

Supplementary Material

Inertial-Robotic Motion Tracking in End-Effector-based Rehabilitation Robots

Table S1. Parameter sensitivity of the estimated shoulder position errors (Euclidean distance) for a large disagreement between the assumed and the actual IMU-to-elbow distance Δp_E . Abbreviations: Proper movement (Prop.Mov.), Compensatory movement (Comp.Mov.), Distance (Dist.), Percentile (%ile).

Subject	Type	Original Error [cm]			Change of the Errors [cm]		
		Dist. IMU to Elbow $\Delta p_E = 15$ cm			Changed to half value: $\Delta p_E = 7.5$ cm		
		Median	5th %ile	95th %ile	Median	5th %ile	95th %ile
S1	Prop.Mov.	4.19	1.94	8.25	0.12	0.01	0.17
	Comp.Mov.	3.94	1.21	8.61	0.06	0.09	-0.09
S2	Prop.Mov.	2.81	0.80	5.23	0.09	0.00	0.14
	Comp.Mov.	3.63	1.11	6.95	0.06	-0.03	0.20
S3	Prop.Mov.	4.98	1.00	9.75	0.14	0.06	0.31
	Comp.Mov.	4.52	1.70	9.17	-0.10	-0.19	0.24
S4	Prop.Mov.	3.79	1.35	6.59	0.10	0.00	0.11
	Comp.Mov.	4.60	1.43	9.40	-0.03	-0.08	-0.14
S5	Prop.Mov.	3.37	1.28	6.70	0.04	-0.01	0.13
	Comp.Mov.	3.83	0.88	8.66	0.11	0.11	0.65
Average		3.97	1.27	7.93	0.06	0.00	0.17
		Average relative change			1.5 %	-0.3 %	2.2 %

Table S2. Parameter sensitivity of the estimated elbow angle errors for a large disagreement between the assumed and the actual IMU-to-elbow distance A_{PE} . Abbreviations: Proper movement (Prop.Mov.), Compensatory movement (Comp.Mov.), Distance (Dist.), Percentile (%ile).

Subject	Type	Original Error [°]			Change of the Errors [°]		
		Dist. IMU to Elbow $A_{PE} = 15$ cm			Changed to half value: $A_{PE} = 7.5$ cm		
		Median	5th %ile	95th %ile	Median	5th %ile	95th %ile
S1	Prop.Mov.	1.79	0.17	5.79	0.05	0.00	-0.01
	Comp.Mov.	4.01	0.41	9.23	-0.28	-0.01	-0.47
S2	Prop.Mov.	2.31	0.21	6.43	0.13	0.00	0.12
	Comp.Mov.	3.90	0.34	9.22	0.19	0.03	0.62
S3	Prop.Mov.	3.12	0.33	8.42	0.38	0.02	1.04
	Comp.Mov.	3.38	0.24	10.13	0.00	0.12	-0.75
S4	Prop.Mov.	2.50	0.27	6.53	0.25	0.02	0.95
	Comp.Mov.	2.95	0.24	8.41	0.14	0.12	0.24
S5	Prop.Mov.	2.19	0.22	5.94	0.13	-0.01	0.37
	Comp.Mov.	3.67	0.27	11.37	1.14	0.37	1.94
Average		2.98	0.27	8.15	0.21	0.07	0.41
		Average relative change			7.1 %	24.4 %	5.0 %

Table S3. Parameter sensitivity of the estimated shoulder position errors (Euclidean distance) for typical to-be-expected variations (± 2.5 cm) in the manually measured upper arm length l_A . Abbreviations: Proper movement (Prop.Mov.), Compensatory movement (Comp.Mov.), Percentile (%ile).

Subject	Type	Original Error [cm]				Change of the Errors [cm]					
		Upper arm length l_A : measured				Changed: $l_A + 2.5$ cm			Changed: $l_A - 2.5$ cm		
		Median	5th %ile	95th %ile		Median	5th %ile	95th %ile	Median	5th %ile	95th %ile
S1	Prop.Mov.	4.19	1.94	8.25		-0.01	0.04	0.75	0.18	-0.13	-0.61
	Comp.Mov.	3.94	1.21	8.61		-0.04	-0.26	0.85	0.19	0.35	-0.65
S2	Prop.Mov.	2.81	0.80	5.23		0.06	-0.07	0.35	0.07	0.09	0.17
	Comp.Mov.	3.63	1.11	6.95		-0.01	-0.06	0.13	0.02	0.11	-0.06
S3	Prop.Mov.	4.98	1.00	9.75		0.38	0.10	0.95	-0.21	-0.03	-0.72
	Comp.Mov.	4.52	1.70	9.17		-0.07	-0.46	0.78	0.18	0.54	-0.46
S4	Prop.Mov.	3.79	1.35	6.59		0.15	-0.06	0.60	-0.05	0.23	-0.21
	Comp.Mov.	4.60	1.43	9.40		-0.01	-0.07	-0.12	0.10	0.20	0.17
S5	Prop.Mov.	3.37	1.28	6.70		0.12	-0.13	0.77	0.05	0.13	-0.60
	Comp.Mov.	3.83	0.88	8.66		-0.05	0.15	0.72	0.15	0.22	-0.65
Average		3.97	1.27	7.93		0.05	-0.08	0.58	0.07	0.17	-0.36
		Average relative change				1.3 %	-6.5 %	7.3 %	1.7 %	13.5 %	-4.6 %

Table S4. Parameter sensitivity of the estimated shoulder position errors (Euclidean distance) for variations of the cutoff frequency of the Butterworth filter for the determination of the time derivative ${}_A\dot{\omega}_A$. Abbreviations: Proper movement (Prop.Mov.), Compensatory movement (Comp.Mov.), Percentile (%ile).

Subject	Type	Original Error [cm]				Change of the Errors [cm]					
		Cutoff frequency = 2.5 Hz				Changed: Cutoff frequency +1 Hz			Changed: Cutoff frequency -1 Hz		
		Median	5th %ile	95th %ile	95th %ile	Median	5th %ile	95th %ile	Median	5th %ile	95th %ile
S1	Prop.Mov.	4.19	1.94	8.25		0.00	0.00	0.00	-0.01	0.00	0.00
	Comp.Mov.	3.94	1.21	8.61		0.00	0.00	0.00	0.00	0.00	0.01
S2	Prop.Mov.	2.81	0.80	5.23		0.00	0.00	0.00	0.00	0.00	0.00
	Comp.Mov.	3.63	1.11	6.95		0.00	0.00	0.00	0.00	0.00	0.00
S3	Prop.Mov.	4.98	1.00	9.75		0.01	-0.01	0.01	0.00	0.00	0.00
	Comp.Mov.	4.52	1.70	9.17		0.00	0.00	0.01	0.00	0.00	0.00
S4	Prop.Mov.	3.79	1.35	6.59		0.00	0.00	0.00	0.00	0.00	0.00
	Comp.Mov.	4.60	1.43	9.40		0.00	0.00	0.00	0.00	0.00	0.00
S5	Prop.Mov.	3.37	1.28	6.70		0.00	0.00	0.00	0.00	0.00	0.00
	Comp.Mov.	3.83	0.88	8.66		0.00	0.00	0.00	-0.08	0.00	0.00
Average		3.97	1.27	7.93		0.00	0.00	0.00	-0.01	0.00	0.00
		Average relative change				0.0 %	-0.1 %	0.0 %	-0.2 %	0.0 %	0.0 %

Table S5. Parameter sensitivity of the estimated elbow angle errors for variations of the cutoff frequency of the Butterworth filter for the determination of the time derivative $\dot{\omega}_A$. Abbreviations: Proper movement (Prop.Mov.), Compensatory movement (Comp.Mov.), Percentile (%ile).

Subject	Type	Original Error [°]				Change of the Errors [°]					
		Cutoff frequency = 2.5 Hz				Changed: Cutoff frequency +1 Hz			Changed: Cutoff frequency -1 Hz		
		Median	5th %ile	95th %ile	95th %ile	Median	5th %ile	95th %ile	Median	5th %ile	95th %ile
S1	Prop.Mov.	1.79	0.17	5.79		0.00	0.00	0.00	0.00	0.00	-0.02
	Comp.Mov.	4.01	0.41	9.23		0.00	0.00	0.00	0.01	0.01	0.02
S2	Prop.Mov.	2.31	0.21	6.43		0.00	0.00	0.00	0.00	0.00	0.00
	Comp.Mov.	3.90	0.34	9.22		0.00	0.00	0.00	0.00	0.00	0.00
S3	Prop.Mov.	3.12	0.33	8.42		-0.01	-0.01	0.01	0.00	0.00	0.00
	Comp.Mov.	3.38	0.24	10.13		0.01	0.00	0.02	0.00	0.00	0.00
S4	Prop.Mov.	2.50	0.27	6.53		0.00	0.00	0.00	0.00	0.00	0.00
	Comp.Mov.	2.95	0.24	8.41		0.00	0.00	0.00	0.00	0.00	0.00
S5	Prop.Mov.	2.19	0.22	5.94		0.00	0.00	0.00	0.00	0.00	0.00
	Comp.Mov.	3.67	0.27	11.37		0.00	0.00	0.00	-0.03	-0.02	0.00
Average		2.98	0.27	8.15		0.00	0.00	0.00	0.00	0.00	0.00
		Average relative change				0.0 %	-0.4 %	0.0 %	-0.1 %	-0.4 %	0.0 %