Automatic Stub Avoidance for a Powered Prosthetic Leg over Stairs and Obstacles (Supplementary Material)

Content

1 Fig. S1: Example of PID controller tracking

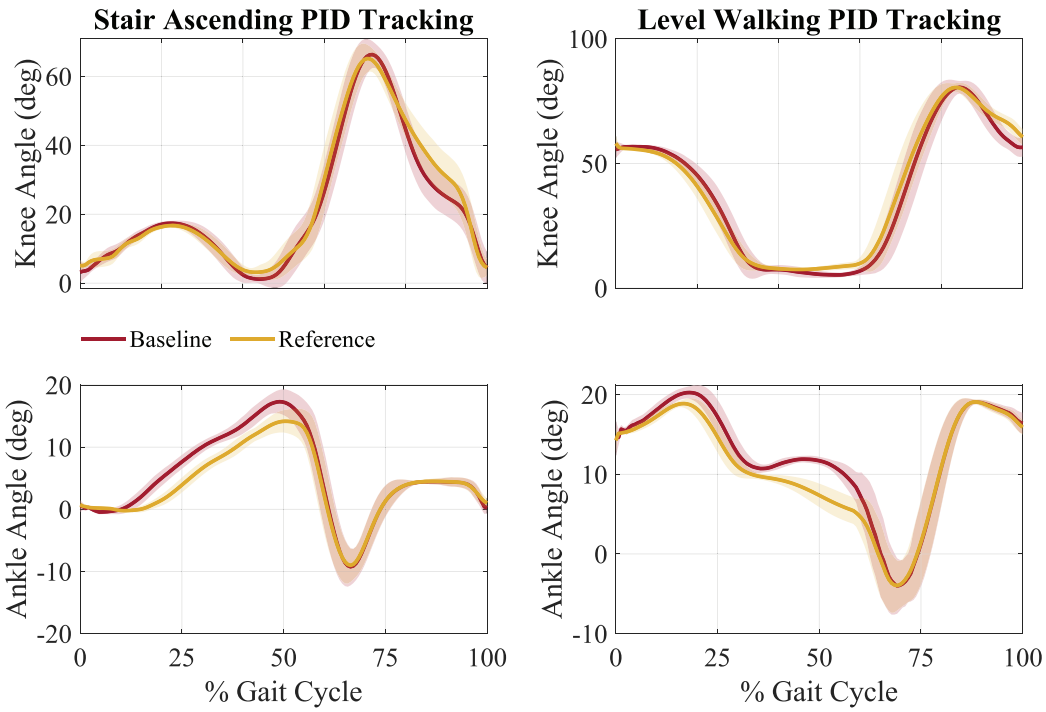

Fig. S1: Example of PID controller tracking. Examples of the position (PID) controller tracking during stair ascending (left) and level walking (right) for the knee (top) and ankle (bottom) with the baseline controller. The red and orange lines with the shaded regions represent the experimental kinematics from the data log of the prosthetic leg and the virtual constraints from the kinematics model, respectively.

2 Fig. S2: Baseline controller kinematics comparison with able-bodied data for TF02

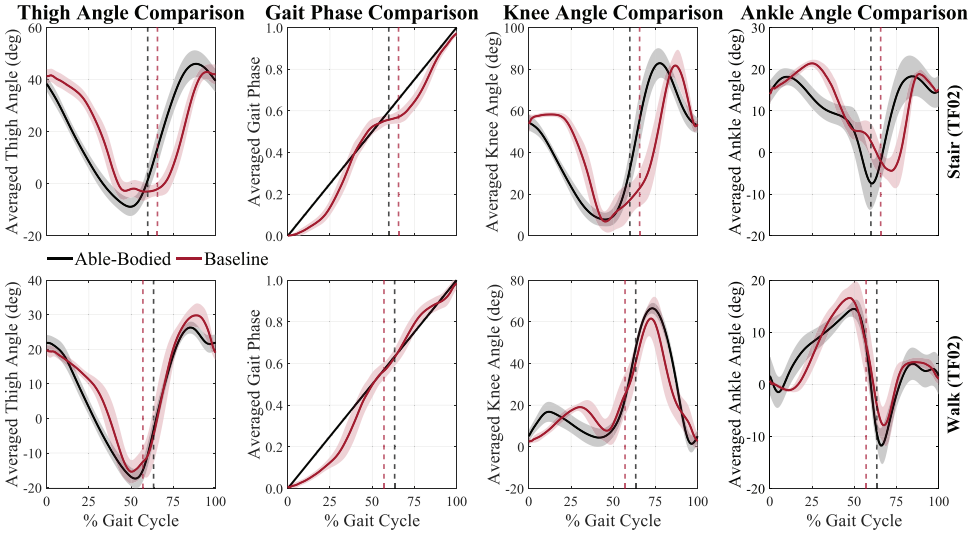

Fig. S2: Baseline controller kinematics comparison with able-bodied data for TF02. TF02's experimental results with the baseline controller compared with nominal able-bodied kinematics for both stair ascending (first row) and level walking (second row). The solid black lines represent the ideal phase variable progression and the nominal kinematics, while the solid red lines show the experimental results. Shaded regions indicate ± 1 standard deviation. The vertical lines demonstrate the average toe-off phases for the corresponding data. Positive kinematic values correspond to knee flexion or ankle dorsiflexion. No passive leg data are shown in the plot as TF02 cannot perform step-by-step stair ascending with his passive leg.

3 Fig. S3: Stub avoidance controller kinematics comparison with baseline controller for TF02

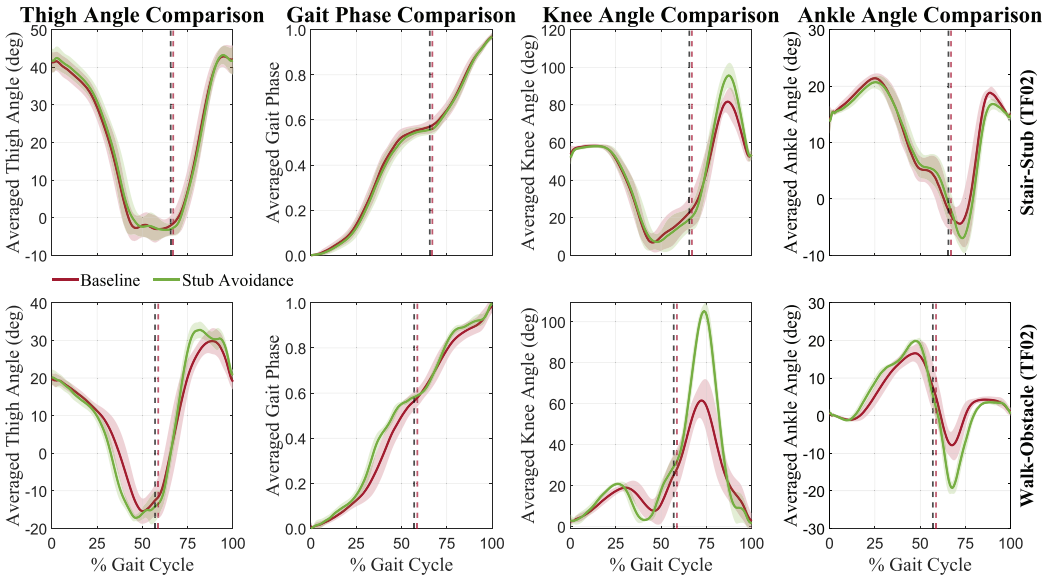

Fig. S3: Stub avoidance controller kinematics comparison with baseline controller for TF02. Comparison of TF02's kinematics and phase variable between baseline (red) and stub avoidance (green) controllers. The first row compares stair ascending with and without the stub avoidance controller (when no stub occurs), and the second row compares level walking with obstacle crossing on level ground. Shaded regions indicate ± 1 standard deviation. Average toe-off phases are indicated as vertical lines in the figure. Positive kinematic values correspond to knee flexion or ankle dorsiflexion.

4 Fig. S4: Frontal plane thigh trajectory for both TF01 and TF02

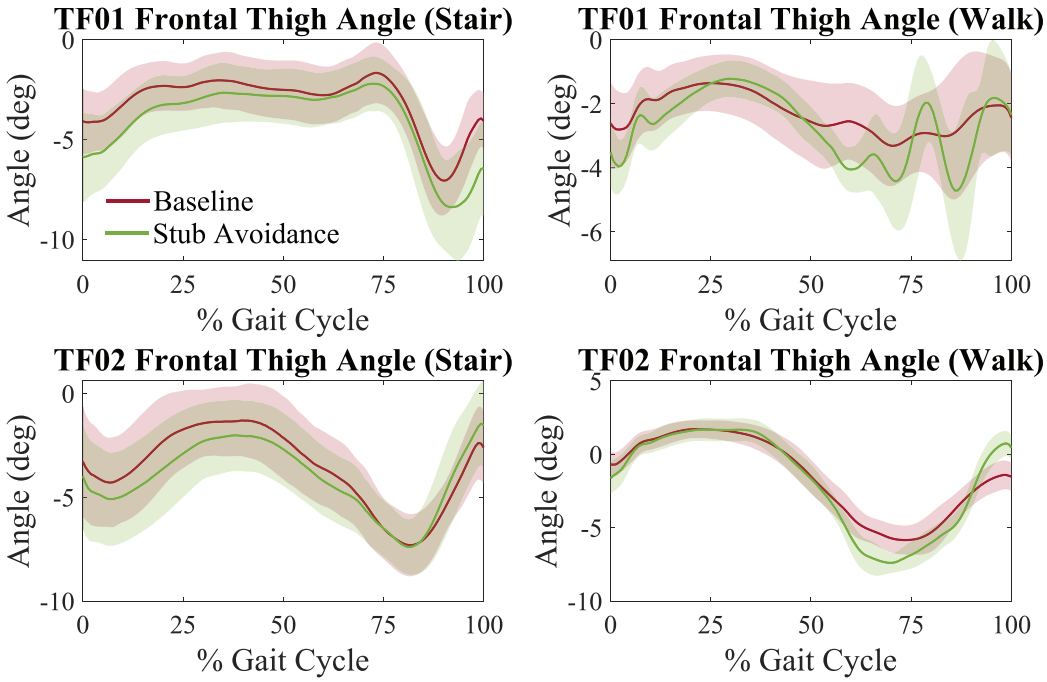

Fig. S4: Frontal plane thigh kinematics. The first column compares the thigh trajectory in the frontal plane during stair ascending with the baseline (red) and the stub avoidance (green) controller to assess hip abduction. The same comparison is made in the second column between obstacle crossing with the stub avoidance controller and level walking (no obstacle) with the baseline controller.

5 Fig. S5: Confusion matrices example

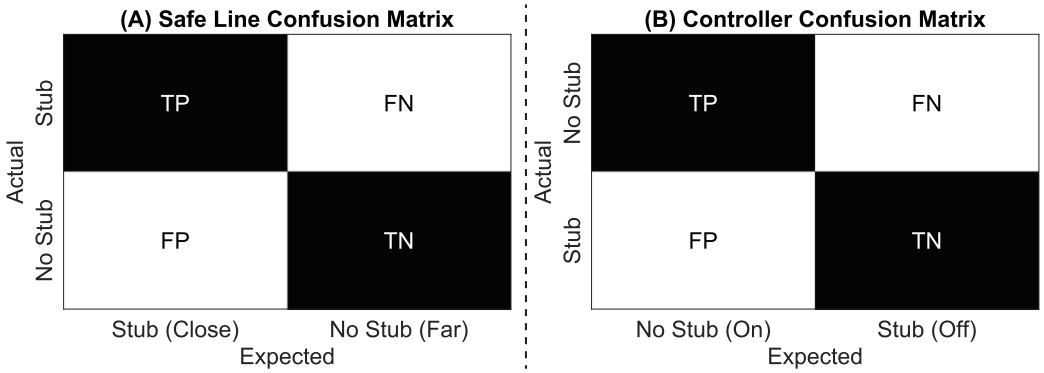

Fig. S5: Confusion matrices example. Example of confusion matrices that evaluate (A) the accuracy of the simulated safe line and (B) stub avoidance controller performance. (A) only uses data with baseline controller, where stubs are expected if the foot is placed close to stairs and no stubs otherwise, (B) only uses data when the foot is placed close to stairs, where stubs are only expected when the stub avoidance controller is on. True positive (TP), false negative (FN), false positive (FP), and true negative (TN) are marked on each confusion matrix.

6 Table S1: Statistics of Absolute Error Between Experimental and Mean Able-bodied Kinematics at Maximum and Minimum Peaks

Table S1: Statistics of Absolute Error Between Experimental and Mean Able-bodied Kinematics at Maximum and Minimum Peaks*

	Thigh			Knee			Ankle		
Activity	TF01	TF01-PAS	TF02	TF01	TF01-PAS	TF02	TF01	TF01-PAS	TF02
SA (↑)	2.45(1.79)	16.05 (7.44)	3.22(2.07)	1.20(1.18)	39.45 (2.45)	2.30(1.93)	2.08(0.75)	6.71 (1.79)	3.29(0.82)
SA (↓)	1.49(1.09)	16.72 (6.51)	3.31(1.29)	3.32(0.96)	4.28 (0.38)	3.92(1.21)	1.12(0.10)	13.26 (0.50)	1.20(0.06)
LW (↑)	4.78(1.46)	14.37 (3.44)	4.55(2.28)	1.79(1.07)	26.39(1.14)	1.25(1.16)	3.53(0.97)	4.30(1.15)	4.02(1.47)
LW (↓)	4.12(1.29)	17.41(10.88)	1.69(1.80)	0.93(0.42)	3.84(0.86)	1.10(0.74)	0.82(0.08)	2.02(1.10)	1.04(0.29)

* Table entries are in the form of mean (standard deviation). The data unit is in degrees. ↑ represents the maximum peak, ↓ represents the minimum peak, and PAS represents passive prosthesis.

7 Table S2: Controller Parameters

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	Stance		Swing	
	Knee	Ankle	Knee	Ankle
k_{p} (Nm/deg)	6.5	12	1.0	12
k_{i} (Nm/deg $\cdot$ s)	2.0	20	0.0	20
k_{d} (Nms/deg)	0.08	0.14	0.08	0.14

Other parameters include $k_{\mathrm{kne}} = 1.5$ deg/cm, $k_{\mathrm{ank}} = -0.375$ deg/cm, $d_{\mathrm{safe}} = 55$ cm for LW and $d_{\mathrm{safe}} = 26$ cm for SA, and $s_{\mathrm{disengage}}$ =0.8.

8 Table S3: Participant Anthropometrics and General Information

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ID	Sex	Age (yrs)	Height (cm)	Mass (kg)	Residual Limb Length (cm)	MFCL	Amputation Type	Passive Prosthesis
TF01	M	18	183	68	15.9	4	Knee-ankle	Genium X3/Pro-Flex LP
TF02	M	26	192	116	26.8	4	Knee-ankle	C Leg 4/Triase

MFCL refers to Medicare Functional Classification Level (i.e., K-level). Both amputee participants were congenital amputees.

9 Movie S1: Video demonstration of the baseline and stub avoidance controllers

The example video file of the experiment is available to download in the supplementary materials.

10 Dataset S1: The datasets generated and analyzed in the current study

The datasets generated and analyzed in the current study are available in the Figshare repository: https://figshare.com/s/c4fa9beb4fb33172e7db