

Automated Calibration for Device Installation Based on Plug & Produce Concept

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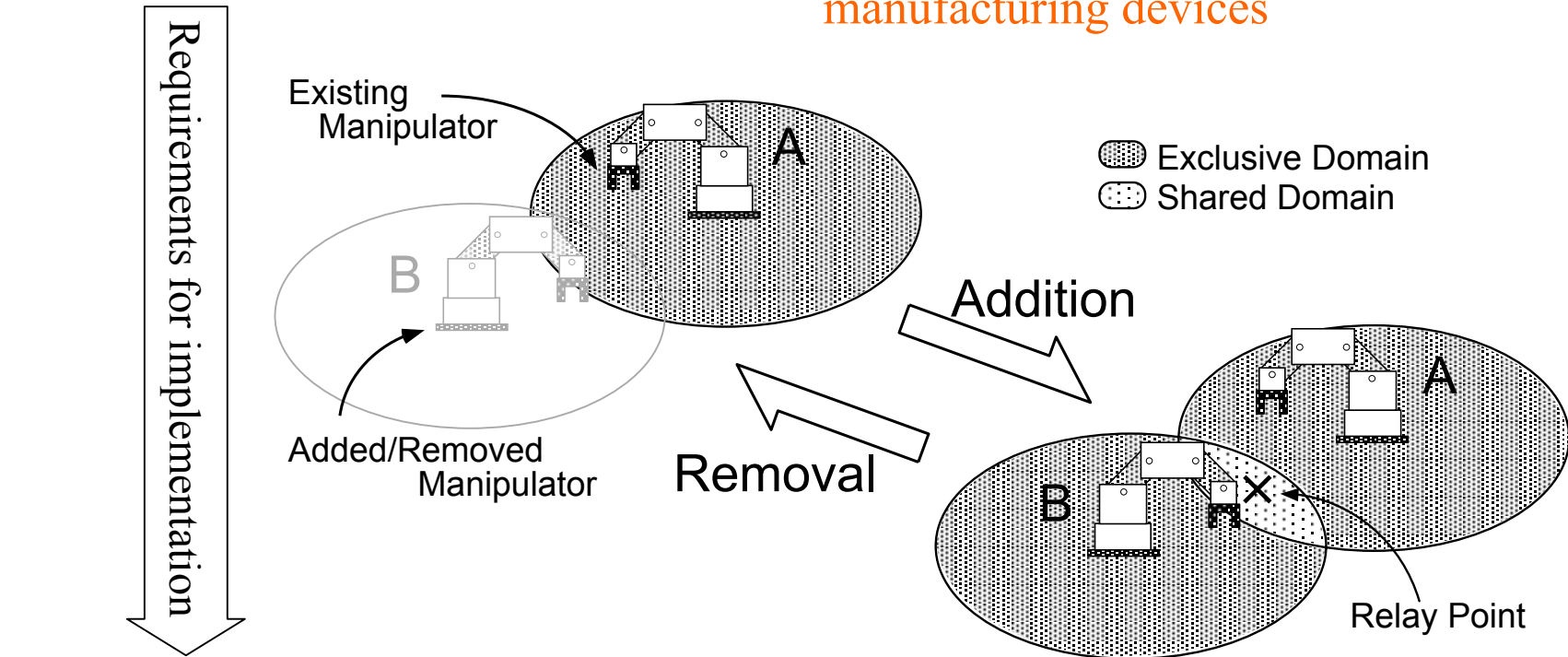
1. Introduction - the concept of Plug & Produce -
2. Features of our calibration method
3. Procedures of calibration
4. Experiment on the Accuracy
5. Conclusion

Introduction -Plug & Produce concept-

Reconfigurability of manufacturing systems

Plug & Produce

Function that enables easy installation/uninstallation of manufacturing devices

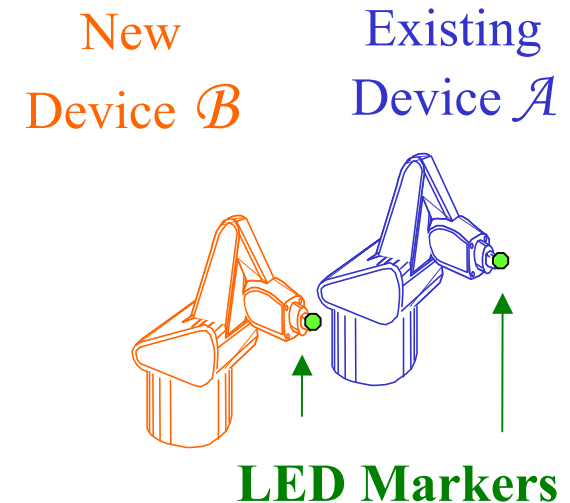


Our proposal

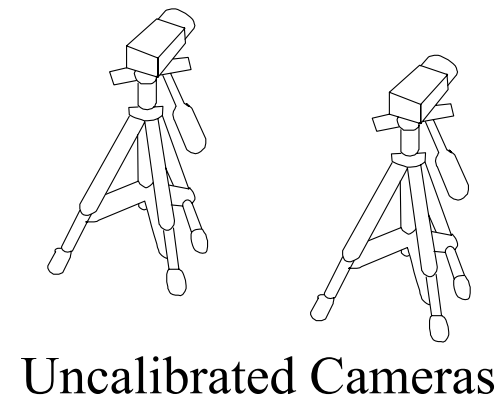
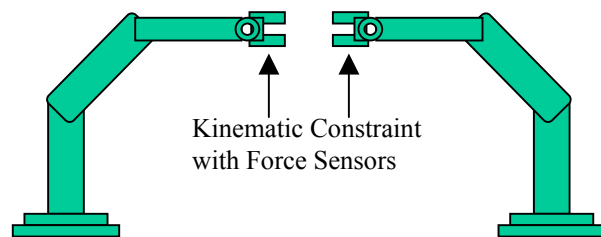
An easy calibration method for device installation between two neighboring devices.

Features of Our Calibration Method

1. Using two uncalibrated cameras to obtain relative positional relationship (DLT Method)
2. Free camera location
3. Almost automated
4. Observing the LED marker attached on the end point of each device

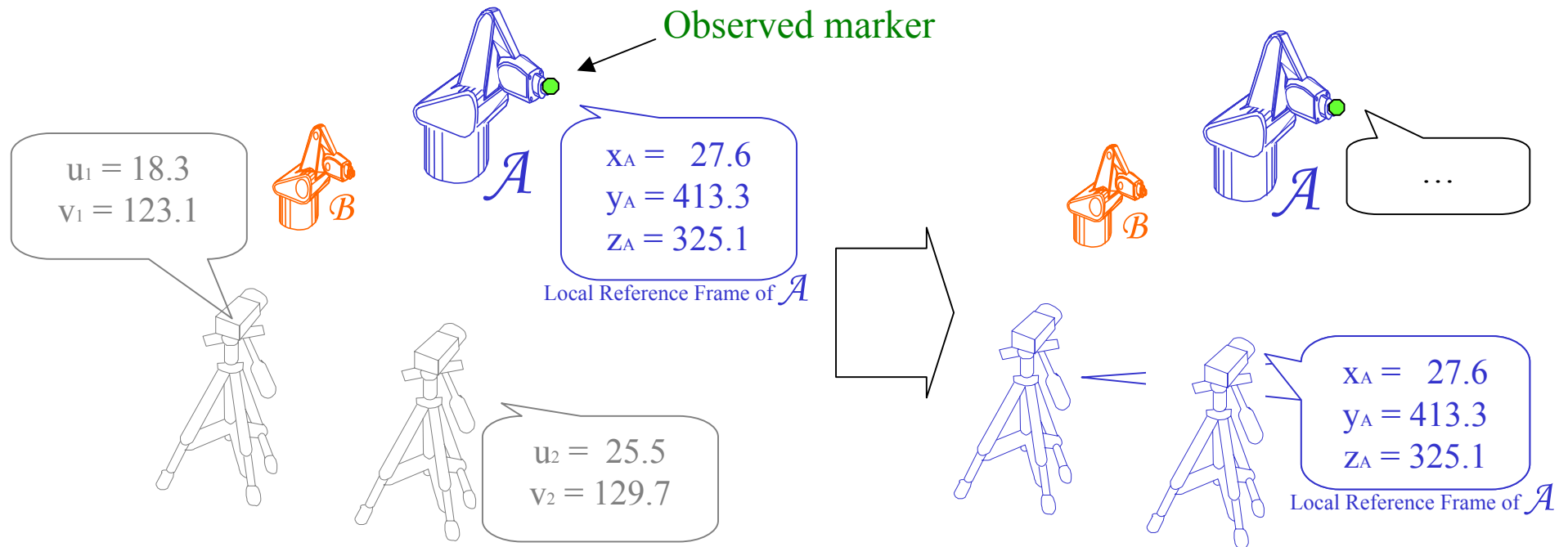


c.f. [Bonitz 1997]



- Using kinematic constraint (precisely machined calibration plates) between two PUMA manipulators
- Achieved calibration error is from 0.3mm to 1.0mm.

Calibration Step 1 (For DLT method)



Camera calibration for **DLT Method**

After calibration

Move an Existing Device \mathcal{A}

- Two uncalibrated cameras observe the marker of \mathcal{A}
- Simultaneously \mathcal{A} gets the coordinates of its own end point in the local reference frame of \mathcal{A}

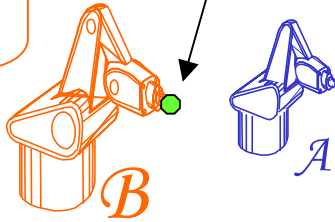
Two cameras can obtain the 3D coordinates in the local reference frame of \mathcal{A}

Calibration Step 2 (For New Device)

Local Reference Frame of \mathcal{B}

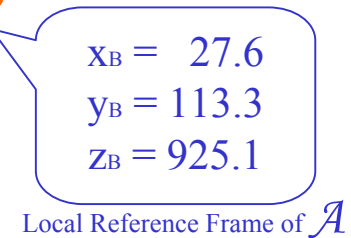
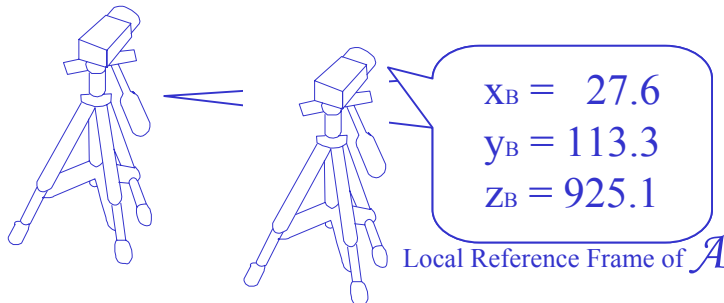
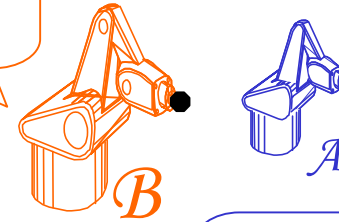
$$\begin{aligned}x_B &= 27.6 \\y_B &= 413.3 \\z_B &= 325.1\end{aligned}$$

Observed Marker



Local Reference Frame of \mathcal{B}

$$\begin{aligned}x_B &= 27.6 \\y_B &= 413.3 \\z_B &= 325.1\end{aligned}$$



Device-to-Device calibration for calculating \mathbf{a}

Homogeneous Transformation Matrix between \mathcal{A} and \mathcal{B}

After calibration

Move a new Device \mathcal{B}

- Two calibrated cameras observe the marker of \mathcal{B} in the local reference frame of \mathcal{A}
- Simultaneously \mathcal{B} gets the coordinates of its own end point at the local reference frame of \mathcal{B}

The device \mathcal{B} can calculate 3D coordinates of its own end point in the local reference frames of \mathcal{A}

Experimental Setup (a Plug-in of new manipulator)

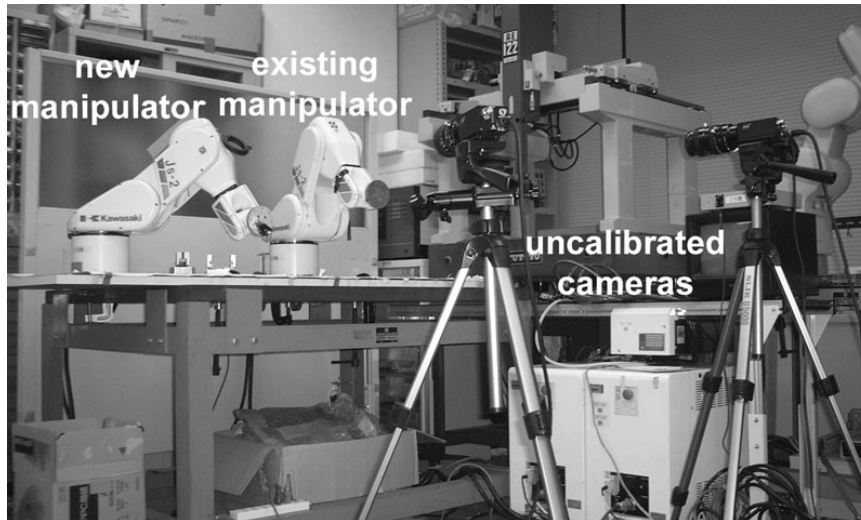


Fig. Experimental Setup

- Manipulator :
JS-2 (6 DOF, ± 0.03 mm repeatability)
CCD Camera Resolution : 640 \times 416
- Sample :
from 2x2x2 to 5x5x5 grid (8-125 points),
covering a space of 200x200x200 mm
- Calibration errors are measured at 5x5x5 grid
that is located on the relay point.

Comparison Points

1. Camera Locations
(c.f. **Setting 1, 2**)
2. No. of samples (control points)
for calibration
3. Calculation Method
(the difference between Sequential
approach and Iterative approach)

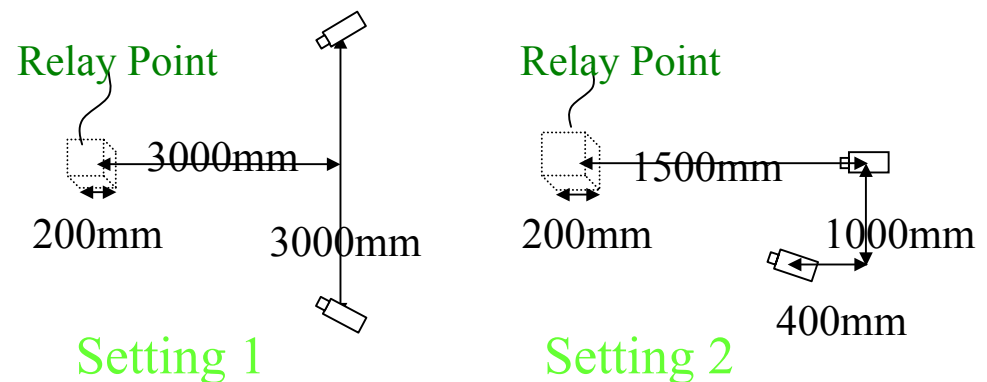


Fig. Camera Settings

Experiment 1 (the influence of camera setting)

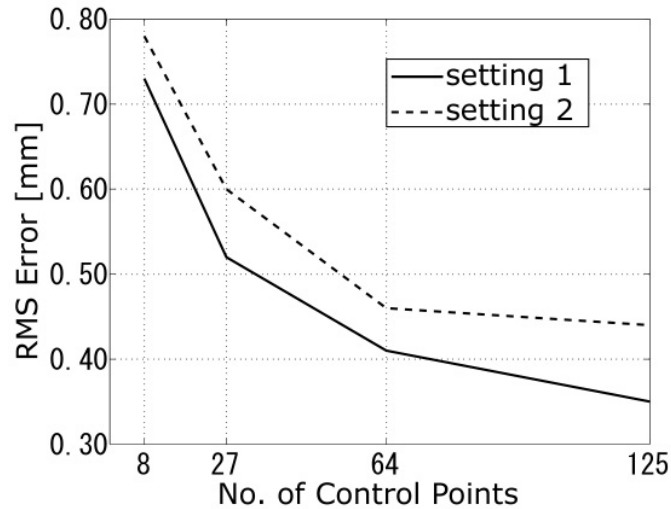


Fig. RMS Error

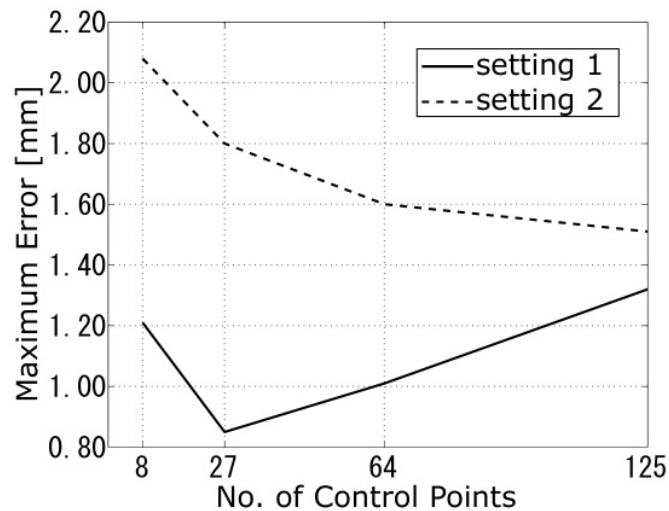


Fig. Maximum Error

1. We should obey the following policies if we need a certain accuracy.

- For effective use of camera resolution, **two cameras should shoot marker motion as large as possible in the camera frame.**
- To reduce errors in the direction of optical axis, **two cameras should keep a certain distance each other.**
- **Calibration should be executed around only a relay point,** because the accuracy of positional relationship is required around only the relay point.
- **We should use a large number of samples** for calibration.

2. Achieved accuracy is at the same level of [Bonitz 1997]

- Achieved accuracy is 0.35mm RMS error and 1.20mm Maximum error.

Experiment 2 (the influence of calculation method)

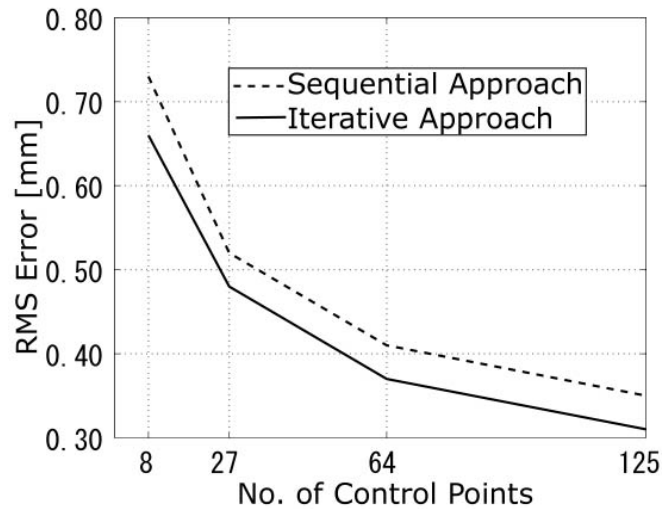


Fig. RMS Error

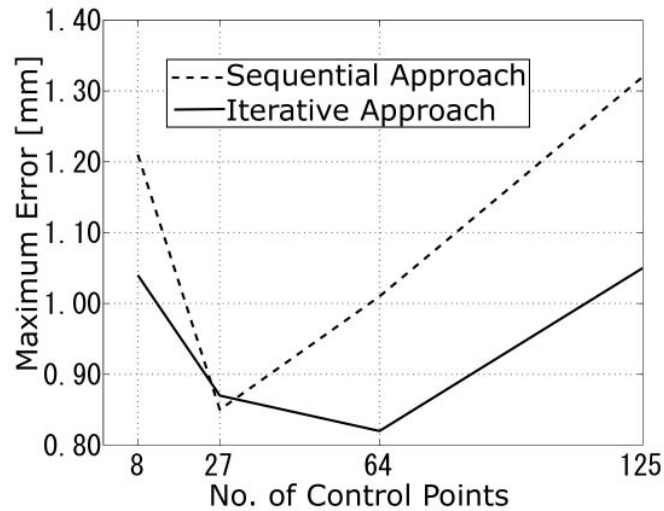
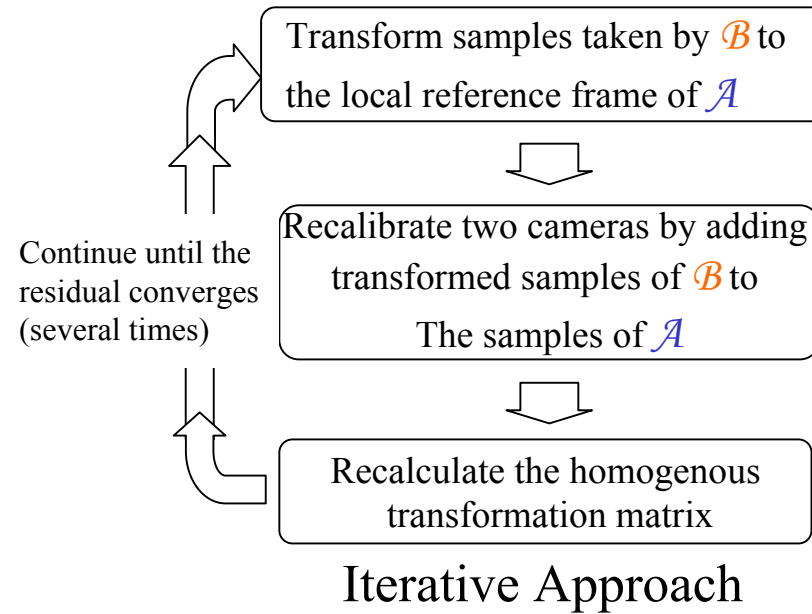


Fig. Maximum Error



- Iterative approach aims to optimize the residual of homogeneous (c.f. appendix) transformation matrix in the condition that 3D coordinates can only observe through two cameras.
- Iterative approach realizes **9.4% improvement** compared with normal (sequential) approach

Conclusion

1. We proposed a method of automated calibration between two devices based on “Plug & Produce” concept for the installation of a new device in assembly systems.
2. Calibration between two robot manipulators was demonstrated. The accuracy of 0.31mm RMS error was achieved. More resolution of CCD cameras or identification of internal parameters of the CCD cameras and the manipulators is required for more accuracy.

Appendix (the DLT method, residual)

- DLT (Direct Linear Transformation) method

In the DLT method, the relation between object-space reference frame (the XYZ system) And image-plane reference frame (the UV system) are :

$$u = \frac{B_1x + B_2y + B_3z + B_4}{B_5x + B_5y + B_7z + 1}$$

$$v = \frac{B_8x + B_9y + B_{10}z + B_{11}}{B_5x + B_5y + B_7z + 1}$$

u,v : 2D camera frame
x,y,z : 3D coordinates
B₁-B₁₁ : DLT parameters

- Residual

$$r = \sqrt{\sum_{j=1}^n \frac{\|C_j - E_j\|^2}{n}}$$

C : coordinates of manipulator's end point
observed by the device itself
E : coordinates of manipulator's end point
reconstructed by a homogenous transformation matrix
n : the number of samples (control points)