CAMERA CALIBRATION

Charmaine S. Tolledo

CONTENTS

Objectives

Methods

Results

Analysis

Reflection

OBJECTIVES

01

Construction

Establish the Tsai grid configuration for camera calibration.

02

Calibration

Perform the camera calibration process using recorded coordinates.

03

Evaluation

Evaluate the accuracy of the calibration results and provide insights.

METHODOLOGY

GRID CONSTRUCTION

- Construct a Tsai grid with checkerboard patterns on two perpendicular flat surfaces.
- Define a global Cartesian coordinate system on the Tsai grid.
- Capture a clear and well-focused image of the Tsai grid using the camera to be calibrated.

DATA COLLECTION AND DOCUMENTATION

- Randomly select a predetermined number of calibration points from the available corner points.
- Record the global coordinates (Xg, Yg, Zg) and their corresponding image coordinates (xi, yi) for the selected points.

MATRIX COMPUTATION

- Set up matrices Q and p based on Equation 31 using the recorded global and image coordinates.
- Compute the elements of the camera calibration matrix a using Equation 33.

TESTING AND VALIDATION

- Validate the calibration by accurately predicting the image coordinates of at least one randomly selected point using the calibration matrix.

ANALYSIS AND INTERPRETATION

- Assess the accuracy and reliability of the camera calibration.
- Analyze and interpret the calibration results.

TSAI GRID SETUP

For this calibration, a Tsai grid consisting of a special pattern of squares on two flat surfaces was used. Each square is approximately 1 inch by 1 inch (2.54 cm by 2.54 cm). A picture of the Tsai grid was then captured using the phone camera designated for calibration. A global Cartesian coordinate system was established on the grid, centered at its base. Finally, a total of 25 corner points on the grid were selected and their corresponding real-world global coordinates (Xg, Yg, Zg) and image coordinates (xi, yi) were recorded.

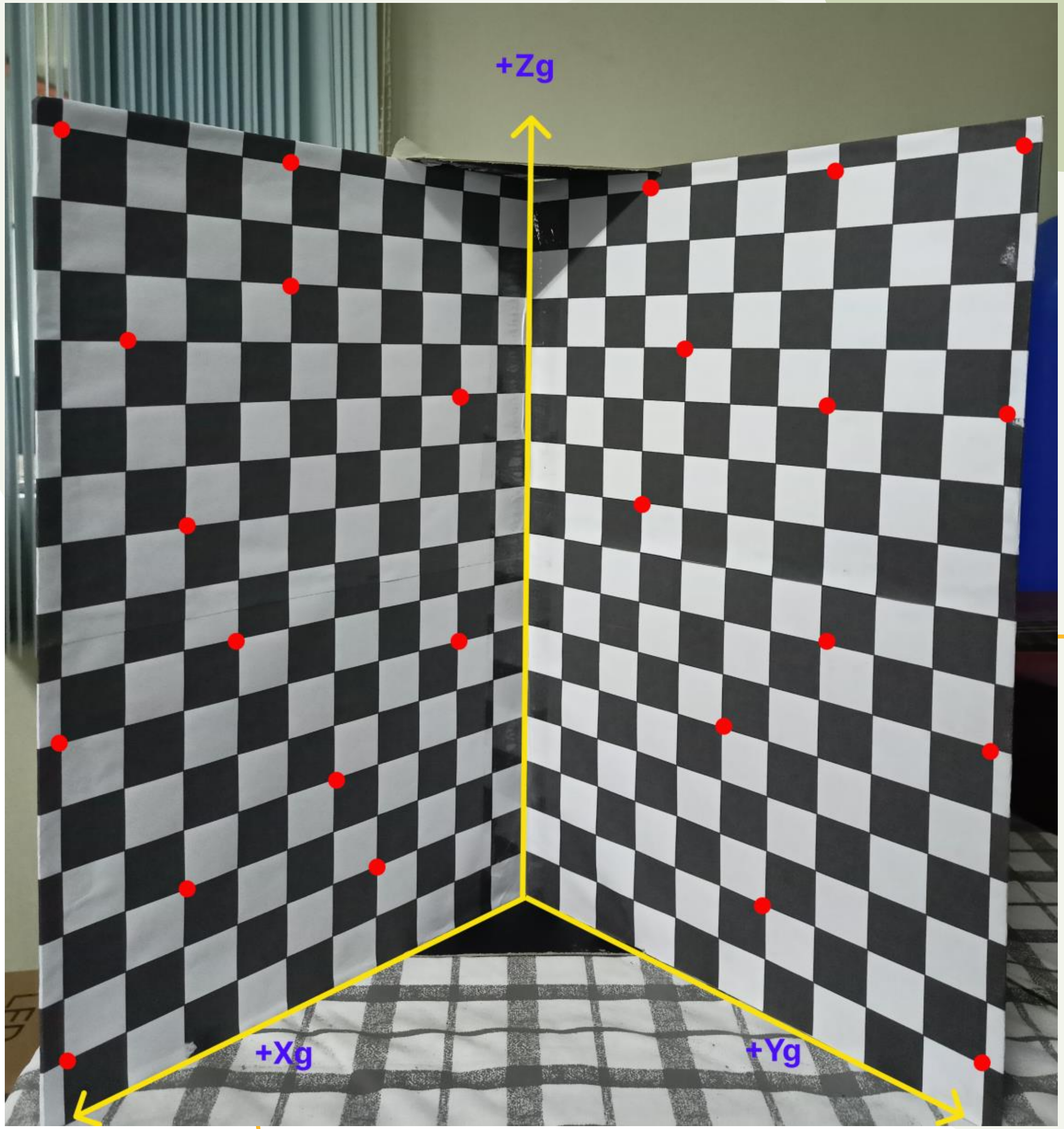

Figure 1
Tsai grid with the 25 randomized points

MATRIX INITIALIZATION

```matlab
% Defining the global coordinates (Xg, Yg, Zg) and their corresponding image coordinates (xi, yi)
Xg = [10, 6, 6, 9, 2, 8, 7, 10, 2, 5, 8, 4, 10, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0];
Yg = [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 3, 7, 10, 4, 7, 10, 3, 7, 10, 5, 6, 10];
Zg = [15, 15, 13, 12, 11, 9, 7, 6, 6, 4, 3, 2, 1, 15, 15, 15, 12, 11, 11, 9, 7, 6, 5, 2, 1];
xi = [158, 905, 905, 374, 1458, 567, 727, 150, 1453, 1054, 567, 1186, 177, 2078, 2680, 3295, 2189, 2653, 3240, 2050, 2652, 3185, 2316, 2442, 3158];
yi = [386, 493, 896, 1073, 1258, 1677, 2054, 2386, 2054, 2507, 2861, 2790, 3422, 576, 521, 438, 1101, 1286, 1313, 1608, 2054, 2413, 2331, 2916, 3428];

% Number of data points
n = length(Xg);

% Initializing matrices Q and p
Q = zeros(2*n, 11);
p = zeros(2*n, 1);

% Filling Q and p matrices based on Equation 31 from lecture note
for i = 1:n
    Q(2*i - 1, 1:4) = [Xg(i), Yg(i), Zg(i), 1];
    Q(2*i - 1, 9:11) = [-xi(i) * Xg(i), -xi(i) * Yg(i), -xi(i) * Zg(i)];

    Q(2*i, 5:8) = [Xg(i), Yg(i), Zg(i), 1];
    Q(2*i, 9:11) = [-yi(i) * Xg(i), -yi(i) * Yg(i), -yi(i) * Zg(i)];

    p(2*i - 1) = xi(i);
    p(2*i) = yi(i);
end
```

(a)

$$\begin{bmatrix} x_o & y_o & z_o & 1 & 0 & 0 & 0 & 0 & -(x_i x_o) & -(x_i y_o) & -(x_i z_o) \\ 0 & 0 & 0 & 0 & x_o & y_o & z_o & 1 & -(y_i x_o) & -(y_i y_o) & -(y_i z_o) \end{bmatrix} \begin{bmatrix} a_{11} \\ a_{12} \\ a_{13} \\ a_{14} \\ a_{21} \\ a_{22} \\ a_{23} \\ a_{24} \\ a_{31} \\ a_{32} \\ a_{33} \end{bmatrix} = \begin{bmatrix} x_i \\ y_i \end{bmatrix} \quad (31)$$

(b)

Figure 2

(a) Code for initializing Q and p matrices (b) Elements of the matrix equation

Here, we kick things off by defining the global coordinates (Xg, Yg, Zg) of the points we selected alongside their corresponding image coordinates (xi, yi). After having our coordinates ready, we proceed to calculate the number of data points to set the stage for the next crucial step. And to properly structure our data, we initialize two matrices, Q and p. This initialization process closely follows the guidance provided in Figure 2b, which is the equation 31 from our lecture notes.

CALIBRATION MATRIX COMPUTATION

```
% Computing the calibration matrix elements using Equation 33 from lecture note
a =     (Q' * Q) \ (Q' * p);

% Displaying the calibration matrix A
disp(a);
```

```
   1.0e+03 *

   -0.1541
    0.0582
   -0.0017
    1.6630
   -0.0338
   -0.0300
   -0.1527
    2.8886
   -0.0000
   -0.0000
   -0.0000
```

Figure 3
Code for computing the calibration matrix a

This section is where we calculate the calibration matrix elements, denoted as 'a' that helps us convert real-world coordinates to image positions. We use Equation 33 from our lecture notes to do this. This equation involves working with the Q matrix and p vector. And as we can see above, we successfully got the calibration matrix.

TESTING OF CALIBRATION MATRIX

```
% Defining the global coordinates for testing
global_coords = [
    0, 9, 9;
    0, 3, 3;
    5, 0, 11
];
for i = 1:size(global_coords, 1)
    % Using Equation 29 and 30 from lecture notes to predict image coordinates
    E(i, 1) = (a(1) * global_coords(i, 1) + a(2) * global_coords(i, 2) + a(3) * global_coords(i, 3) + a(4)) / ...
        (a(9) * global_coords(i, 1) + a(10) * global_coords(i, 2) + a(11) * global_coords(i, 3) + 1); % Predicted x
    E(i, 2) = (a(5) * global_coords(i, 1) + a(6) * global_coords(i, 2) + a(7) * global_coords(i, 3) + a(8)) / ...
        (a(9) * global_coords(i, 1) + a(10) * global_coords(i, 2) + a(11) * global_coords(i, 3) + 1); % Predicted y

 end

% Displaying the predicted image coordinates
disp(E);
```

```
  1.0e+03 *

   3.0195    1.7297
   2.0218    2.5821
   1.0617    1.2630
```

Figure 4
Predicted coordinates using the calibration matrix

$$x_i = \frac{a_{11} x_o + a_{12} y_o + a_{13} z_o + a_{14}}{a_{31} x_o + a_{32} y_o + a_{33} z_o + a_{34}}$$

(a)

$$y_i = \frac{a_{21} x_o + a_{22} y_o + a_{23} z_o + a_{24}}{a_{31} x_o + a_{32} y_o + a_{33} z_o + a_{34}}$$

(b)

Figure 5
Equations (a) 29 and (b) 30 from lecture note

Now, to evaluate the accuracy of the calibration matrix we've obtained, we tested it with a set of predefined global coordinates, here we used 3 points: (0,9,9), (0,3,3), and (5,0,11). Using Equation 29 and 30 from our lecture notes, we predict their corresponding image coordinates. And as we can see above, we obtained 3 image coordinates as well.

ANALYSIS

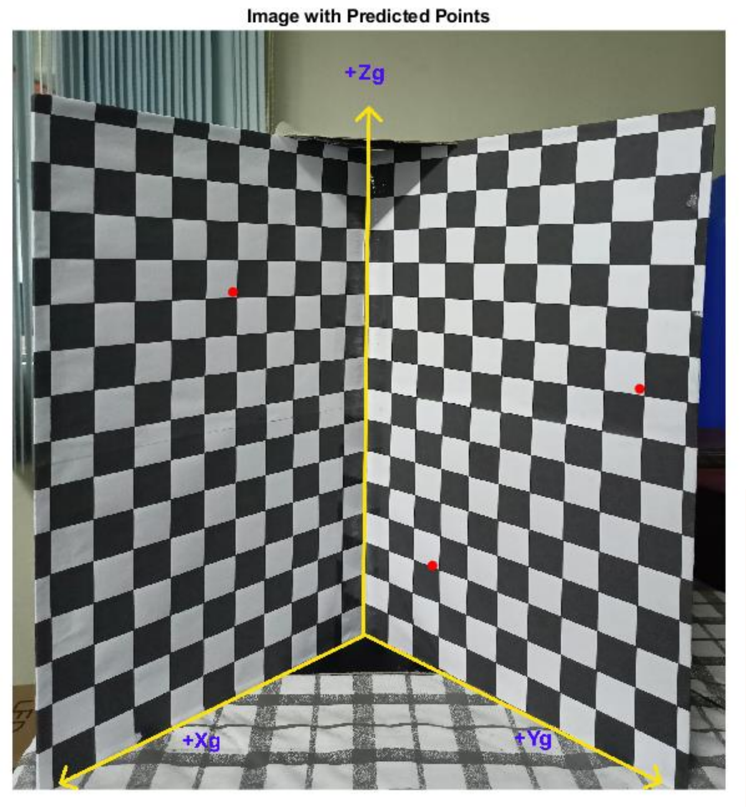

Figure 6
Overlay of Predicted Points on Original Image

```
% Displaying percent error
disp(percent_error);
```

```
    0.1149    0.4176
    0.0585    0.3530
    0.3078    0.3189
```

Figure 7
Calculated Percent error between predicted and actual image coordinates

After computing the predicted image coordinates (E) based on our calibration matrix, we now visually assess the accuracy of our calibration process. To do so, we overlay the calculated points onto the original image. And from figure 6, we observe an alignment of the three red dots with the predicted locations. This alignment serves as a strong validation of the accuracy of our calibration process. This assertion is reinforced by our analysis in Figure 7, where we calculated the percent error. Our findings reveal minimal deviations between the predicted and actual coordinates, underscoring the high level of calibration precision.

REFLECTION

This marks just the beginning of our journey in this subject, and yet, I've already faced some challenges. It took me some time to grasp the task at hand, and I initially struggled to find a suitable checkerboard for calibration. I considered using a cardboard chessboard as an alternative until Mar Princer kindly lent me his personally crafted board – a big shout-out to Mar for the assistance.

Despite the initial challenges that left me feeling a bit overwhelmed, the sense of fulfillment I experienced when successfully calibrating the camera was indescribable. Reflecting on the journey, I believe I accomplished all the objectives I set out to achieve. I poured a substantial amount of effort into preparing this presentation, and I believe I was able to provide a clear explanation of the results.

So, I'm giving myself a perfect score of 100/100!

THANK YOU!