Highly-Accurate Manipulator Calibration via Extended Kalman Filter-Incorporated Residual Neural Network: Supplementary File

This is the supplementary file for the paper entitled *Highly-Accurate Manipulator Calibration via Extended Kalman Filter-Incorporated Residual Neural Network.* It mainly contains a) the evaluation metrics and position accuracy of experimental models on D1 and D2, and b) three supplementary tables recording the performance of the comparison models and calibration results.

PART. I. SUPPLEMENTARY FIGURES

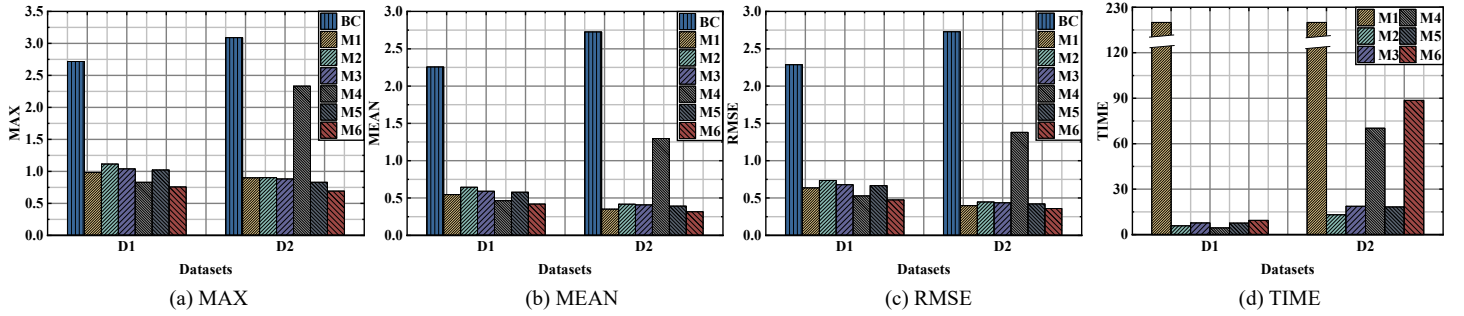(a) MAX   (b) MEAN   (c) RMSE   (d) TIME

Fig. S.1. The evaluation metrics of experimental results on D1 and D2. Note that in panel (d), the truncation marker is added to keep the bar graph clear because of the excessive time cost of M1.

(a)Position accuracy of BC, M1 on D1   (b) Position accuracy of M1-6 on D1   (c) Position accuracy of BC, M1 on D2   (d) Position accuracy of M1-6 on D2
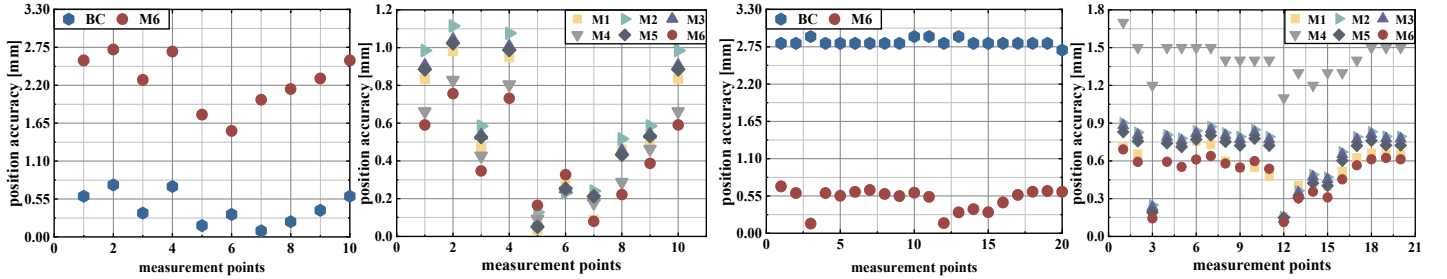
Fig. S.2. The position accuracy of the measuring point on D1 and D2 of each algorithm. (a), (c) Compared with BC (before calibration), the position accuracy of D-H parameters compensated by M6 is significantly optimized on both D1 and D2. (b), (d) Moreover, On D1, M6 performs better than other five algorithms 80% of the time and 85% of the time on D2.

PART. II. SUPPLEMENTARY TABLES

TABLE S.I
THE COMPARATIVE TEST ERROR CALIBRATION RESULTS.

Dataset	Metric(mm)	BC	M1	M2	M3	M4	M5	M6
	MEAN	2.2557	0.5457	0.6444	0.5903	0.4643	0.5781	0.4200
D1	RMSE	2.2869	0.6364	0.7360	0.6793	0.5277	0.6663	0.4756
	MAX	2.7180	0.9815	1.1150	1.0406	0.8280	1.0226	0.7557
	MEAN	2.7261	0.3512	0.4179	0.4081	1.2974	0.3921	0.3160
D2	RMSE	2.7283	0.3971	0.4471	0.4369	1.3808	0.4209	0.3589
	MAX	3.0906	0.8994	0.9013	0.8822	2.3339	0.8297	0.6921

TABLE S.II
TIME COST OF METHODS M1-M6 ON RMSE.

Dataset	Item	M1	M2	M3	M4	M5	M6
D1	Iteration	40	10	10	14	5	5
	Time(s)	220.9302	5.8721	7.7915	4.4923	7.6834	9.4193
D2	Iteration	50	10	10	15	6	6
	Time(s)	220.5976	13.1632	18.7527	70.2240	18.3151	88.5746

TABLE S.III
D-H PARAMETER DEVIATIONS OF ABB IRB120 MANIPULATOR AFTER CALIBRATION.

Joint	EKF				ResNN				EKF-ResNN Calibrator			
	$\Delta\alpha_{i\text{-}1}$/°	$\Delta a_{i\text{-}1}$/mm	$\Delta\theta_{i\text{-}1}$/°	Δd/mm	$\Delta\alpha_{i\text{-}1}$/°	$\Delta a_{i\text{-}1}$/mm	$\Delta\theta_{i\text{-}1}$/°	Δd/mm	$\Delta\alpha_{i\text{-}1}$/°	$\Delta a_{i\text{-}1}$/mm	$\Delta\theta_{i\text{-}1}$/°	Δd/mm
1	0.0000	0.0003	0.0000	-0.0009	0	0	0.0017	0	0.0000	0.0003	0.0002	-0.0009
2	0.0000	-0.0009	0.0000	-0.0001	0	0	0.0022	0	0.0000	-0.0009	-0.0005	-0.0001
3	0.0000	0.0000	0.0003	-0.0001	0	0	0.0024	0	0.0000	0.0000	0.0010	-0.0001
4	0.0000	0.0000	0.0000	0.0002	0	0	0.0014	0	0.0000	0.0000	-0.0001	0.0002
5	0.0000	0.0000	0.0000	0.0001	0	0	0.0011	0	0.0000	0.0000	-0.0009	0.0001
6	0.0000	0.0001	0.0000	0.0000	0	0	0.0018	0	0.0000	0.0001	-0.0008	0.0000