

Implementation and Evaluation of Inverse Dynamics Actuation Control with Respect to Human Coordinates for Exoskeletons- Supplementary Material

Table S 1: Body Names Exoskeleton Model

Number	Name
1	HIP_BELT
2	BACK_RAIL
3	RIGHT_SWIVEL_JOINT
4	RIGHT_LEG_RAIL
5	LEFT_SWIVEL_JOINT
6	LEFT_LEG_RAIL

Table S 2: Body Numbering Test Bench Model

Number	Name in OpenSim	Name in Paper
1	Huefte2	Trunk
2	Anbau	
3	Bein_L	Left Upper Leg
4	Gelenk_unten_L	Left Knee
5	Bein_R	Right Upper Leg
6	Gelenk_unten_R	Right Knee

Table S 3: Test Bench Parallel Kinematic Coupling Constraints

Number m	$b(m)$	$T_{\text{bench},b(m)}^{C,m}$					W_m
1	1	1	0	0	0.2		{1,4,5,6}
		0	$\cos\left(-\frac{\pi}{4} + \theta_t\right)$	$-\sin\left(-\frac{\pi}{4} + \theta_t\right)$	0.52		
		0	$\sin\left(-\frac{\pi}{4} + \theta_t\right)$	$\cos\left(-\frac{\pi}{4} + \theta_t\right)$	-0.48		
		0	0	0	1		
2	2	1	0	0	0		{4}
		0	$\cos(\theta_t)$	$-\sin(\theta_t)$	0		
		0	$\sin(\theta_t)$	$\cos(\theta_t)$	0		
		0	0	0	1		
3	3	1	0	0	0		{4}
		0	$\cos(\theta_t - \theta_h)$	$-\sin(\theta_t - \theta_h)$	0		
		0	$\sin(\theta_t - \theta_h)$	$\cos(\theta_t - \theta_h)$	0		
		0	0	0	1		
4	4	1	0	0	0.335		{1,2,3,4,6}
		0	$\cos(13.8^\circ)$	$-\sin(13.8^\circ)$	0.0886		
		0	$\sin(13.8^\circ)$	$\cos(13.8^\circ)$	-0.1636		
		0	0	0	1		
5	6	1	0	0	0.065		{1,2,4,6}
		0	$\cos(13.8^\circ)$	$-\sin(13.8^\circ)$	0.0456		
		0	$\sin(13.8^\circ)$	$\cos(13.8^\circ)$	0.0112		
		0	0	0	1		

Table S 4: Exoskeleton Test Bench Coupling Coupling based on [16]

Number m	$b_{C,\text{bench}}(m)$	$b_{C,\text{exo}}(m)$	$T_{C,\text{bench},m}^{\text{bench},b_{C,\text{bench}}(m)}$				$T_{C,\text{exo},m}^{\text{exo},b_{C,\text{exo}}(m)}$				W_m
1	2	1	-1	0	0	0	1	0	0	0	{1,2,3,4,5,6}
			0	1	0	0.0361	0	1	0	0	
			0	0	-1	-0.0655	0	0	1	0	
			0	0	0	1	0	0	0	1	
2	2	2	-1	0	0	0	1	0	0	0	{1,3}
			0	1	0	0.093	0	1	0	0.26	
			0	0	-1	-0.188	0	0	1	0	
			0	0	0	1	0	0	0	1	
3	5	4	-1	0	0	0	1	0	0	-0.1	{1,3}
			0	1	0	-0.209	0	1	0	-0.25	
			0	0	-1	-0.1	0	0	1	0.08	
			0	0	0	1	0	0	0	1	
4	3	6	-1	0	0	0	1	0	0	0.1	{1,3}
			0	1	0	-0.209	0	1	0	-0.25	
			0	0	-1	-0.1	0	0	1	0.08	
			0	0	0	1	0	0	0	1	

Table S 5: Cable-based Routing Model Properties

Number j	Number n	$b_{sec}(j, n)$	${}^{exo, b_{sec}(j, n)}\mathbf{p}_{j, n}$	Cable Length
1	1	2	$[0.1378 \ 0.07 \ -0.0326]^T$	0.7420
1	2	1	$[0.134 \ 0.085 \ 0.0889]^T$	
1	3	1	$[0 \ 0 \ 0.111]^T$	
1	4	1	$[-0.1334 \ -0.004 \ 0.0889]^T$	
1	5	1	$[-0.1336 \ -0.0925 \ 0.091]^T$	
1	6	6	$[0.11 \ -0.215 \ 0.09]^T$	
2	1	2	$[-0.108 \ 0.07 \ -0.078]^T$	0.504
2	2	1	$[0.109 \ 0.03 \ 0.109]^T$	
2	3	1	$[0.109 \ 0.03 \ 0.109]^T$	
2	4	1	$[0.122 \ -0.0405 \ 0.106]^T$	
2	5	1	$[0.12 \ -0.095 \ 0.107]^T$	
2	6	4	$[-0.11 \ -0.215 \ 0.09]^T$	
3	1	2	$[0.0335 \ 0.07 \ 0.0206]^T$	0.5812
3	2	1	$[0.0312 \ -0.0095 \ 0.139]^T$	
3	3	1	$[0.078 \ -0.0118 \ 0.1187]^T$	
3	4	1	$[0.1042 \ -0.013 \ 0.1112]^T$	
3	5	1	$[0.107 \ -0.095 \ 0.11159]^T$	
3	6	4	$[0.107 \ -0.095 \ 0.11159]^T$	
4..6	mirrored on y-z-planes			

Table S 6: Exoskeleton Actuator Coupling

Number j	$b_{act}(j)$	$\mathbf{T}_{C, act, j}^{exo, b_{act}(j)}$			
1	2	-0.050826	0.9987074	0	0.1378
		0.997101	0.05074491	0.056688	0.07
		0.0566147	0.00288126	-0.9983919	-0.0326
		0	0	0	1
2	2	-0.05444	0.99851	0	0.10763
		0.997190	0.0543725	0.0551838	0.07
		0.051447	0.0028052	-0.99867	-0.00778
		0	0	0	1
3	2	0.0541	0.998535	0	0.03349
		0.998361	-0.054099	0.0186576	0.07
		0.01863	-0.00100	-0.99976	0.020618
		0	0	0	1
4..6	mirrored on y-z-plane				

Table S 7: Assistive Torque Indices in Nm according to [14]

Actual Support Torque	ATI_{1000}^{Lower}	ATI_{200}^{Lower}	ATI_{1000}^{Hold}	ATI_{1000}^{Raise}	ATI_{200}^{Raise}
$\sum \tau_{sup, hum, actu}$	10.74	10.94	10.28	9.10	9.84
$\sum \tau_{sup, hum, actu2}$	9.23	8.70	8.09	7.41	7.64
$\sum \tau_{sup2, hum, actu}$	14.09	14.15	13.19	11.91	12.79
$\sum \tau_{sup2, hum, actu2}$	11.57	10.89	10.18	9.32	9.73