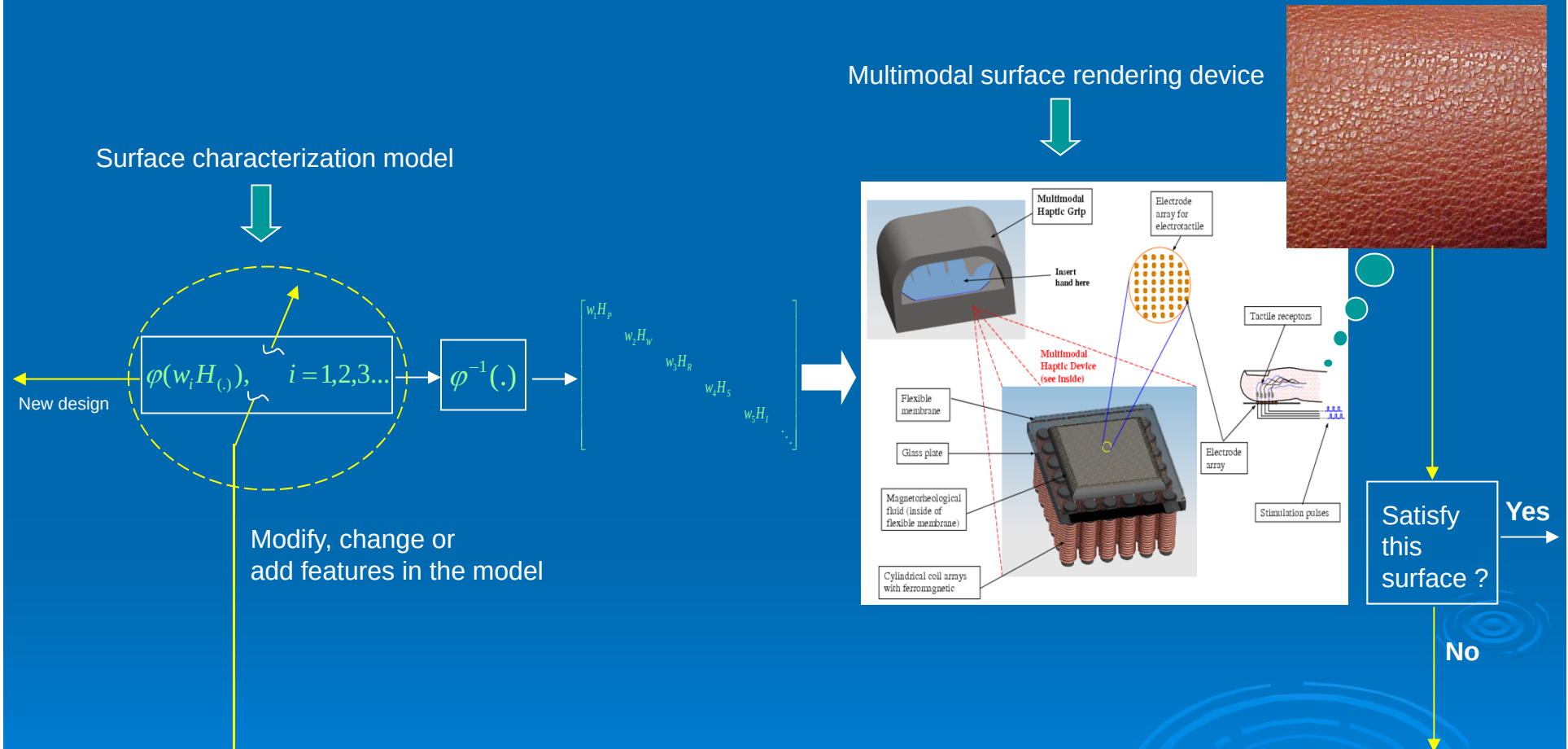
H_i

$[H_{(.)}]_{m \times n}$

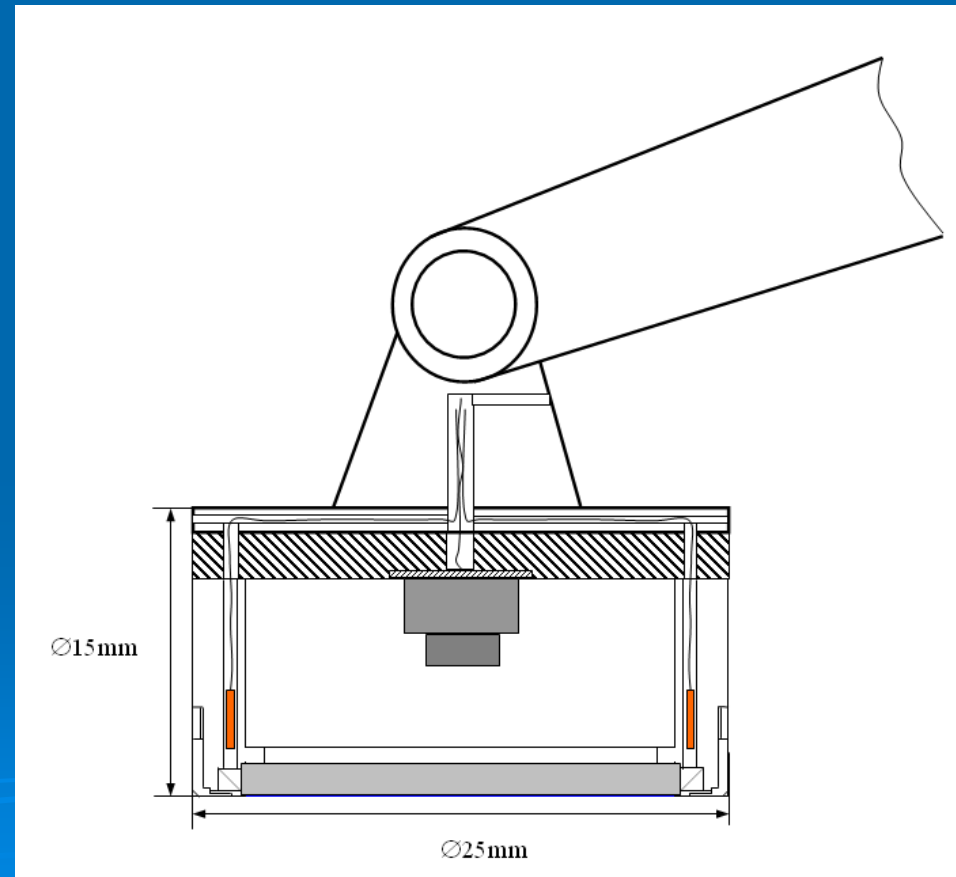
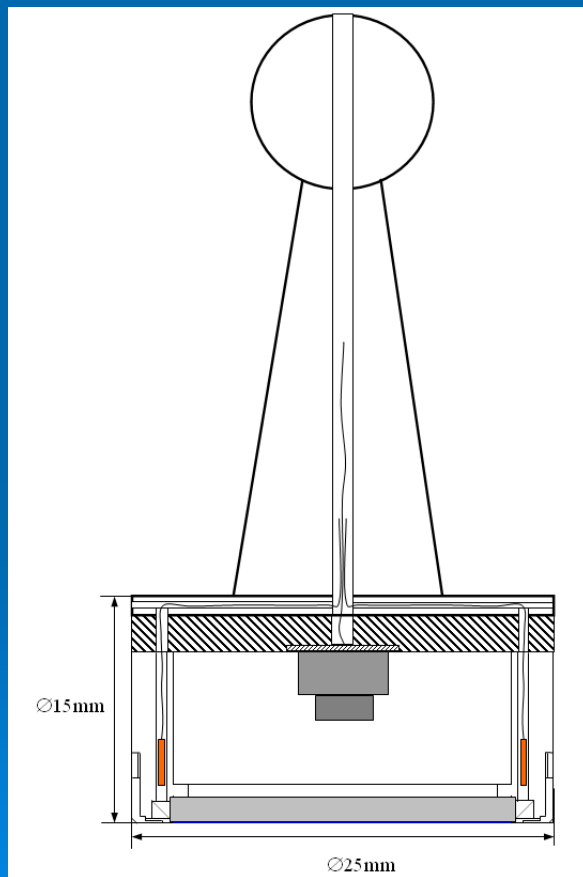
$\phi(\cdot)$

...

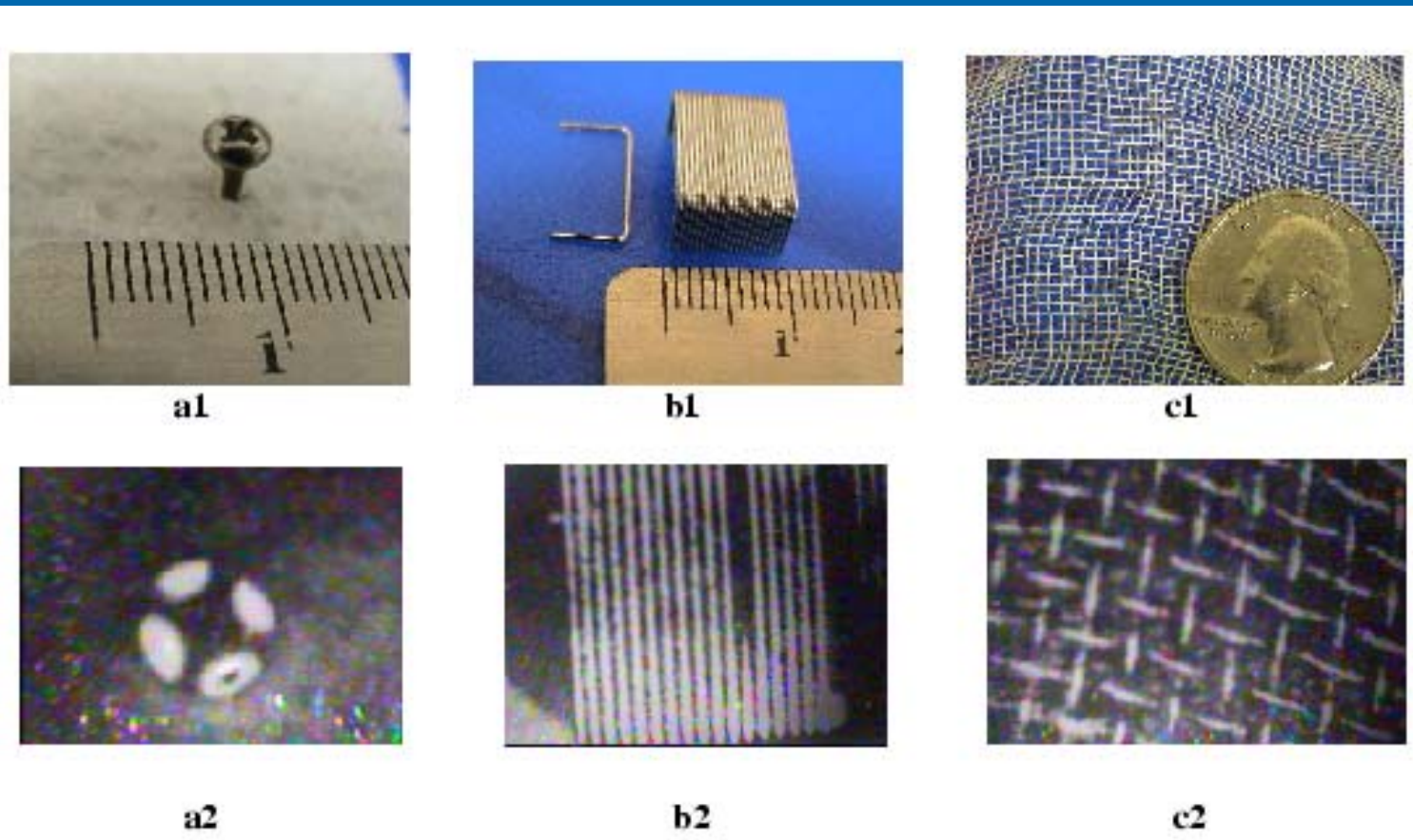
Surface Synthesis



Tactile Sensor Design



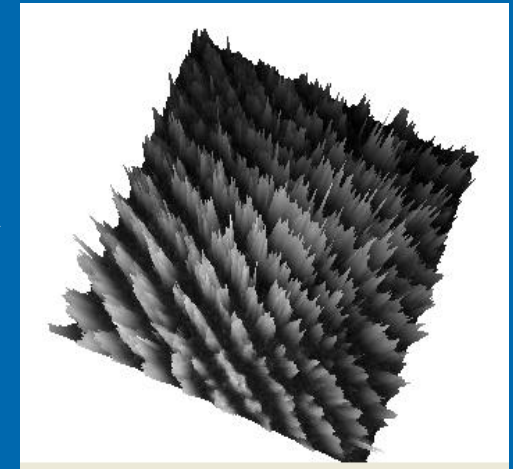
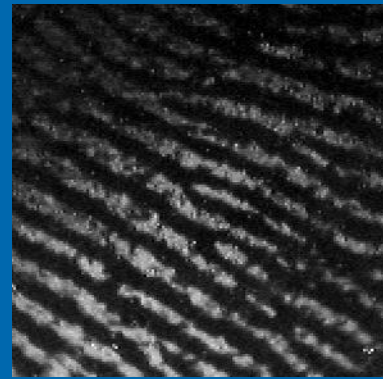
Tactile Sensing and Results



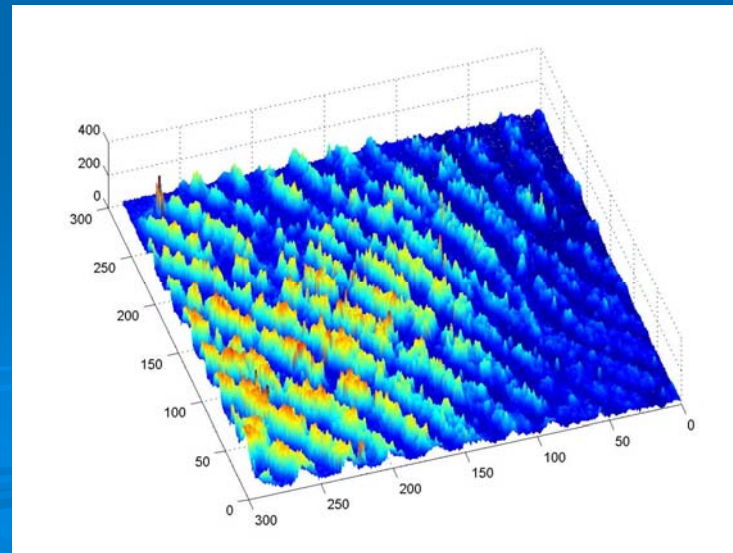
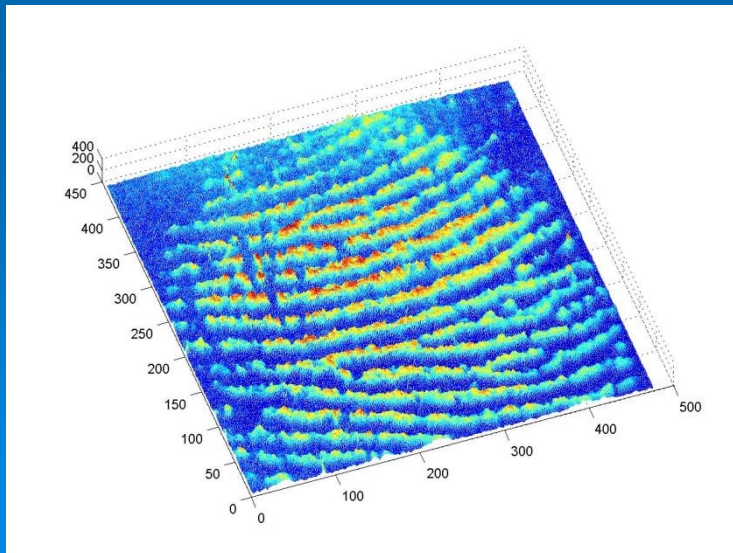
- a2, the tactile image of the cap of a small cross nut in Fig. a1;
- b2, the tactile image of a staple row in Fig. b1;
- c2, the tactile image of the soft and thin tissue in Fig. C1.

Sensing Results: fingerprints

2D tactile images of fingerprints:



3D tactile images of fingerprints:



Texture Classification

- Using χ^2 – statistic to define the distance of two images:

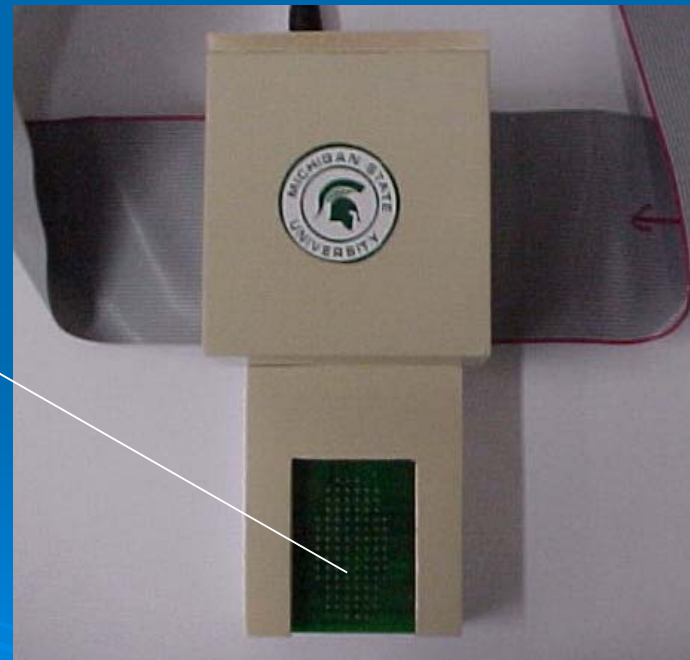
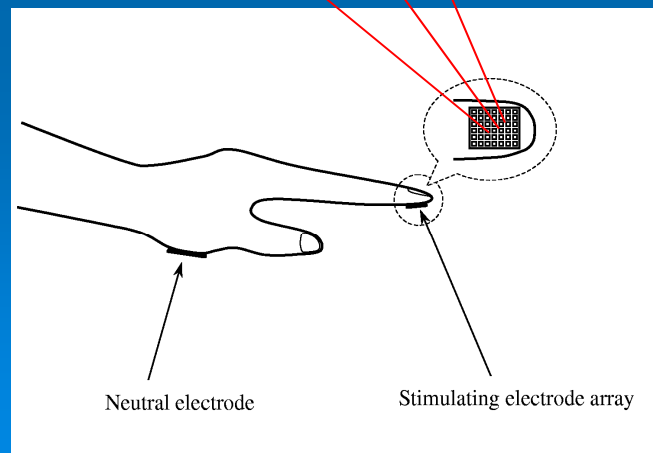
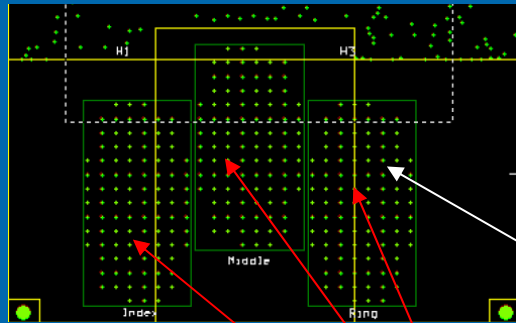
$$\chi^2(H_{W1}, H_{W2}) = \sum_{\alpha=1}^k \sum_z \frac{(H_{W1}^{(\alpha)}(z) - H_{W2}^{(\alpha)}(z))^2}{H_{W1}^{(\alpha)}(z) + H_{W2}^{(\alpha)}(z)}$$

- Given a database with texture types, the average spectral histogram H_{ave} of each type can be available, then a minimum-distance is used to classify the texture:

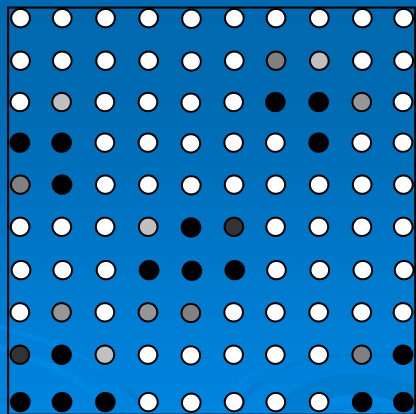
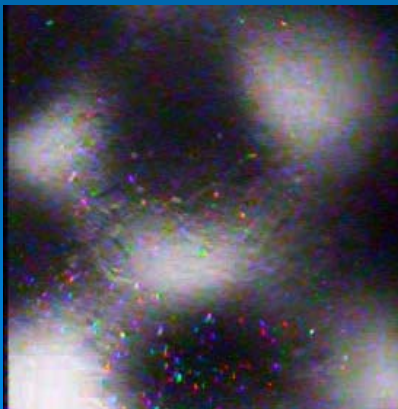
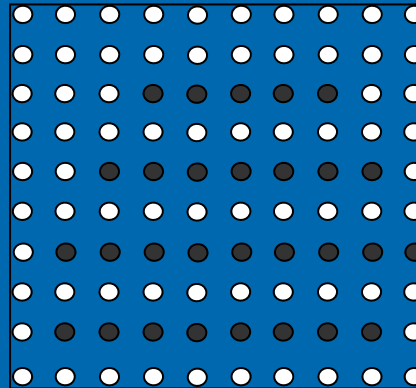
$$m_{wi}^* = \min \chi^2(H_{wi}, H_{ave})$$

Rendering Device

PCB based
Electrode array:



Surface Rendering Results:

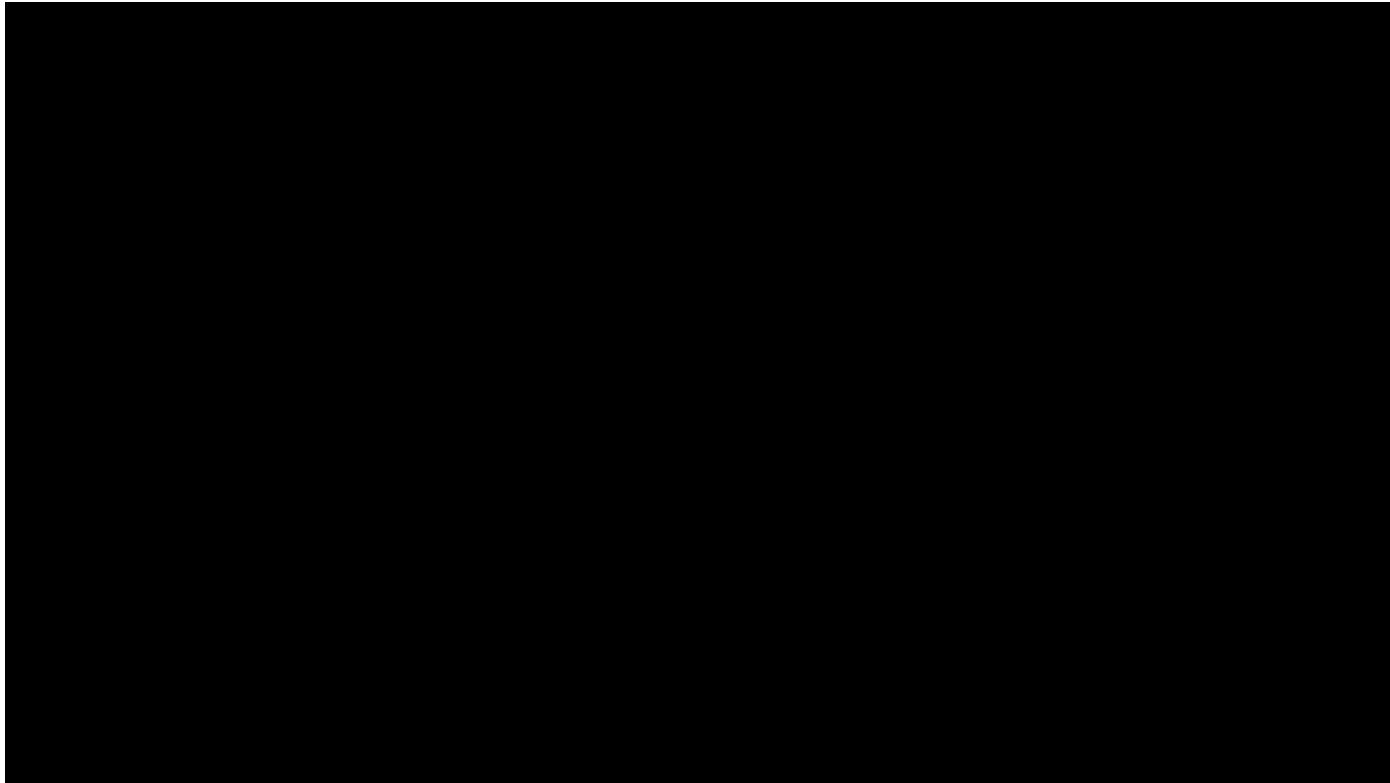


- High intensity Stimulation electrode
- Low intensity stimulation electrode
- Non-stimulated electrode

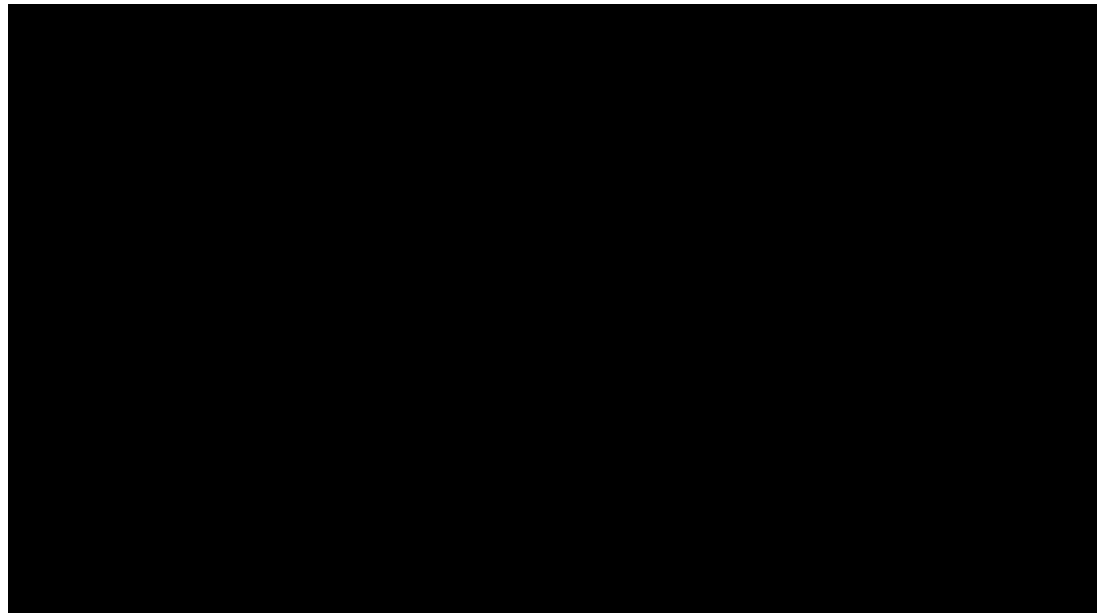
Assembly in Automotive Manufacturing



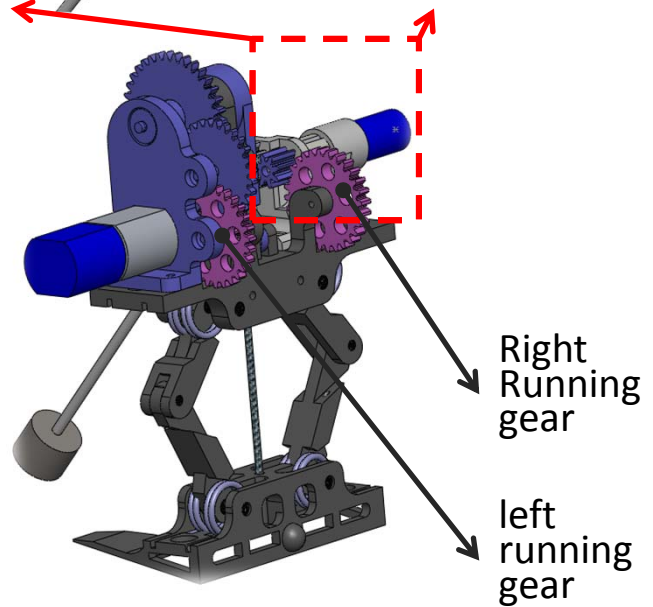
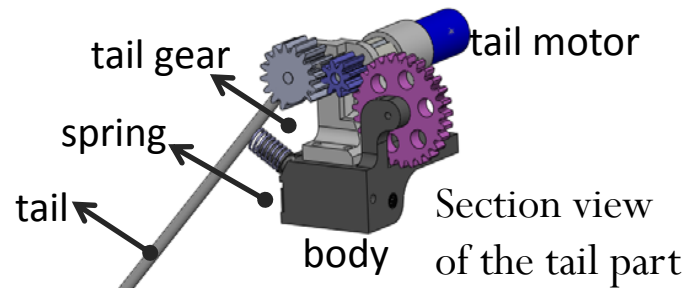
Assembly in Automotive Manufacturing



Assembly in Automotive Manufacturing



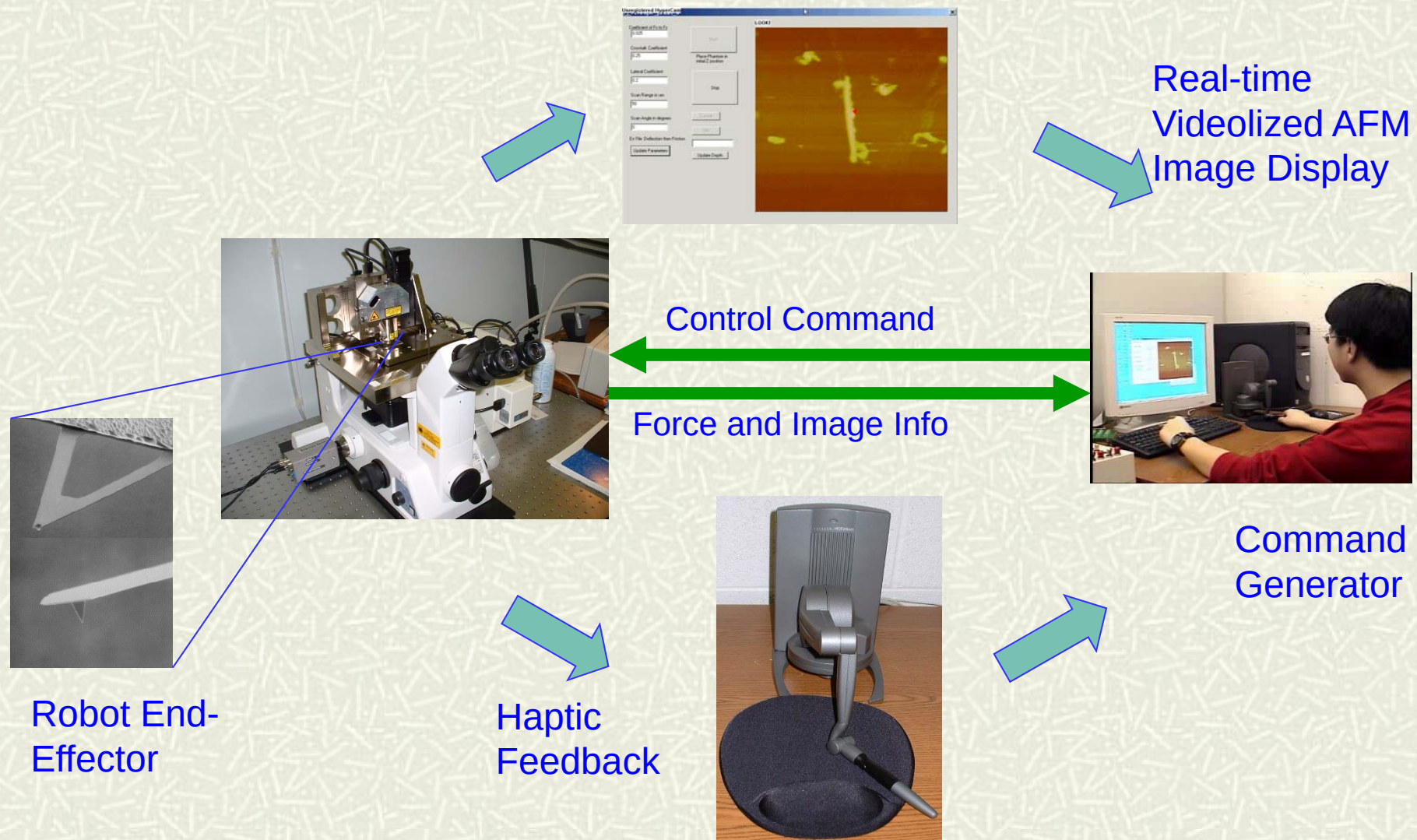
Mobile Sensor Network



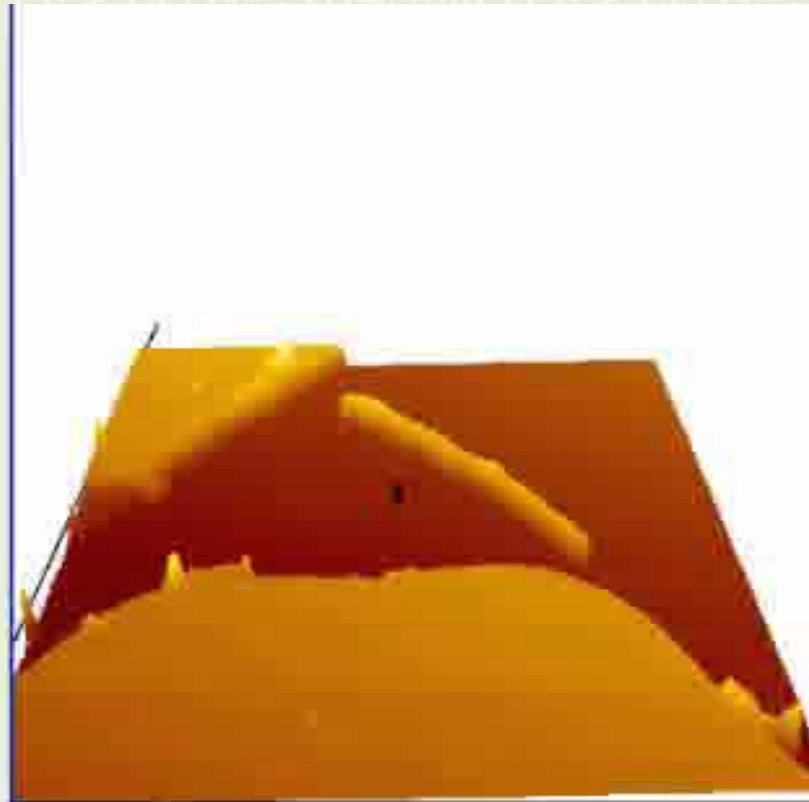
Solid model of the robot



AFM Based Robotic System

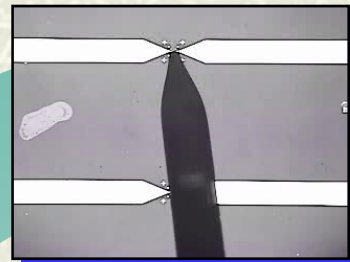


Assembly of Carbon Nanotube Devices



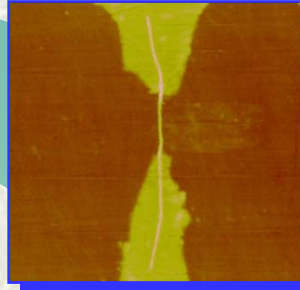
Manufacturing Process for CNT IR Sensors

Semi-conducting CNT selection



CNT Deposition

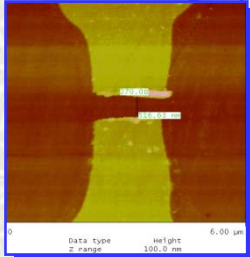
CNT assembly



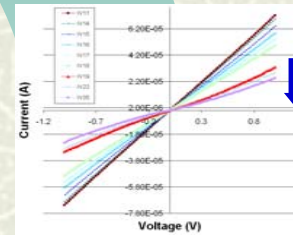
Technical challenges:

- Semi-conducting CNT selection
- Single CNT deposition and assembly
- CNT band gap tuning
- Signal readout
- Chip packaging

Nano lithography



Reliable nano-manufacturing process for CNT Based IR detectors

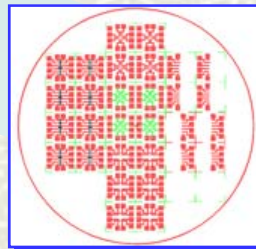


Band gap tuning

Substrate fabrication



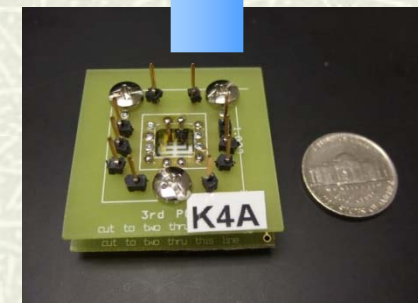
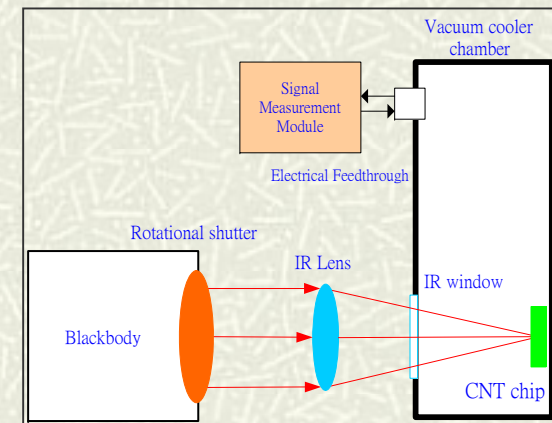
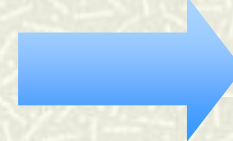
Chip design



Chip packaging

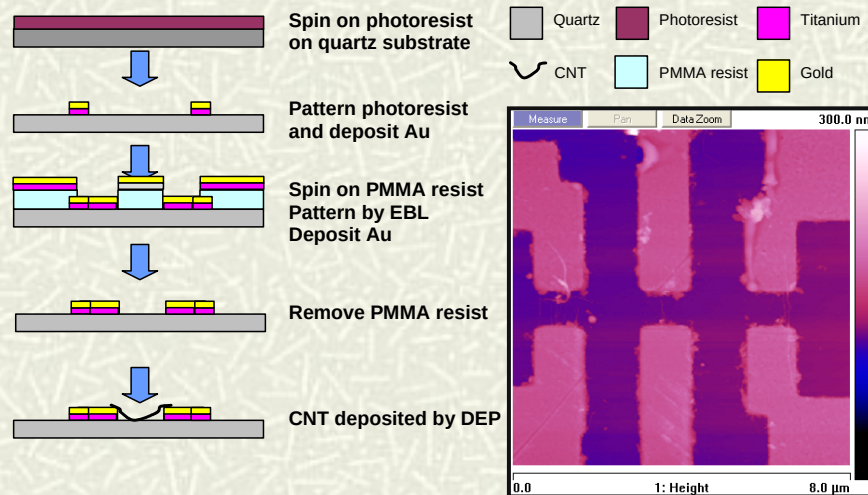


Final testing



CNT Based IR Detector Array

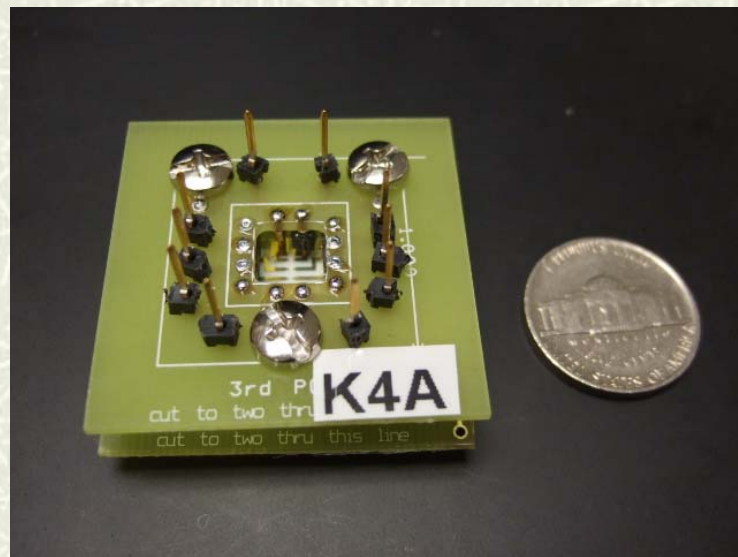
Design



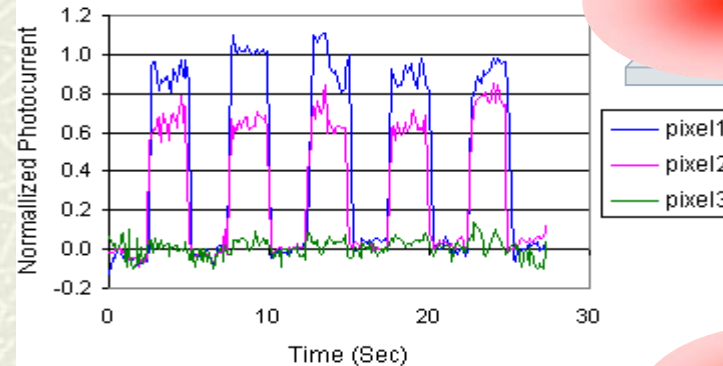
• Gap distance: 700 nm

• Pixel distance: 2 μm

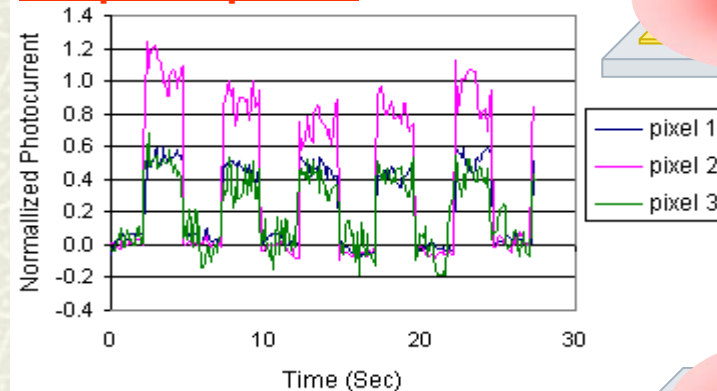
Multiple Pixel (3x3) CNT IR Sensor



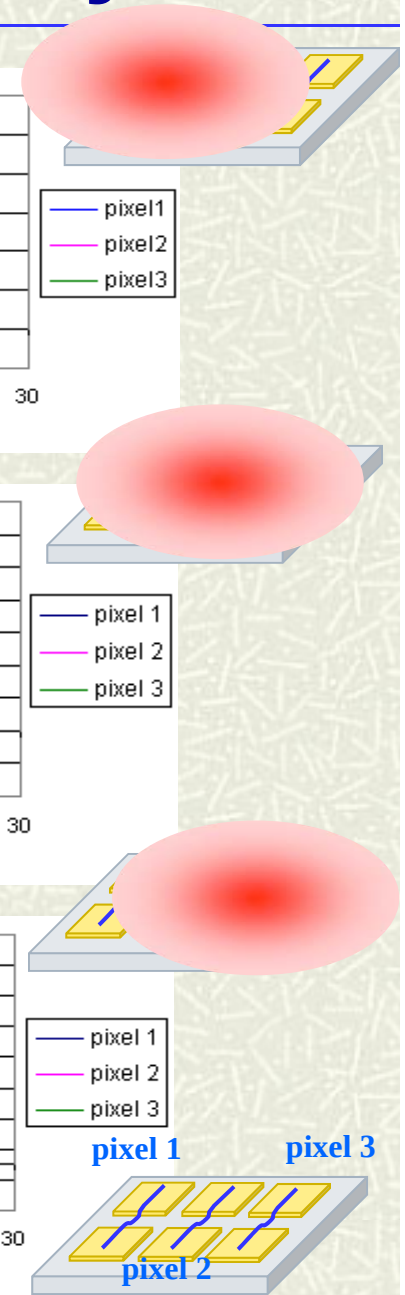
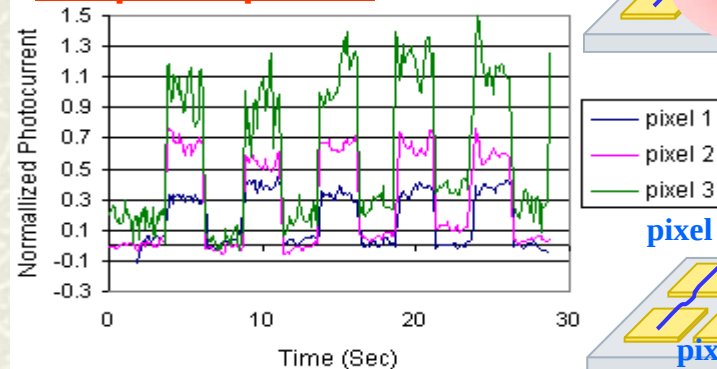
IR spot at pixel 1



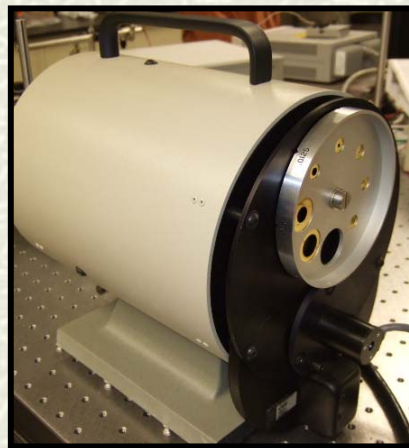
IR spot at pixel 2



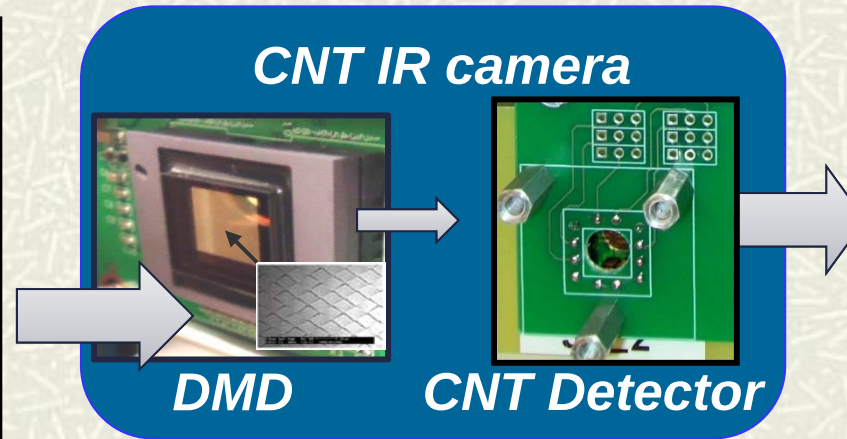
IR spot at pixel 3



Experimental Testing of CNT-based IR Camera



*Blackbody
IR Source*



100x100 IR image, $\lambda=830$ nm

CNT-based IR Camera Specification:

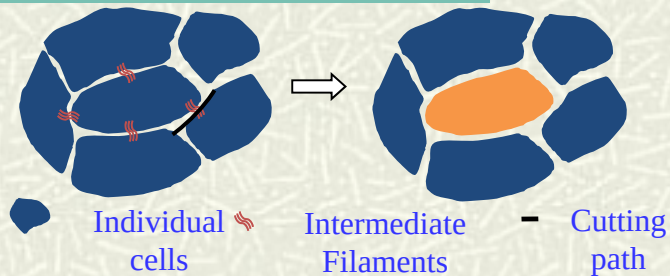
- Response time: 120 ns
- Quantum efficiency: 0.313
- Dark current: 2×10^{-14} A
- Signal-to-noise ratio: ~ 1500
- NETD: 14.5 mK
- Dynamic range: > 80 dB
- ADC resolution: 9 bit



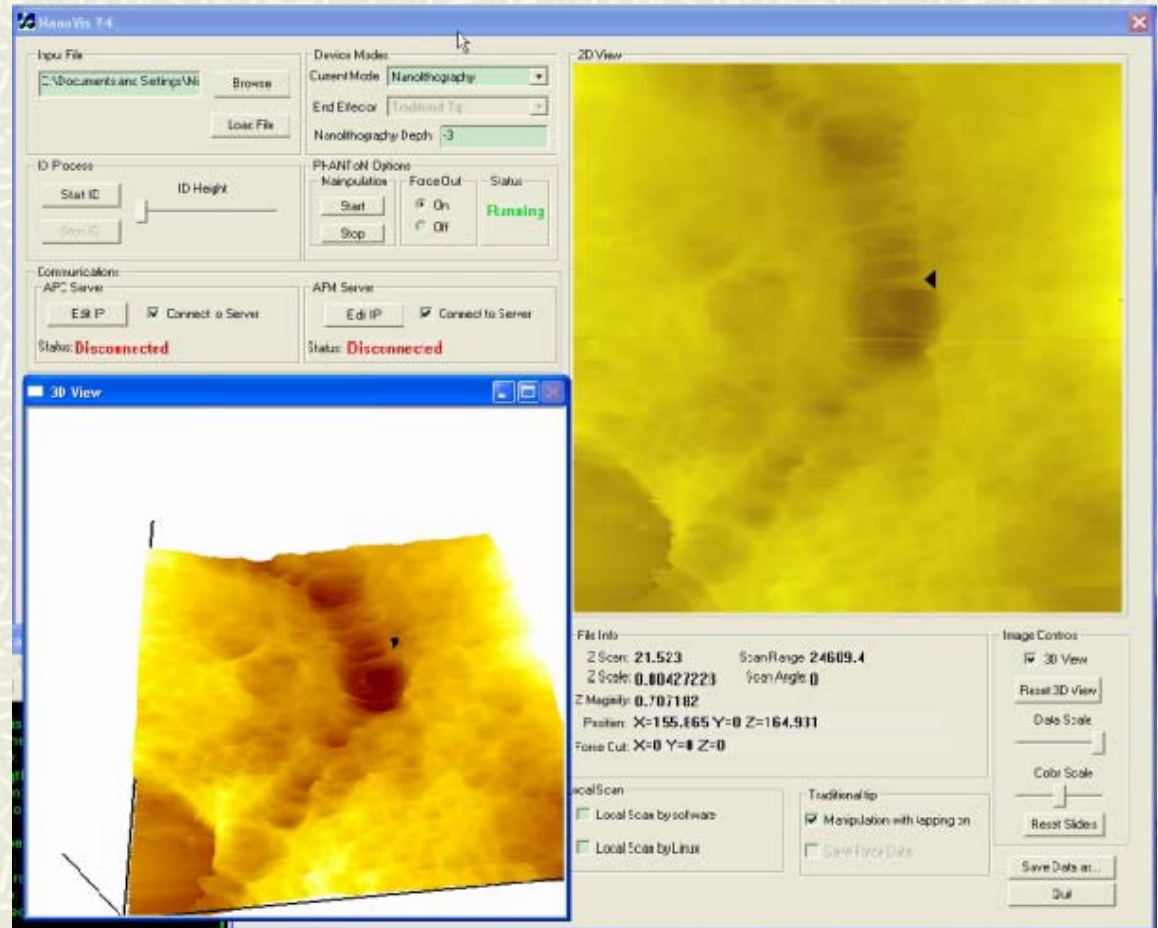
10x10 IR video (14 fps) , $\lambda = 830$ nm

Nanosurgery on live cells

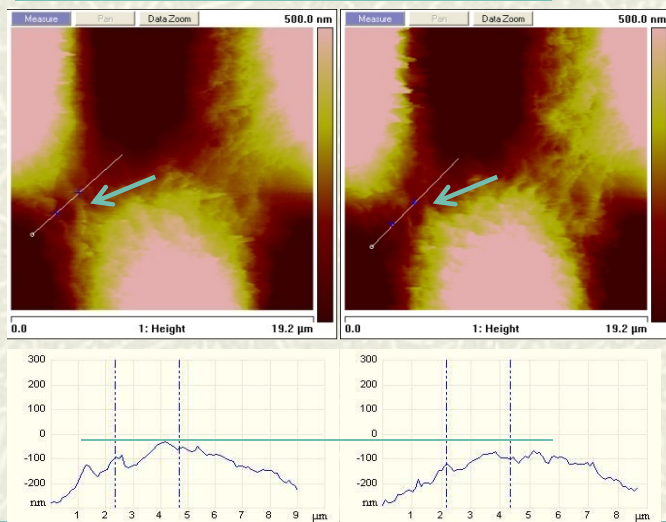
Schematic nanodissection



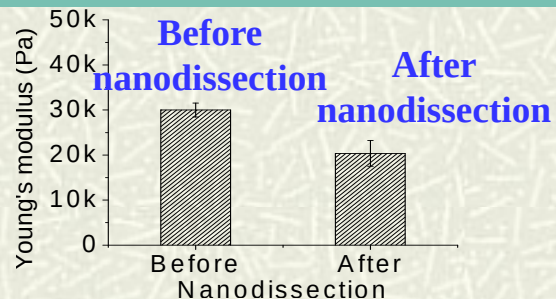
Software interface when performing nanosurgery on intercellular junction



Nanodissection experiment



Stiffness loss after nanodissection



Acknowledgements

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Research Associates and Graduate Students

Thank You