

Ziwei WAN, Chunlin ZHOU, Haotian ZHANG, Jun WU, 2023. Development of an onsite calibration device for robot manipulators. *Frontiers of Information Technology & Electronic Engineering*, 24(2):217-230.

<https://doi.org/10.1631/FITEE.2200172>

Development of an onsite calibration device for robot manipulators

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

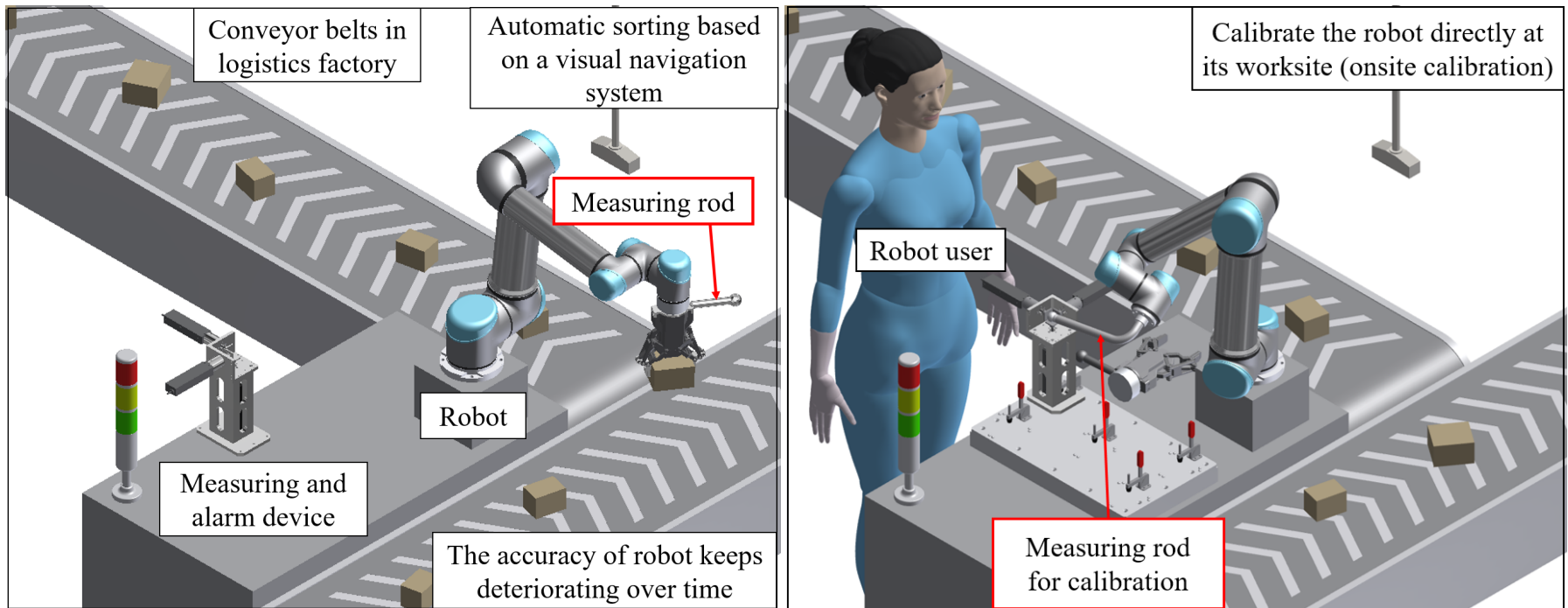
Ziwei WAN

E-mail: wanzw@zju.edu.cn

 ORCID: <https://orcid.org/0000-0002-3717-187X>

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)

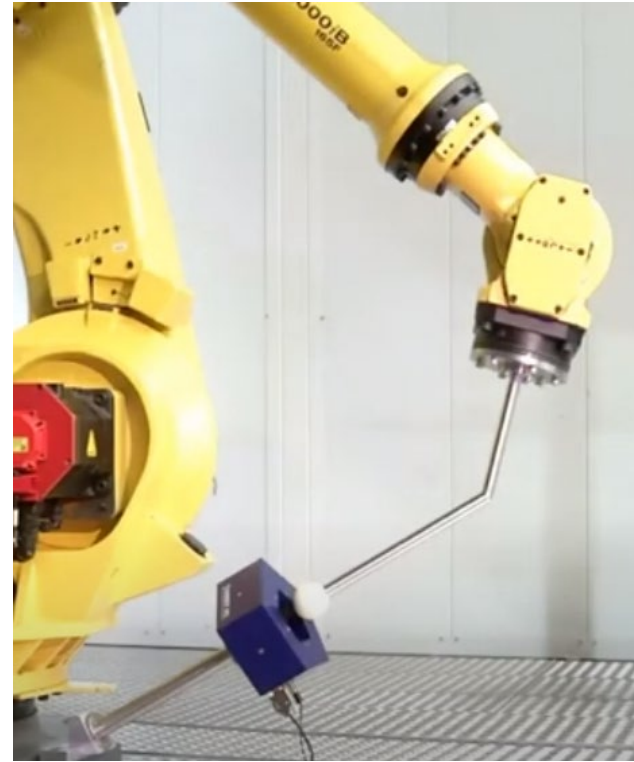
Deficiency of existing equipments

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



Probe

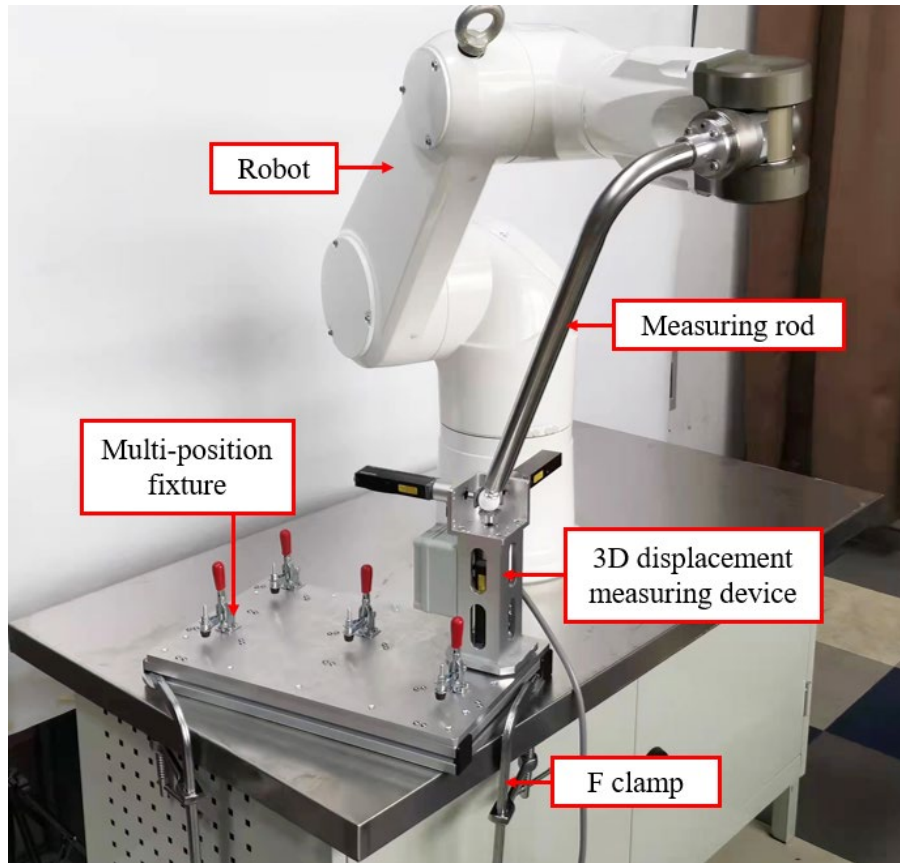
- The measurement process is complex
- Easy to collide



Displacement sensors

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

A new onsite calibration device: MultiCal



Description of MultiCal

Main idea

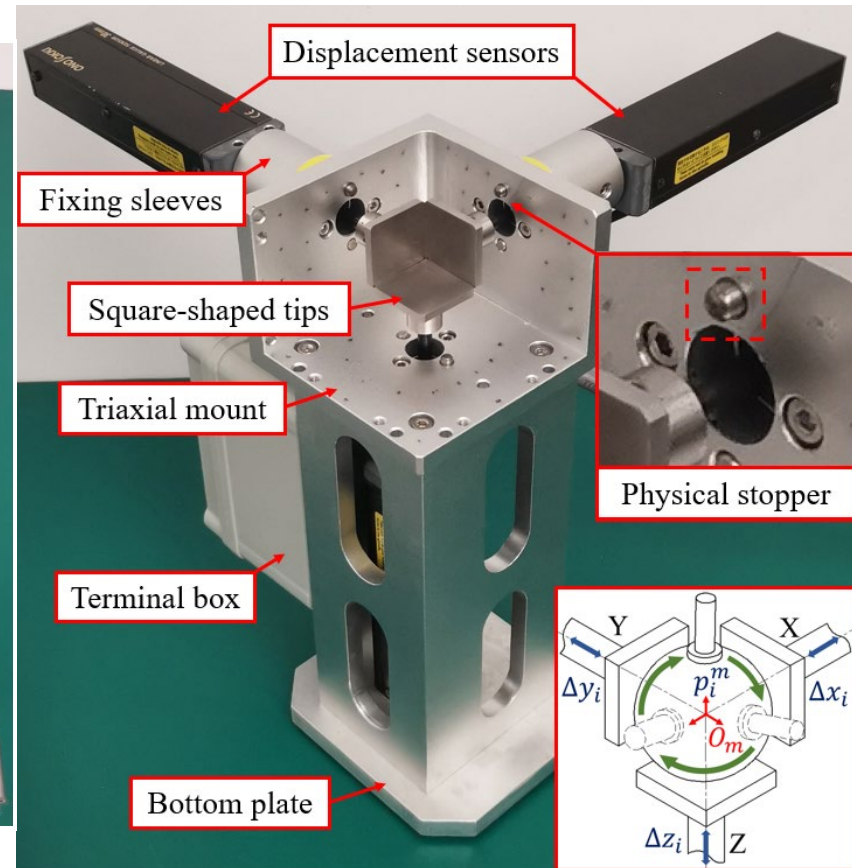
- ❑ Long measuring rod: enlarge the motion space of the robot
- ❑ 3D displacement measuring device: realize a single point constraint
- ❑ Multi-position fixture: realize multi-point constraint (high calibration robustness)

MultiCal and its accessories



Measuring rod

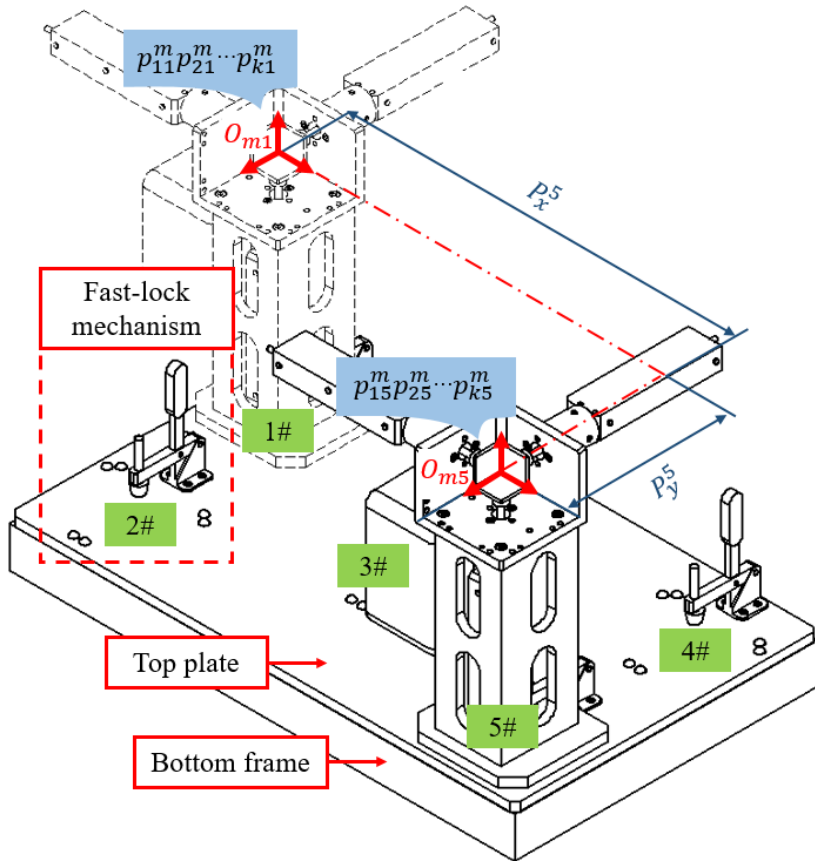
- The size and shape of the rod can be customized for different robot types



3D measuring device

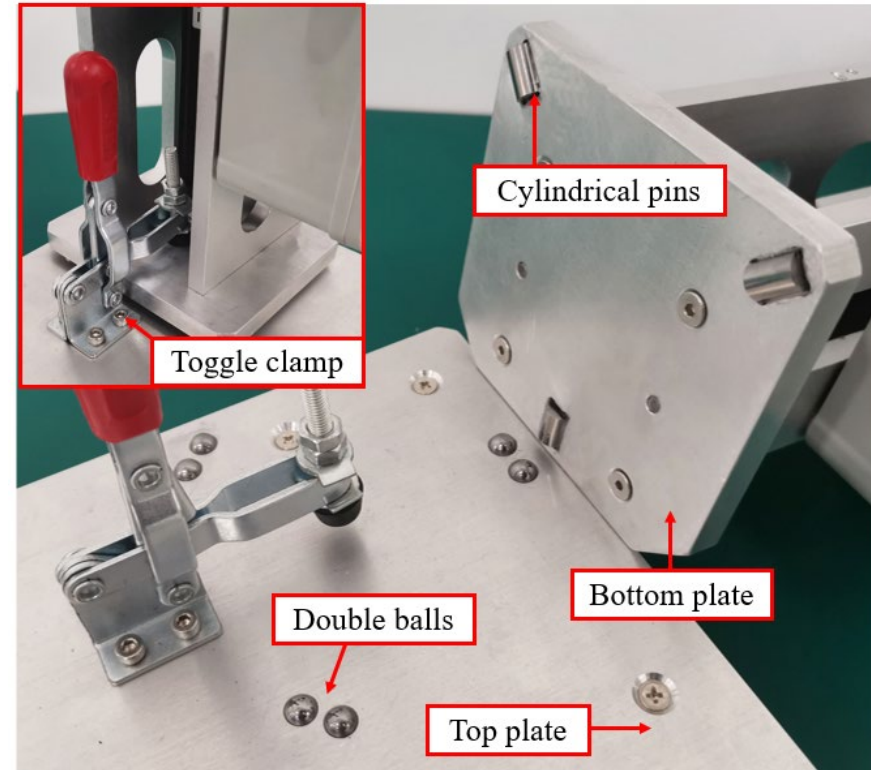
- Measurement accuracy of $3 \mu\text{m}$
- Measurement range of $30 \text{ mm} \times 30 \text{ mm} \times 30 \text{ mm}$

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 ($<35 \mu\text{m}$)
- Quick clamping ($<15 \text{ s}$)

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

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

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).