An approach to camera calibration in industrial robotics using HexSight

Facoltà di Ingegneria dell'informazione, informatica e statistica
Corso di Laurea Magistrale in Artificial Intelligence and Robotics

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How the presentation is organized

I. Vision systems in industrial robotics
II. Camera calibration in industrial robotics
III. Proposed solution
IV. Results

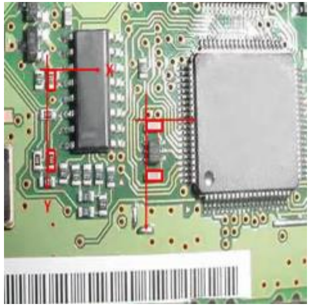
I. Vision systems in industrial robotics

Common applications :

- Measurement
- Localization
- Counting
- Decoding

Vision systems in industrial robotics

Estimate 3D information



Common applications :

- Measurement
- Localization
- Counting
- Decoding

Vision systems in industrial robotics

Estimate 2D information

Common applications :

- Measurement
- Localization
- Counting
- Decoding

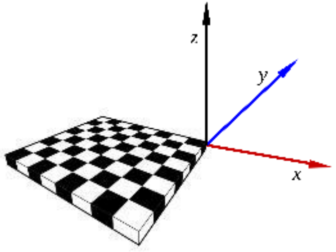
II Camera calibration in industrial robotics

2D point 3D point

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_x \\ r_{21} & r_{22} & r_{23} & t_y \\ r_{31} & r_{32} & r_{33} & t_z \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} = K \cdot [R|t] \cdot \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

Intrinsic Extrinsic

Camera matrix



1. Coordinates Acquisition $\begin{bmatrix} u_i \\ v_i \end{bmatrix} \longleftrightarrow \begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix}$

01100
10110
11110

2. Parameters Estimation $\longrightarrow$ calibration algorithm (Zhang, **Tsai**..)

3. Reprojection Tests $\sum_i d(\mathbf{x}_i, \hat{\mathbf{x}}_i)^2$

x_i estimation

$\hat{x}_i$ ground truth

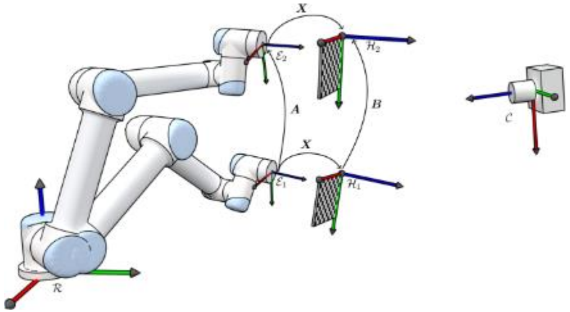
Camera calibration in industrial robotics

1. **Fixed** calibration support

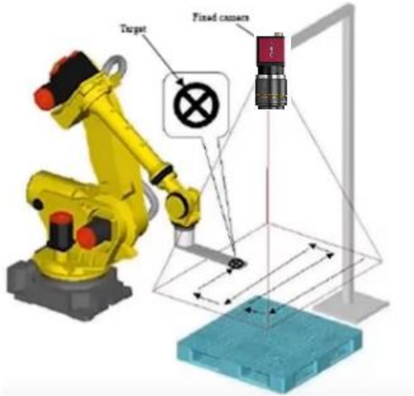
$$\begin{bmatrix} u_1 & u_2 & u_3 & u_n \\ v_1, & v_2, & v_3, & v_n \end{bmatrix} = \text{IP}$$

$$\begin{bmatrix} x_1 & x_2 & x_3 & x_n \\ y_1, & y_2, & y_3, & y_n \\ z_1 & z_2 & z_3 & z_n \end{bmatrix} = \text{WP}$$

2. **Robot-held** support



3. **Robot-generated** support



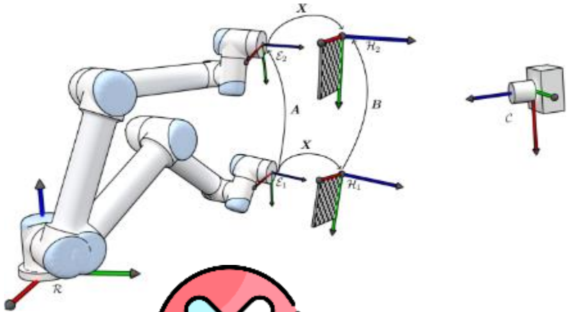
Camera calibration in industrial robotics

Fixed support

- Manual approach
- It needs specialized operator
- Single-point acquisition

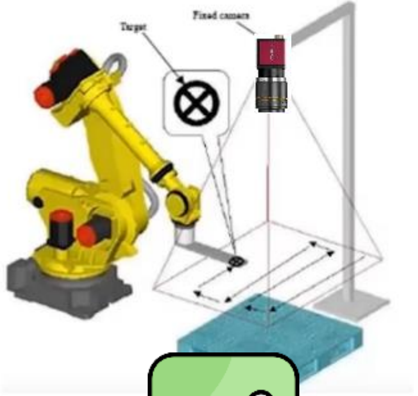
Robot-held

- Automatic approach
- Needs accuracy
- Multi-point acquisition



Robot-generated

- Automatic approach
- Flexible
- Single-point acquisition



III Proposed Solution

List of ingredients

Goal of the **project**

Develop a flexible and accurate automatic calibration process

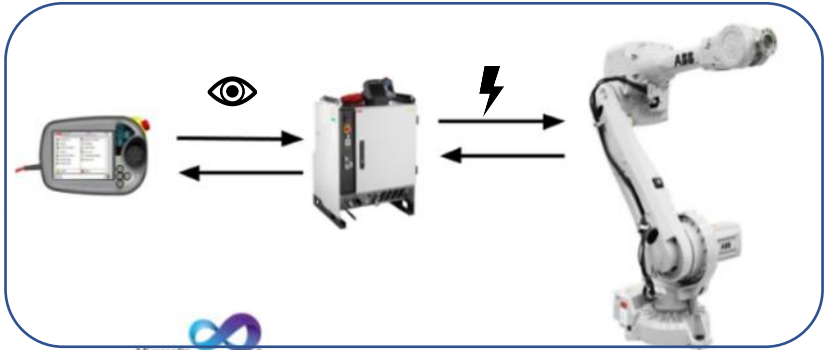


ABB IRB4600

- 6 axis
- 2.5m reach

HexSight library

- VB.NET

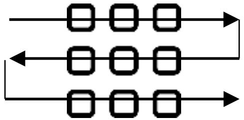
Mako G-503

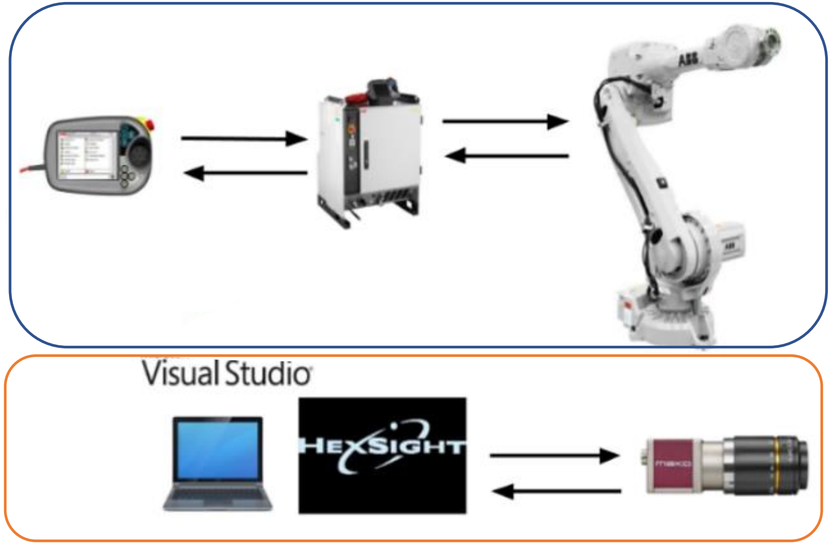
- 2592 x 1944 resolution
- 5 megapixel
- 14 frames/second
- Gigabit Ethernet

III Proposed Solution

Goal of the
robotics branch

Move the
calibration target
along a grid path
decided by the user





Goal of the
vision branch

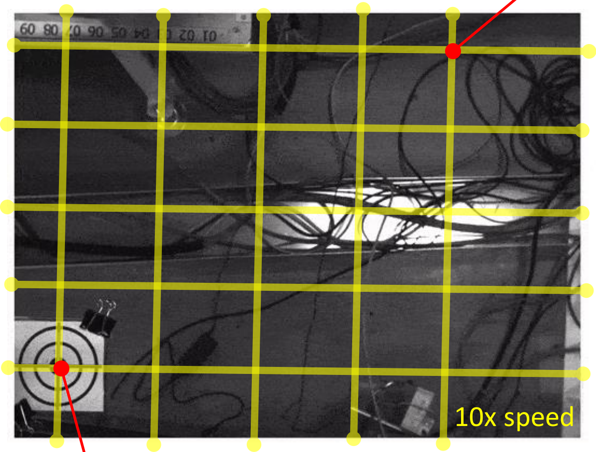
Acquire the target
coordinates and
compute the
calibration

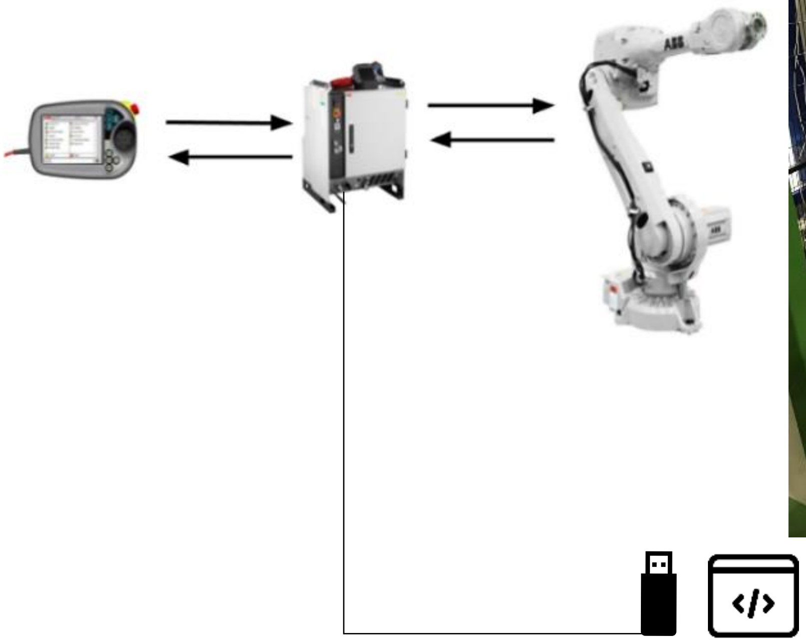
III Proposed Solution

Result

Final pos

Robotics branch



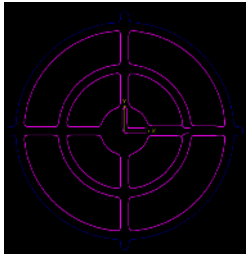


Starting pos

III Proposed Solution

More details

1. **Model** of the target to find



2. **Calibration method** to execute

Tsai calibration[1]

- Planar control points
- 2 Stage optimization
- Lens correction

III Proposed Solution

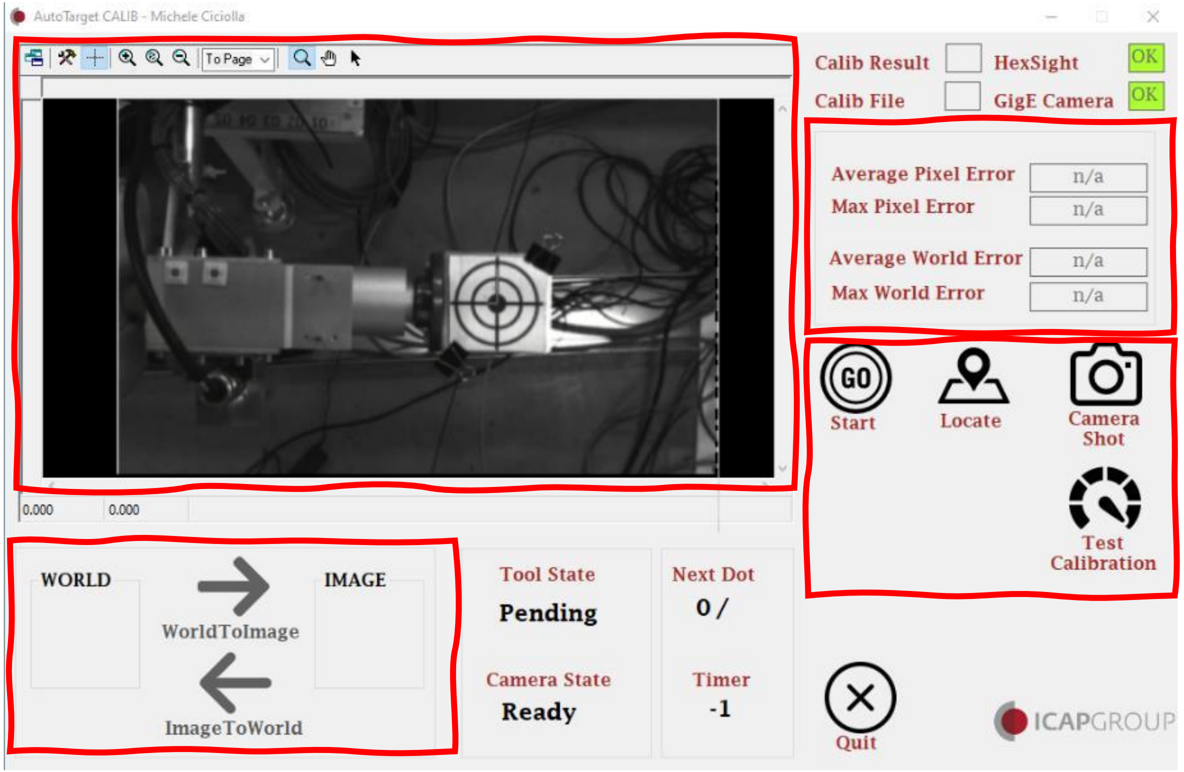
HMI : Visual Basic HexSight

Display

Result dashboard

Action buttons

Testing interface



IV Results

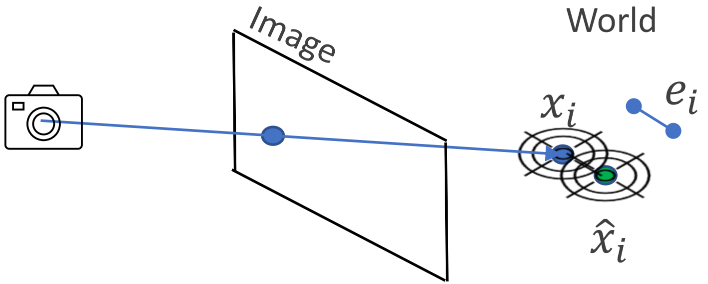
Performance evaluation:

Image-To-World estimation

$$\sum_i d(\mathbf{x}_i, \hat{\mathbf{x}}_i)^2$$

x_i World estimation

$\hat{x}_i$ World ground truth



Estimate 3D information

Measurement

Localization

$$\boldsymbol{e} = [e_1, e_2, e_3, e_4, e_i, ..e_n]$$

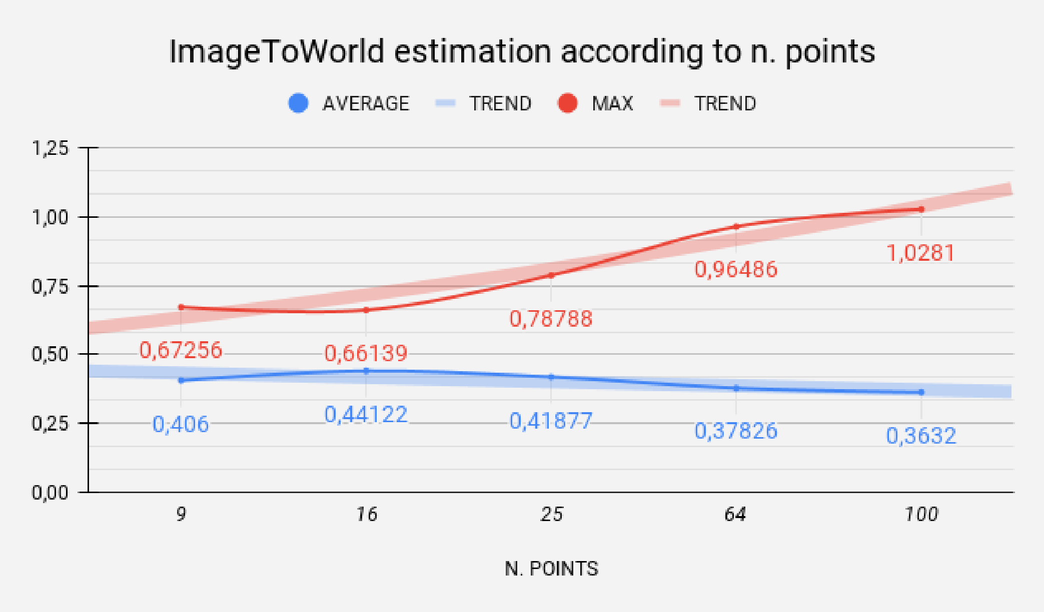
$$i = 1 \ldots N$$

$$\boldsymbol{max\_e} = \max(\boldsymbol{e})$$

$$\boldsymbol{avg\_e} = \boldsymbol{e}/N$$

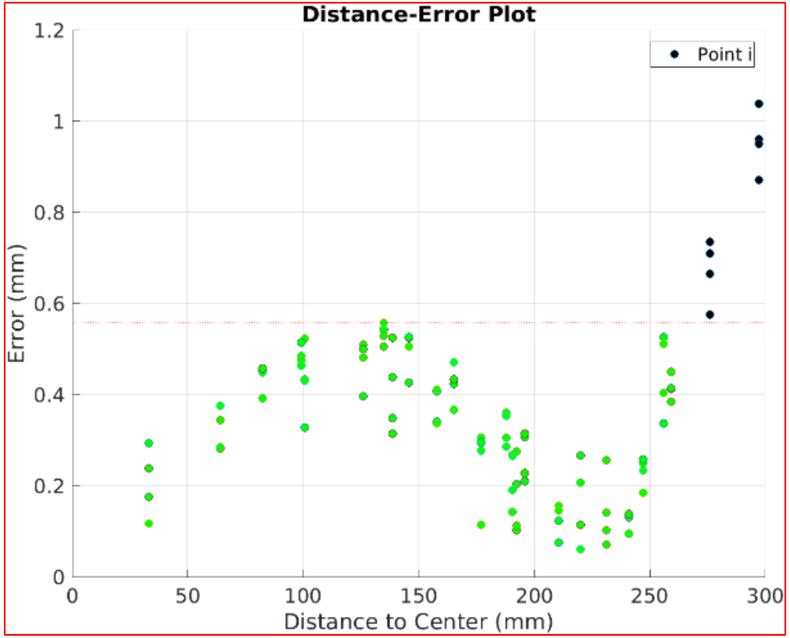
IV Results

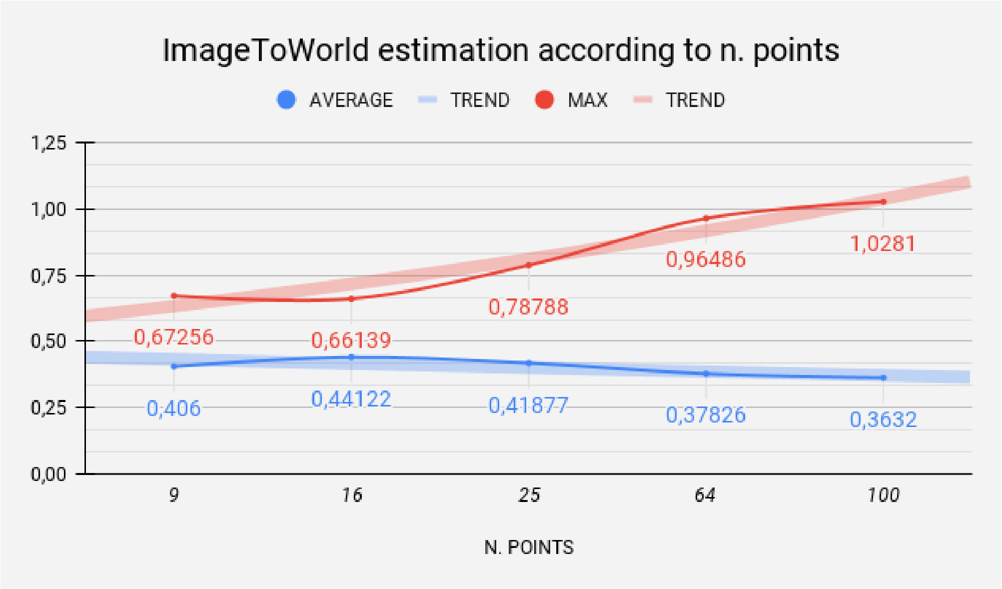
1. Performance trend according to **number of points** N



IV Results

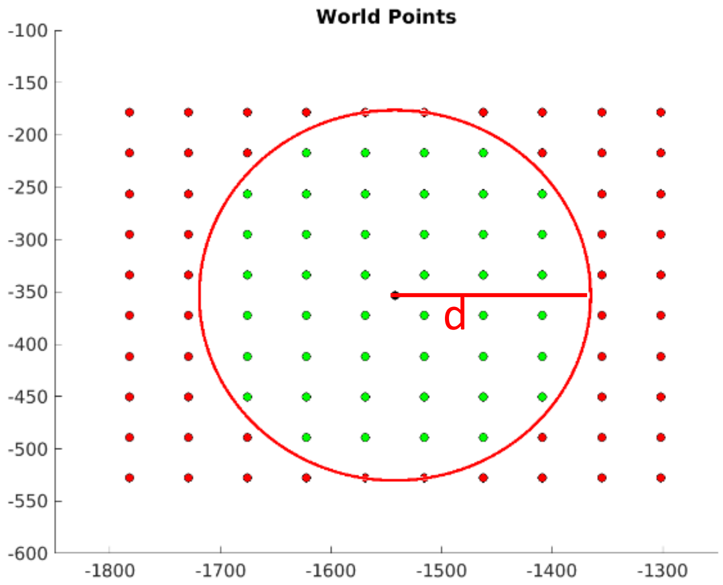
1. Performance trend according to **number of points** N

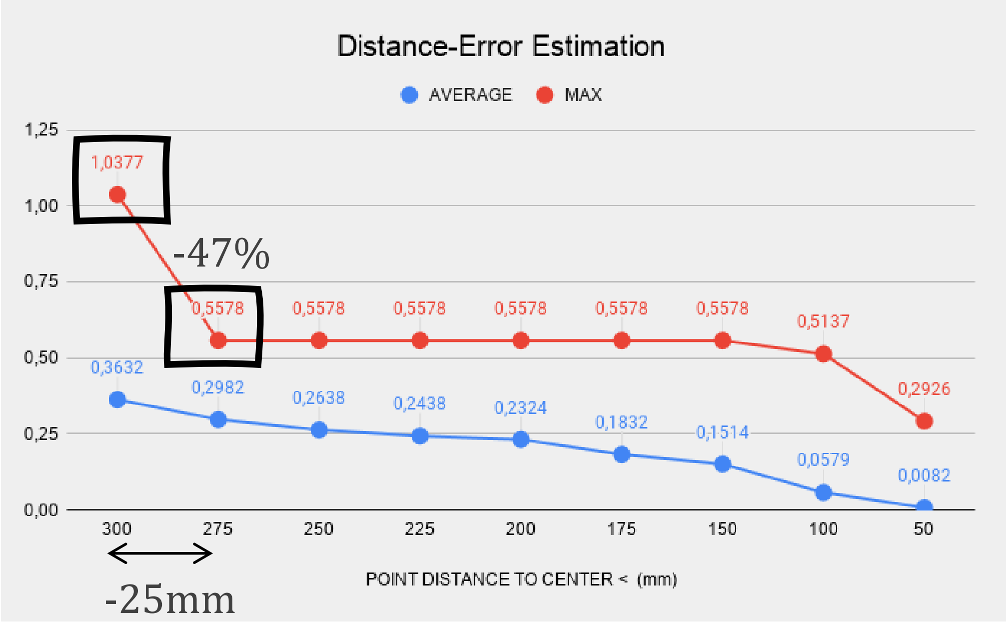




IV Results

1. Performance trend according to **number of points** N





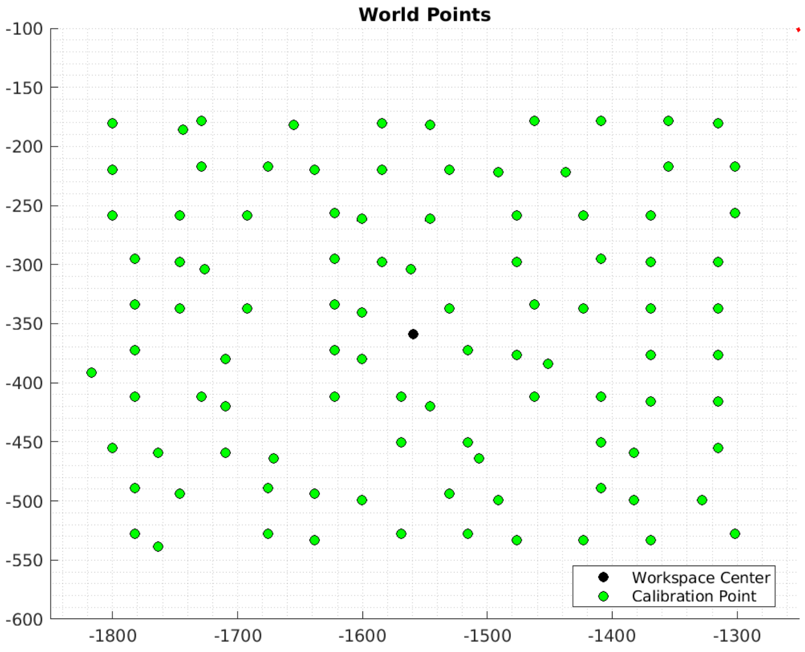
IV Results

2. Procedure robustness to noise : **World** coordinates

noise = ± 1.5 mm

% Points	%Disturb	Average I2W	Max I2W
5	0.5	0.967	8.933
5	0.1	0.427	2.04
5	0.01	0.369	1.03
25	0.5	3.03	14.14
25	0.1	0.740	3.043
25	0.01	0.363	1.062
50	0.5	4.66	21.11
50	0.1	0.975	2.66
50	0.01	0.372	1.071
75	0.5	5.6	18.27
75	0.1	1.08	3.67
75	0.01	0.38	1.15
100	1	15.11	67.53
100	0.5	6.6	21.22
100	0.1	1.9	4.6
100	0.01	0.39	1.09

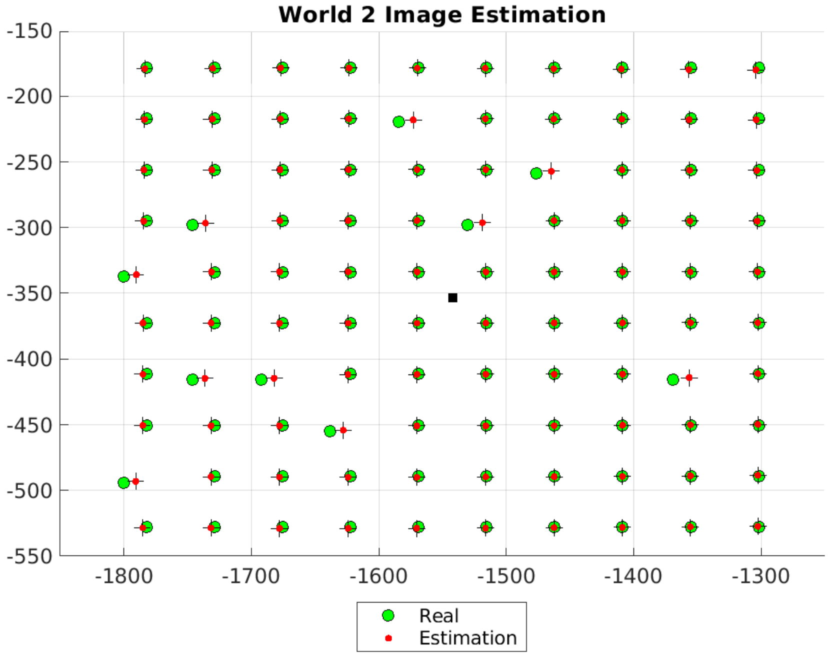
10x10 grid



IV Results

2. Procedure robustness to noise : **Pixel** coordinates

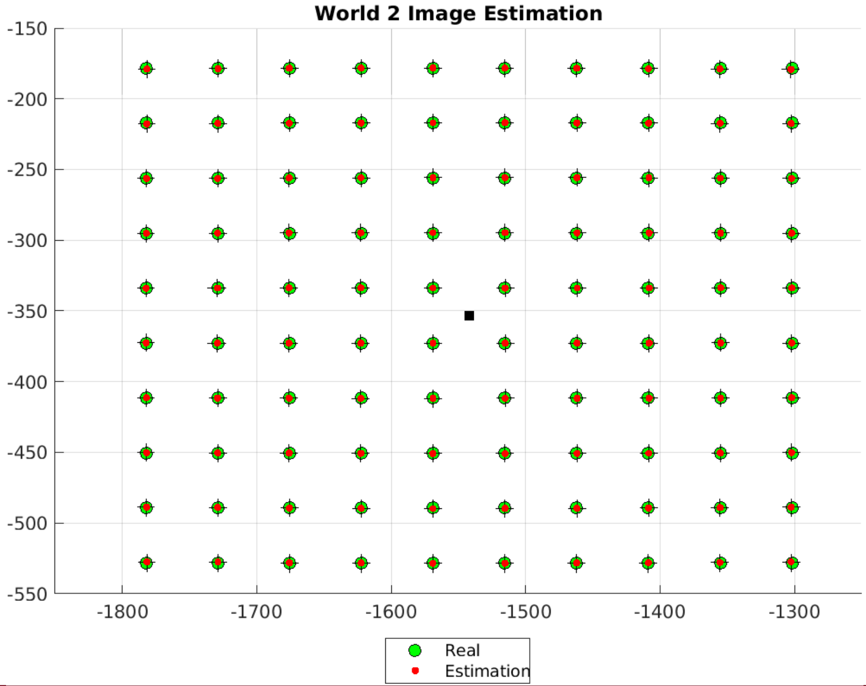
% Points	%Disturb	Average I2W	Max I2W
5	1	0.550	5.17
5	0.5	0.476	2.72
5	0.1	0.365	1.052
5	0.01	0.364	1.039
25	1	1.68	15.94
25	0.5	0.7979	2.28
25	0.1	0.399	1.058
25	0.01	0.3637	1.038
50	1	2.27	15.7
50	0.5	1.179	5.25
50	0.1	0.44	1.23
50	0.01	0.363	1.04
75	1	2.90	12.28
75	0.5	1.553	6.354
75	0.1	0.506	1.575
75	0.01	0.366	1.031
100	1	3.02	11.91
100	0.5	1.42	6.40
100	0.1	0.466	1.2521
100	0.01	0.36	1.0304



IV Results

2. Procedure robustness to noise : **Pixel-World** coordinates

% Points	%Disturb	Average I2W	Max I2W
10	1	2.24	12.55
10	0.5	1.22	6.16
10	0.1	0.45	2.59
50	1	7.48	42.41
50	0.5	3.73	21.62
50	0.1	0.81	2.28
100	1	10.04	36.72
100	0.5	4.57	19.53
100	0.1	1.02	4.41
100	0.01	0.36	1.05

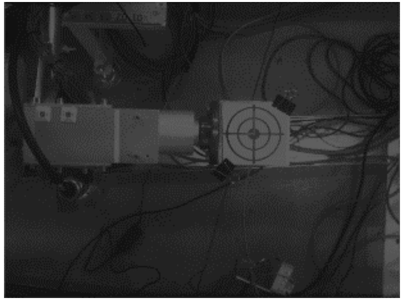


IV Results

3. Procedure **repeatability**

N attempts	Average I2W	Max I2W
5	0.41862	0.78688
10	0.41236	0.76257
15	0.42344	0.76535

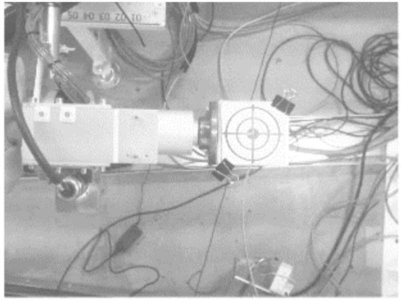
5x5 grid



4. **Robustness** to **light** exposure

Exposure Type	Average I2W	Max I2W
Gain +15db	0,47105	1,06852
Gain +20db	/	/
Gain -15db	0,47169	1,0577
Gain -20db	0,454242	1,04193

9x9 grid



V Conclusions

What has been done

Robot movement **algorithm**

Plug-and-play **vision application**

Comprehensive **tests**

Results obtained

Ready to be commercialized/employed

Flexible procedure

Desired accuracy performance

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