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Development of an onsite calibration device for robot manipulators

Key words: Calibration device; Kinematic calibration; Onsite calibration; Absolute accuracy

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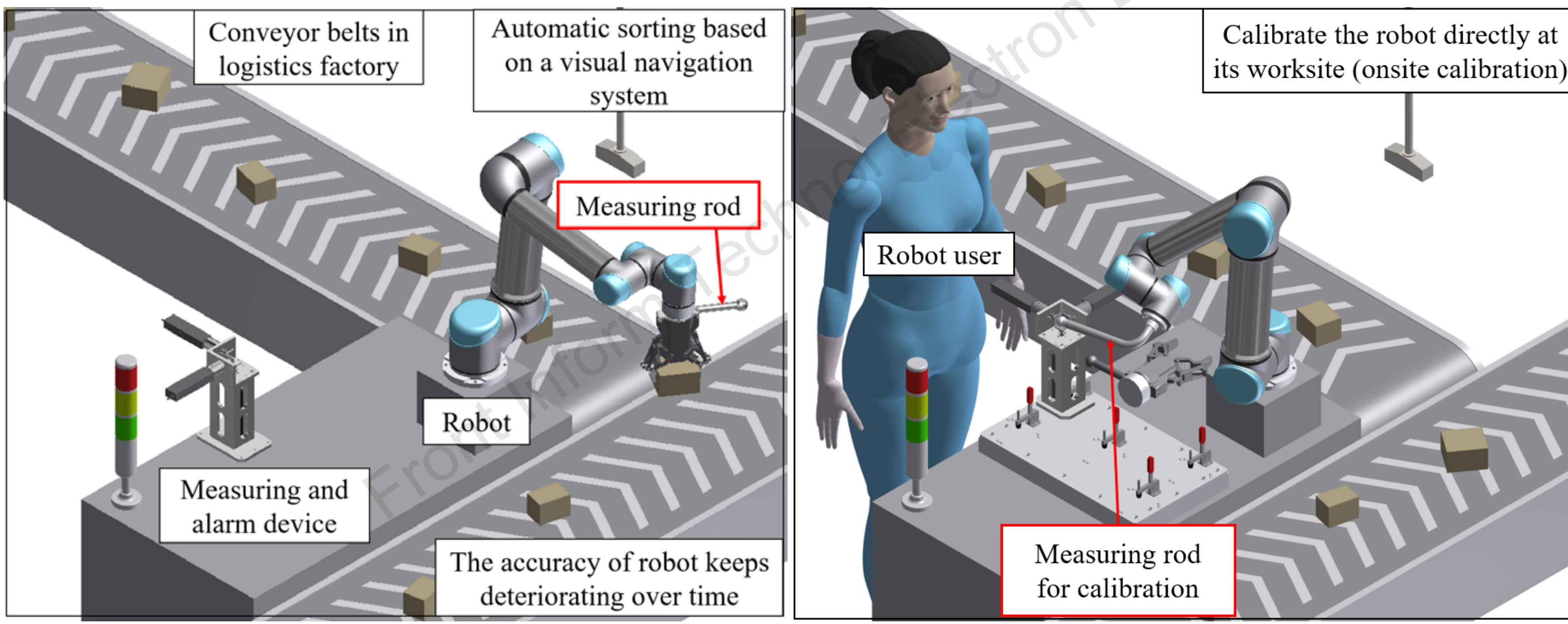
What is onsite robot calibration?

- Quick response with less downtime
- Suitable for routine maintenance and recalibration by the robot user



Typical application of onsite robot calibration in a logistics factory

Deficiency of existing equipments

- Calibration equipment can be classified into open-loop and closed-loop.
- Open-loop equipment can measure a robot under relatively few constraints.
- Existing open-loop equipment is not suitable for onsite calibration.

Laser tracker

- Easily restricted by the environment
- Too expensive (>US$100 000)

Wire draw encoder

- Low measurement accuracy (>0.1 mm)
- Single point constraint (low calibration robustness)

Deficiency of existing equipments

- ☐ Closed-loop equipment can measure a robot under physical constraints.
- ☐ Existing closed-loop equipment still has many problems in use.

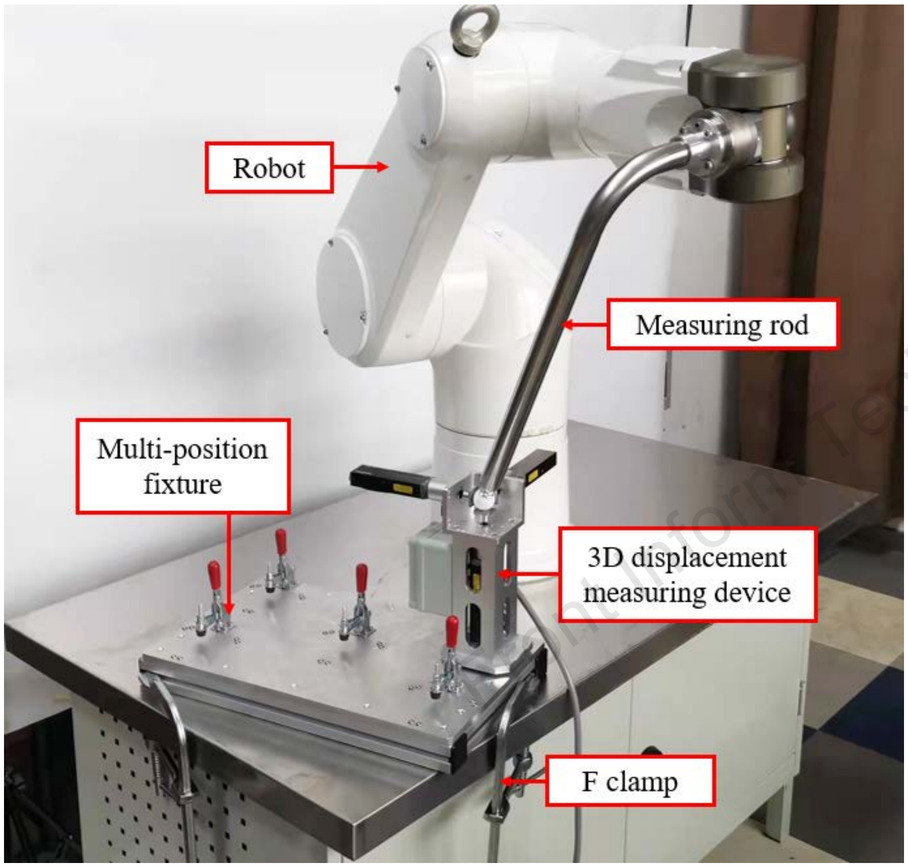
Probe

- The measurement process is complex
- Easy to collide

Displacement sensors

- Single point constraint (low calibration robustness)
- Still expensive (>US$10 000)

A new onsite calibration device: MultiCal

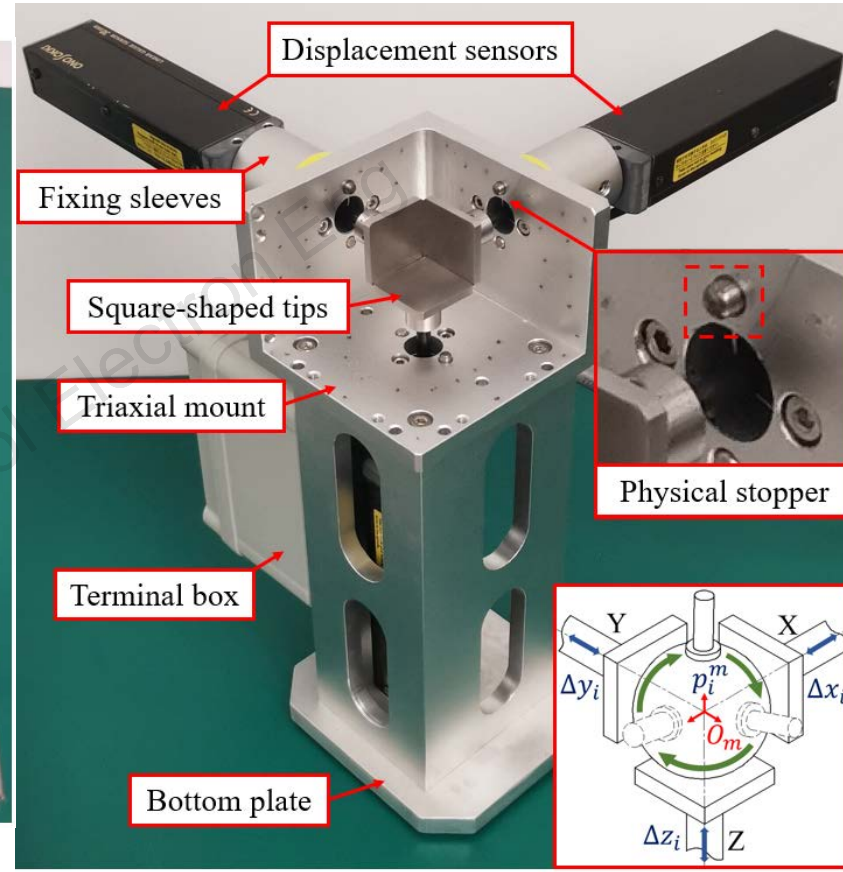


Description of MultiCal

Main idea

- Long measuring rod: enlarge the motion space of the robot
- 3D displacement measuring device: realize a single point constraint
- Multi-position fixture: realize multi-point constraint (high calibration robustness)

MultiCal and its accessories



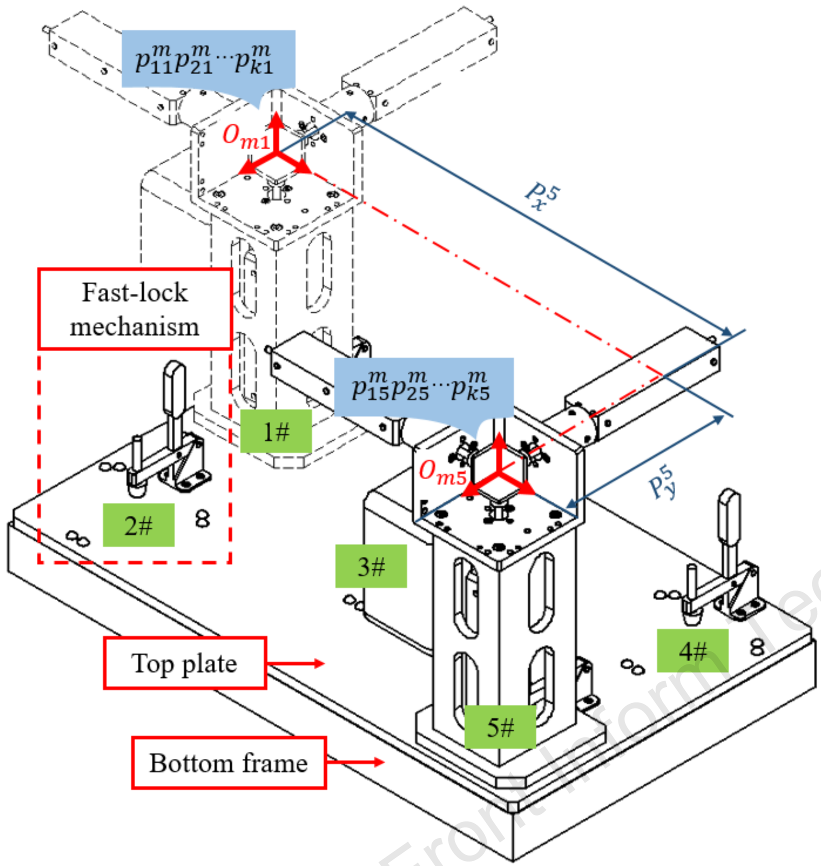
Measuring rod

- The size and shape of the rod can be customized for different robot types

3D measuring device

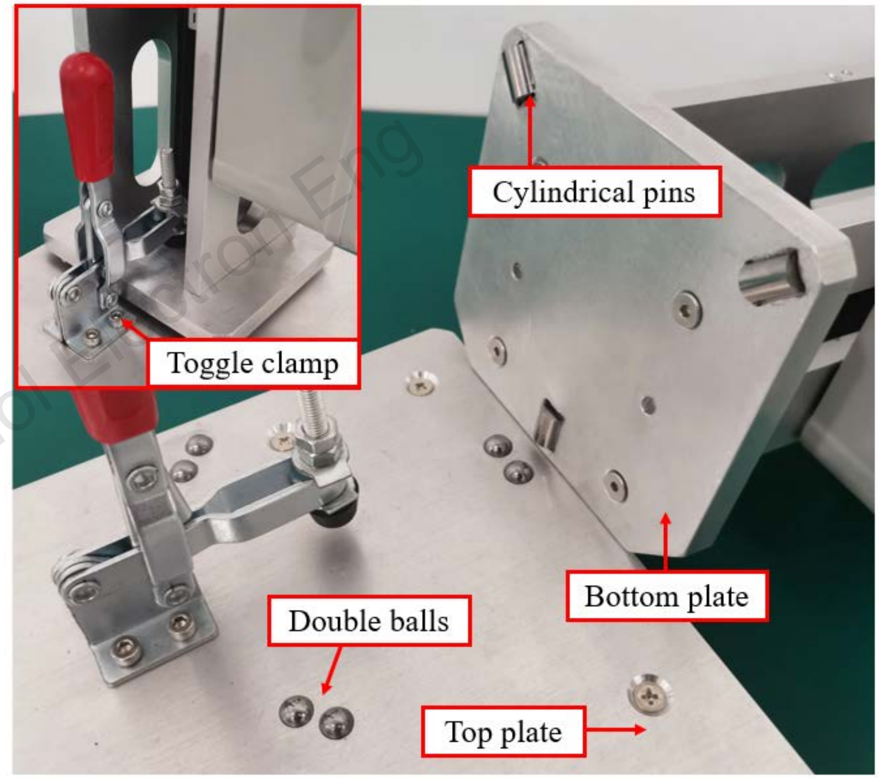
- Measurement accuracy of 3 μm
- Measurement range of 30 mm×30 mm×30 mm

MultiCal and its accessories



Multi-position fixture

- Provide multiple clamping positions for the 3D measuring device
- The relative positions between different clamping positions are accurately measured



Fast-lock mechanism

- High assembly accuracy (<35 μm)
- Quick clamping (<15 s)

Calibration algorithm

- A Staubli TX90 robot is selected as a representative to test MultiCal.
- The MDH method is used to establish the kinematic model, and 21 error terms are determined to be identified (redundant error terms are removed).
- Calibration is converted into an optimization problem, and the Levenberg-Marquardt algorithm is used for optimization.

Table 1 The MDH parameters of the Staubli TX90 robot

Link	θ (°)	d (mm)	a (mm)	α (°)	β (°)
0–1	θ_1	150	$50+\delta a_1$	$90+\delta\alpha_1$	0
1–2	$\theta_2+90+\delta\theta_2$	$-50+\delta d_2$	$425+\delta a_2$	$0+\delta\alpha_2$	$0+\delta\beta_2$
2–3	$\theta_3+90+\delta\theta_3$	0	δa_3	$90+\delta\alpha_3$	0
3–4	$\theta_4+\delta\theta_4$	$425+\delta d_4$	δa_4	$-90+\delta\alpha_4$	0
4–5	$\theta_5+\delta\theta_5$	δd_5	δa_5	$90+\delta\alpha_5$	0
5–6	$\theta_6+\delta\theta_6$	$z_{\text{tool}}+100+\delta d_6$	$x_{\text{tool}}+\delta a_6$	0	0

$$(\boldsymbol{e},\boldsymbol{x})=\arg\min\sum_{i=1}^{k}\sum_{j=1}^{p}\left\|T(\boldsymbol{x})\boldsymbol{p}_{ij}^{m}-f(\boldsymbol{q}_{ij},\boldsymbol{e})\right\|^{2}$$

Major results

Device and number of configurations		Mean (mm)	Max (mm)	Standard deviation (mm)	t (min)	Cost (US$)
Laser scanner (3DM)	20	0.345	0.852	0.163	–	>50 000
	30	0.323	0.721	0.151	–	
	40	**0.302**	**0.707**	**0.145**	–	
Binocular vision (6DM)	20	0.841	1.786	0.441	12.5	>30 000
	30	0.714	1.517	0.353	18.2	
	40	0.616	1.434	0.301	24.1	
MultiCal	20	0.392	0.993	0.198	15.2	<**5000**
	30	0.348	0.869	0.156	23.5	
	40	0.339	0.831	0.151	30.5	

The bold number indicates the best performance

Table 2 Calibration results of MultiCal, a measuring arm with a laser scanner, and a 6D binocular vision measuring system

- MultiCal reduces the maximum and mean absolute position errors from 6.245 mm and 2.211 mm to 0.831mm and 0.339 mm, respectively.
- MultiCal presents a reduction of only 7% to 14% in calibration accuracy compared to a measuring arm with a laser scanner, and a reduction of 21% to 30% in time efficiency compared with a 6D binocular vision measuring system.
- MultiCal significantly reduces the device cost.

Conclusions

- We present a novel in-contact robot calibration device called MultiCal, which is accurate, low-cost, robust, and suitable for onsite calibration, to obtain high calibration accuracy and robustness in the whole robot workspace.
- The necessity of customizing a long measuring rod for a specific robot type is proved, since a well-designed measuring rod can greatly improve MultiCal's calibration performance.
- In a comparative experiment, MultiCal presents a reduction of only 7% to 14% in calibration accuracy compared to a measuring arm with a laser scanner, and a reduction of 21% to 30% in time efficiency compared with a 6D binocular vision measuring system, yielding maximum and mean absolute position errors of 0.831 mm and 0.339 mm, respectively.
- MultiCal can be easily fabricated at a low cost (less than US$5000).