# 3D Scanner Calibration Methodology for Advanced Remote Dismantling System

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## 1. Introduction

Dismantling of nuclear power plants requires the remote system because human access is limited to the work place having a high radiation [1]. For this reason, teleoperation robot will be accessible with dismantling mission. But, before dismantling, actual nuclear power plant environment need to be acknowledged. So, the 3D scanner can be used for recognizing dismantling environment.

This research proposes a methodology to calibrate the transformation matrix of the 3D scanner. Position obtained by the transformation matrix of the 3D scanner may have an error of the order of a few millimeters because most 3D scanners are designed to acquire object's shape, not position. In this research, a calibration methodology based on ICP algorithm is used to find transformation matrix aligning scanned point cloud data with a true cad model. Experimental results show that localization using the calibrated matrix achieves an acceptable level of error.

## 2. 3D Scanner Calibration Methodology

ICP algorithm [2] is used for acquiring distance and angular differences between true data which is accurate CAD position data and scanned data. Transformation matrix is used for transforming coordinate from scanner's camera to mount origin.

### *2.1 3D registration with ICP algorithm*

Iterative Closest Point algorithm is designed to minimize error between two-point cloud data.

$$\mathrm{E(R,t)} = \frac{1}{N_p}\sum_{i=1}^{N_p}\|x_i - Rp_i - t\|^2 \qquad (1)$$

Where translation t and rotation R minimize the sum of the squared error. $x_i$ and $p_i$ are corresponding points.

### *2.2 Calibration Sequence*

Calibration process is followed with this steps.

Step 1. Getting point cloud data from scanner

Step 2. Transform point cloud to origin of scanner mount by transformation matrix.

Step 3. Acquire calibration matrix with ICP algorithm between true data and scanned data.

### *2.3 Acquiring Calibrated Matrix*

Raw data from scanner is just distance from camera, not actual distance from mount origin.

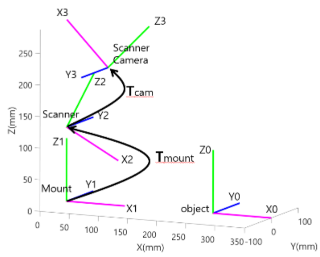

Fig. 1. Coordination System of Experiment.

Thus, data need to be transformed to mount origin with transformation calculation.

$$\mathbf{D}_{\mathrm{modified}} = \mathbf{T}_{\mathrm{mount}}\mathbf{T}_{\mathrm{cam}}\mathbf{D}_{\mathrm{raw}} \qquad (2)$$

As shown in Fig. 1, $\mathbf{T}_{\mathrm{mount}}$ is transformation from mount origin to scanner origin, $\mathbf{T}_{\mathrm{cam}}$ is transformation from scanner origin to main camera, $\mathbf{D}_{\mathrm{raw}}$ is raw point cloud data. ICP algorithm is used for comparing true data and modified data. Result of ICP algorithm $\mathbf{T}_{\mathrm{ICP}}$ is the matrix with distance and angular transformation.

$$\begin{aligned}\mathbf{D}_{\mathrm{true}} &= \mathbf{T}_{\mathrm{ICP}}\mathbf{T}_{\mathrm{mount}}\mathbf{T}_{\mathrm{cam}}\mathbf{D}_{\mathrm{raw}} \\ &= \mathbf{T}_{\mathrm{mount}}\mathbf{T}_{\mathrm{cam'}}\mathbf{D}_{\mathrm{raw}}\end{aligned} \qquad (3)$$

$\mathbf{T}_{\mathrm{mount}}$ is different when mount changed to other environment like robot arm. Thus, $\mathbf{T}_{\mathrm{cam'}}$ matrix which is unchanged need to be calculated.

$$\mathbf{T}_{\mathrm{cam}'} = (\mathbf{T}_{\mathrm{mount}})^{-1}\mathbf{T}_{\mathrm{ICP}}\mathbf{T}_{\mathrm{mount}}\mathbf{T}_{\mathrm{cam}} \qquad (4)$$

Invariant scanner calibration matrix $\mathbf{T}_{\mathrm{cam}'}$ is acquired by calculation (4).

## 3. Experiment

Experiment repeated 6 times to get average of result for reliability.

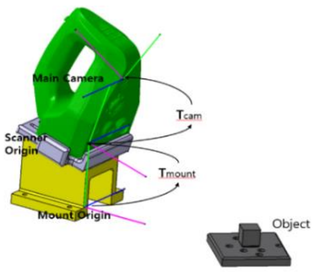


Fig. 2. Experiment Setup.

Mount and object are printed by 3D printer. Materials are fixed to test table with bolt.

## 4. Result

*4.1 Calibrated Camera Transformation Matrix*

$$\begin{bmatrix} -0.9998 & -0.0100 & 0.0148 & -0.1219 \\ -0.0053 & 0.9572 & 0.2894 & 122.4096 \\ -0.0171 & 0.2893 & -0.9571 & 16.9045 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (5)$$

$$\begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0.9547 & 0.2975 & 120.97 \\ 0 & 0.2975 & -0.9547 & 16.053 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (6)$$

Matrix (5) is final calibrated $T_{cam'}$ matrix which is averaged with all iteration result. Matrix (6) is given by manufacturer. Camera transformation matrix calibrate +1.44mm in direction of Y-axis, +0.85mm in direction of Z-axis, -0.12mm and -0.49 degrees on the X-axis.

*4.2 Error Analysis*

Fig. 3 shows verification of calibration matrix.

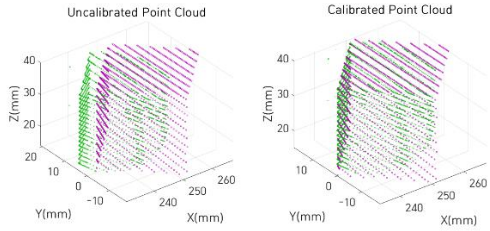


Fig. 3. Differences between True and Calibrated Data.

Result proves that method derives satisfactory calibration data. As shown in Fig. 4, RMS error of point cloud data are 0.06mm~0.07mm. Thus, Calibration method can reach accuracy with in 0.1mm expressed in scanner specification [3].

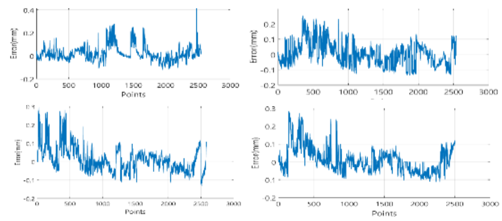

Fig. 4. Plotting 4 cases Error between True and Calibrated Point Cloud Data.

## 5. Conclusion

The calibration methodology proposed in this paper can get precision calibrated result that derives low error between true and scanned data. Method show that calibration using ICP algorithm is appropriate for calibrating scanner.

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