A Phase-Shifting Based Human Gait Phase Estimation for Powered Transfemoral Prostheses

Sunwoong Moon

Gwangju Institute of Science and Technology
Mechanical Engineering
milk5048@gm.gist.ac.kr

Index

1. Introduction
2. Preliminaries
3. Methods
4. Experiment and Results
5. Discussion
6. Conclusion

Introduction : Prosthesis control

Impedance based Control

- impedance based control
  : modulate many impedance parameters
  : but more comfortable for users

Tracking based Control

- Tracking-based control
  : use parameterized variable
  : But user have to follow pre-defined move

Introduction : Hybrid control

Impedance based Control

Tracking based Control

Hybrid Control

⁎Phase Variable Estimation

: 사용자가 어떤 phase에 있는지 로봇이 알고 그에 맞는 제어, 보행 궤적을 제공해야한다.

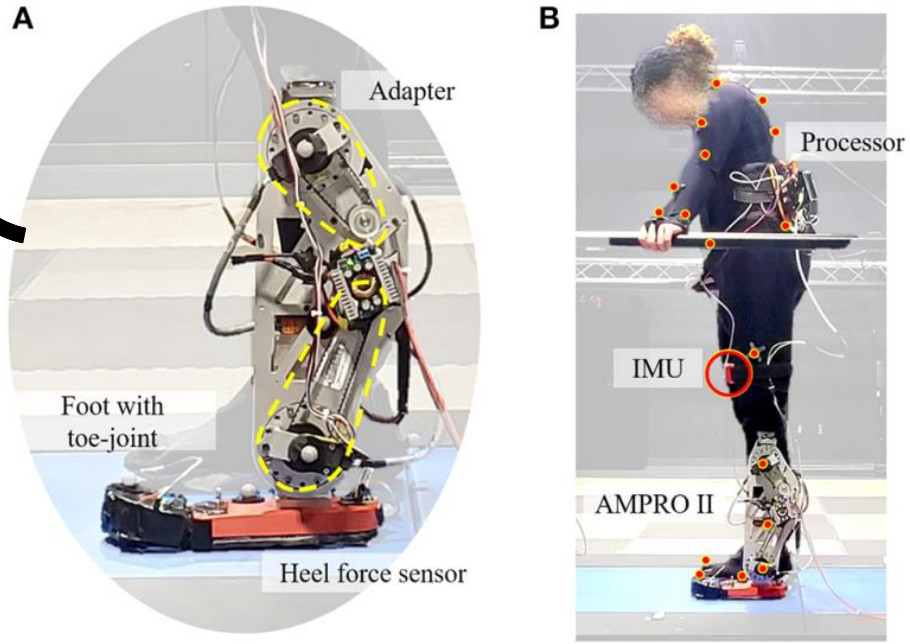
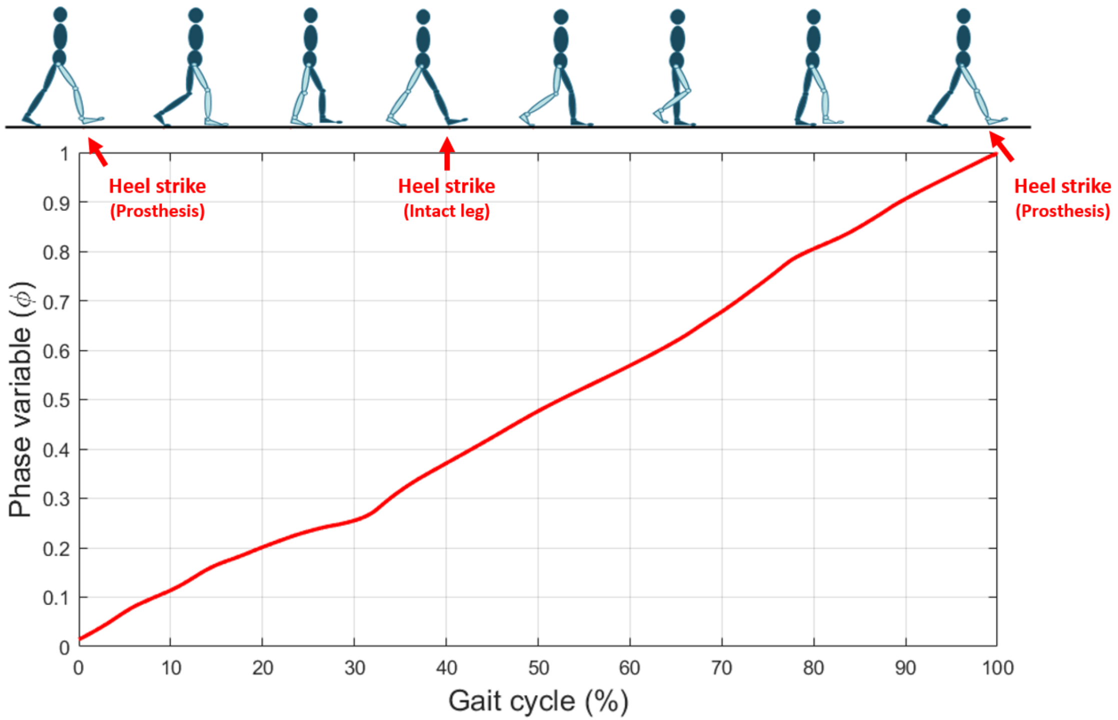


Figure 1. (A) Powered Transfemoral Prosthesis (AMPRO Ⅱ), **(B)** Amputee Walking with AMPRO Ⅱ

Introduction : Phase Variable

Gait Phase Estimation

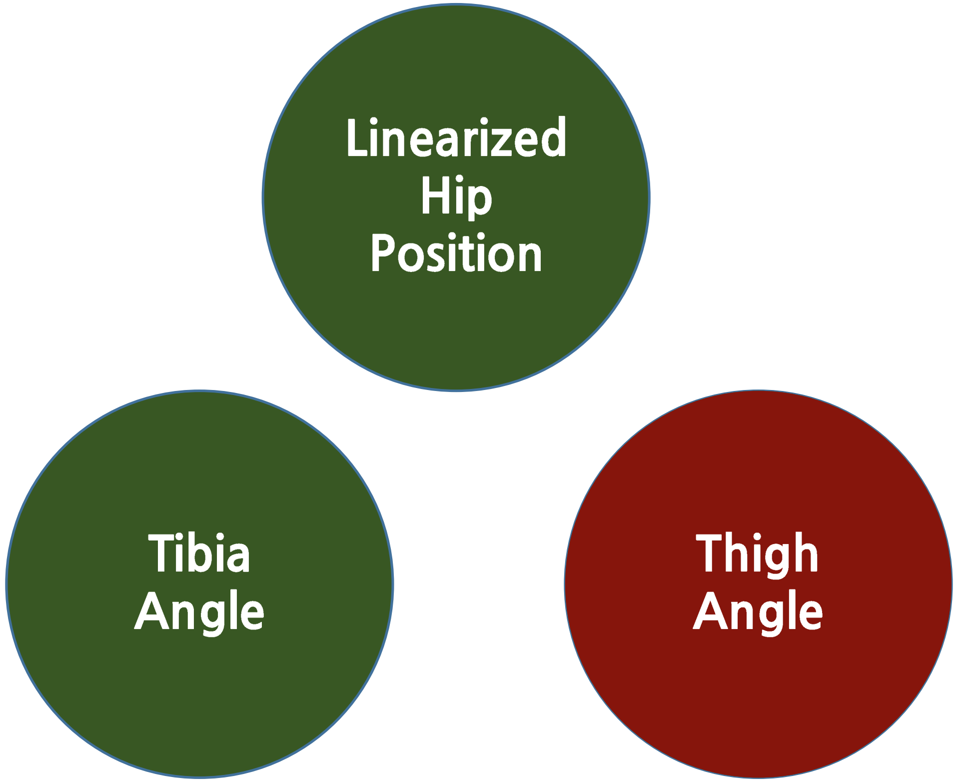


*Phase Variable Qualification

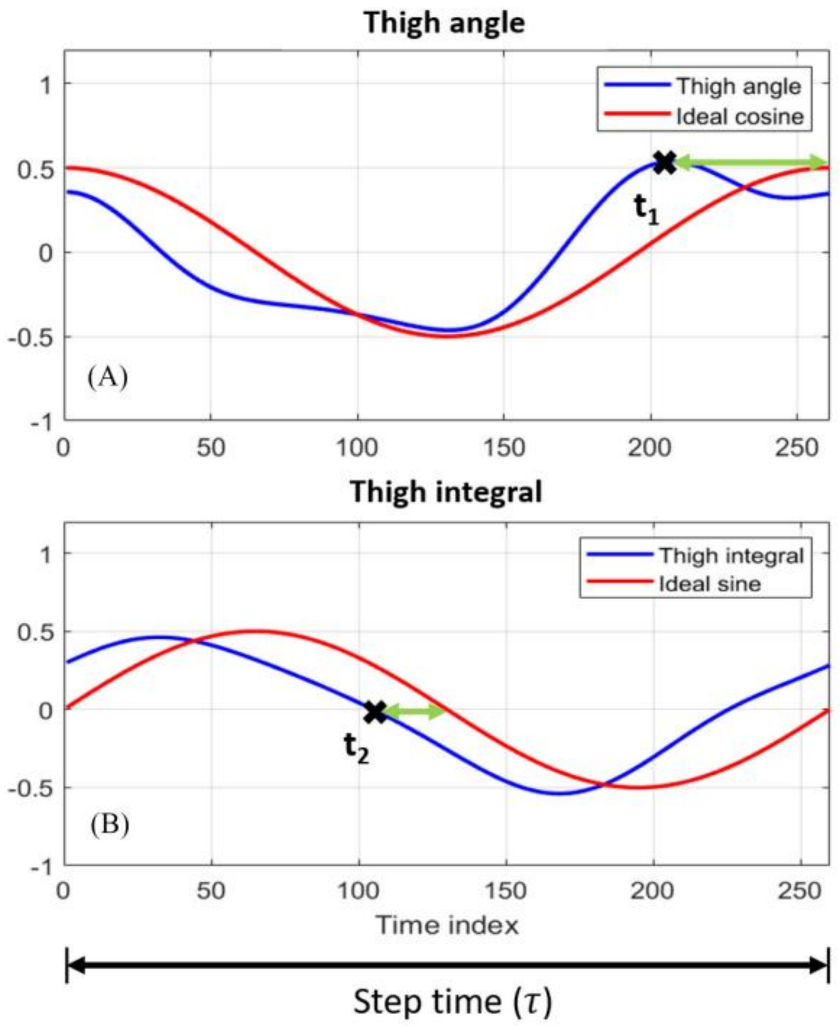
i) monotonic, bounded on [0,1]

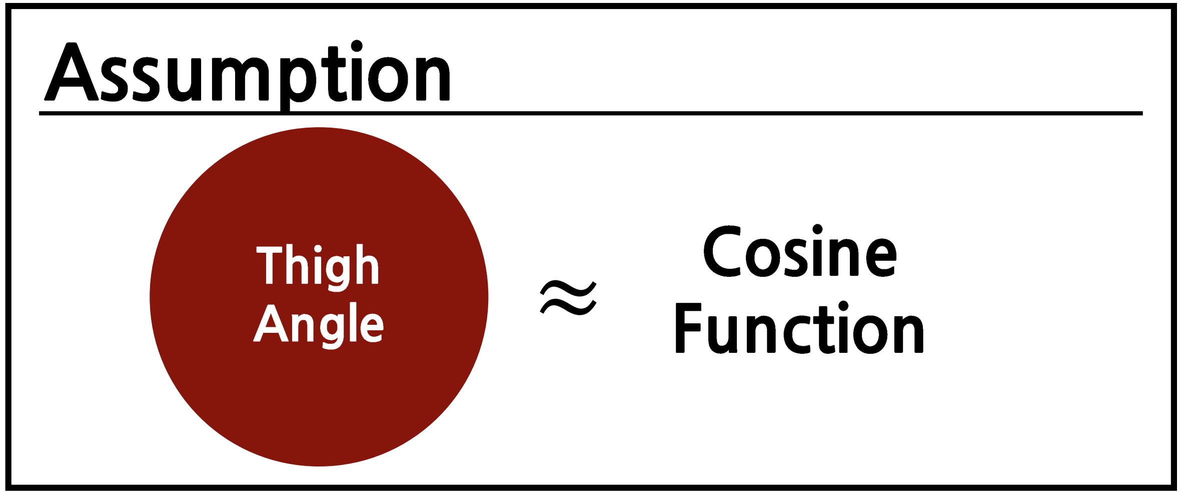
ii) purely controlled by user

보행 추정에 자주 쓰이는 상태 변수



Introduction : Contribution





오차

문제 발생 (HS detection)

하지만 아직 연구가 되어 있지 않음

Introduction : Hypothesis

Hypthesis

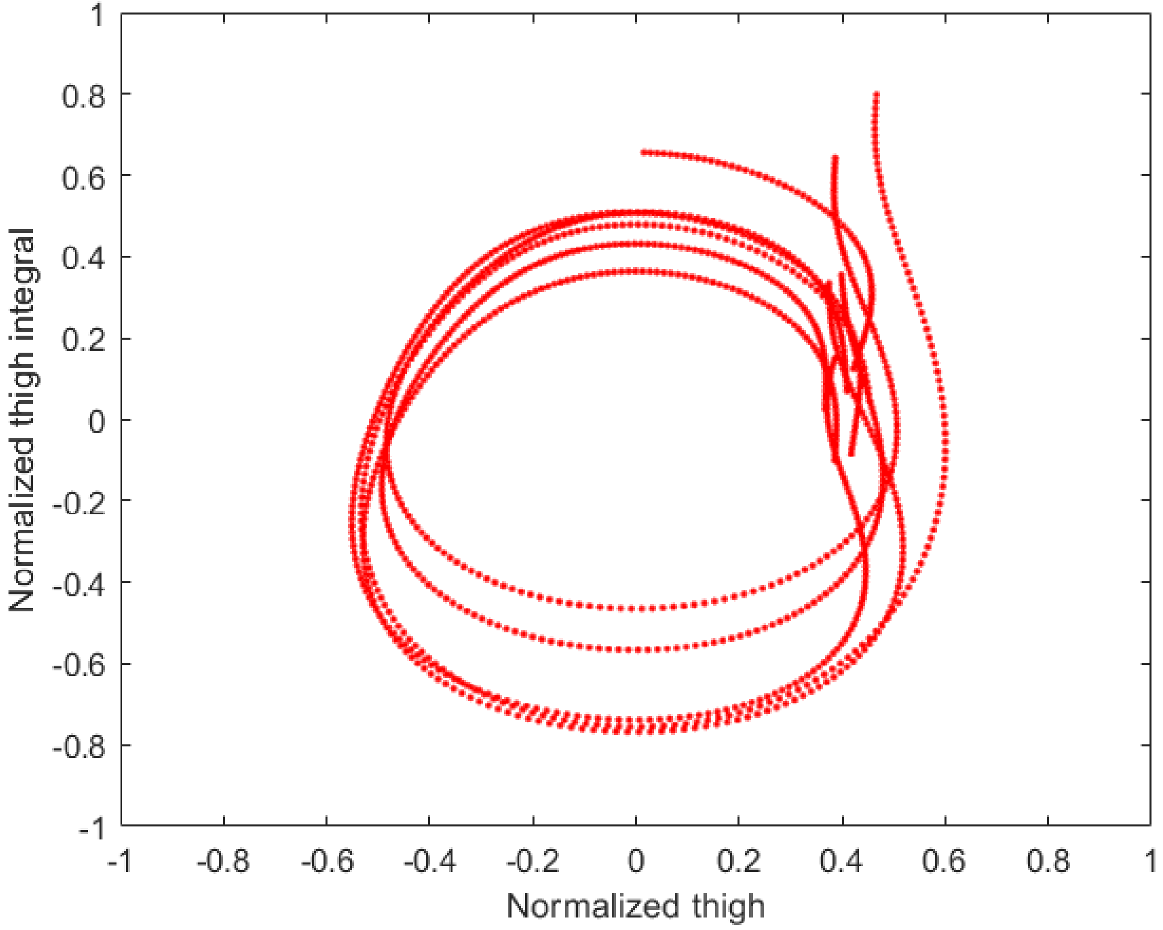
① 허벅지 각도를 위상 변화 시키면 코싸인 함수에 더 가까워진다

② 허벅지각 적분 함수를 위상 변화 시키면 싸인 함수에 더 가까워진다

③ 위상 변화를 하면 위상 변수의 선형성이 증가한다

④ 위상 변화를 하면 Heel Strike를 더 정확히 예측한다

Preliminaries



Parameters

$$\Phi(t) = \frac{1}{2\pi} \operatorname{atan2}(k(\Theta(t) - \alpha), (\theta(t) - \beta))$$

$$k = \frac{|\theta_{max} - \theta_{min}|}{|\Theta_{max} - \Theta_{min}|}$$

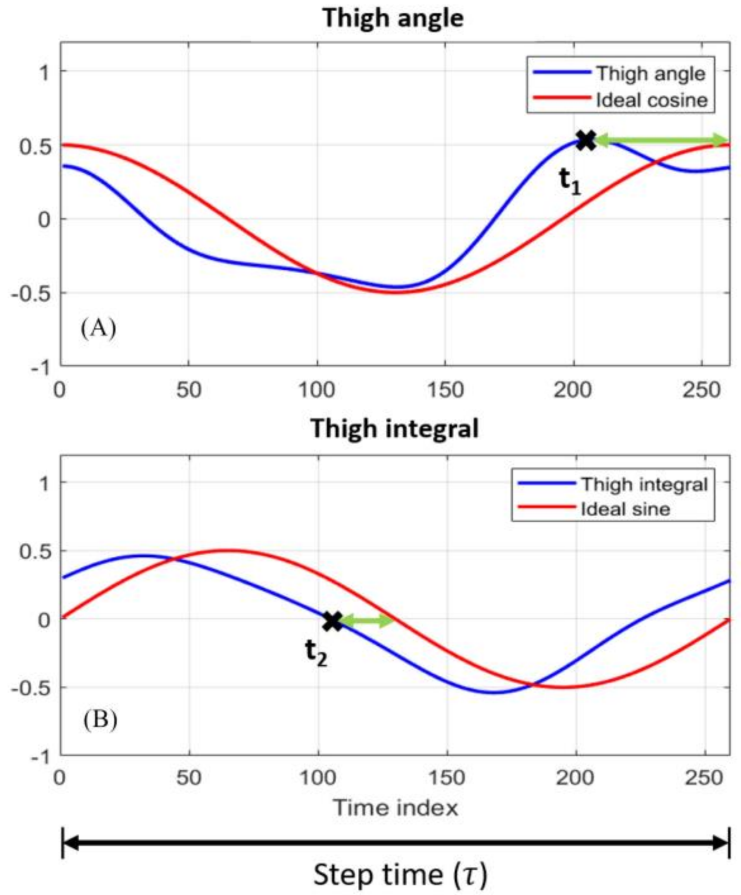
$$\alpha = \frac{|\Theta_{max} - \Theta_{min}|}{2}$$

$$\beta = \frac{|\theta_{max} - \theta_{min}|}{2}$$

$$\Phi(t) = \begin{cases} \Phi(t) & \text{for } \Phi(t) \geq 0 \\ \Phi(t) + 1 & \text{for } \Phi(t) < 0 \end{cases}$$

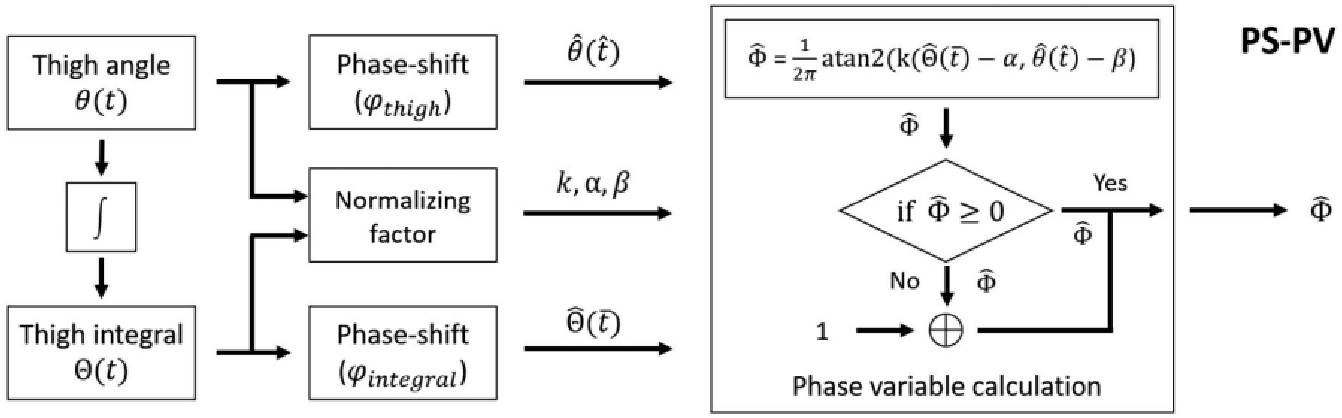
Methods

Cross Correlation : 이상적인 삼각 함수 피팅을 위한 최적의 위상 변화를 구함



$$\hat{\theta}(\hat{t}) = \theta(t + \varphi_{thigh})$$

$$\hat{\Theta}(\bar{t}) = \Theta(t + \varphi_{integral})$$



Experiment

Healthy Walking Analysis

Amputee Walking Analysis

Real time Implementation

Experiment and Results : Healthy Walking

Cross correlation
vs. ideal sinusoidal

RMS Error
vs. linear function

Error
vs. ideal peak (HS)

Table1. THE MEAN AND A STANDARD DEVIATION OF THE FOUR METRICS ACROSS 50 CONSECUTIVE STEPS FOR THREE SUBJECTS

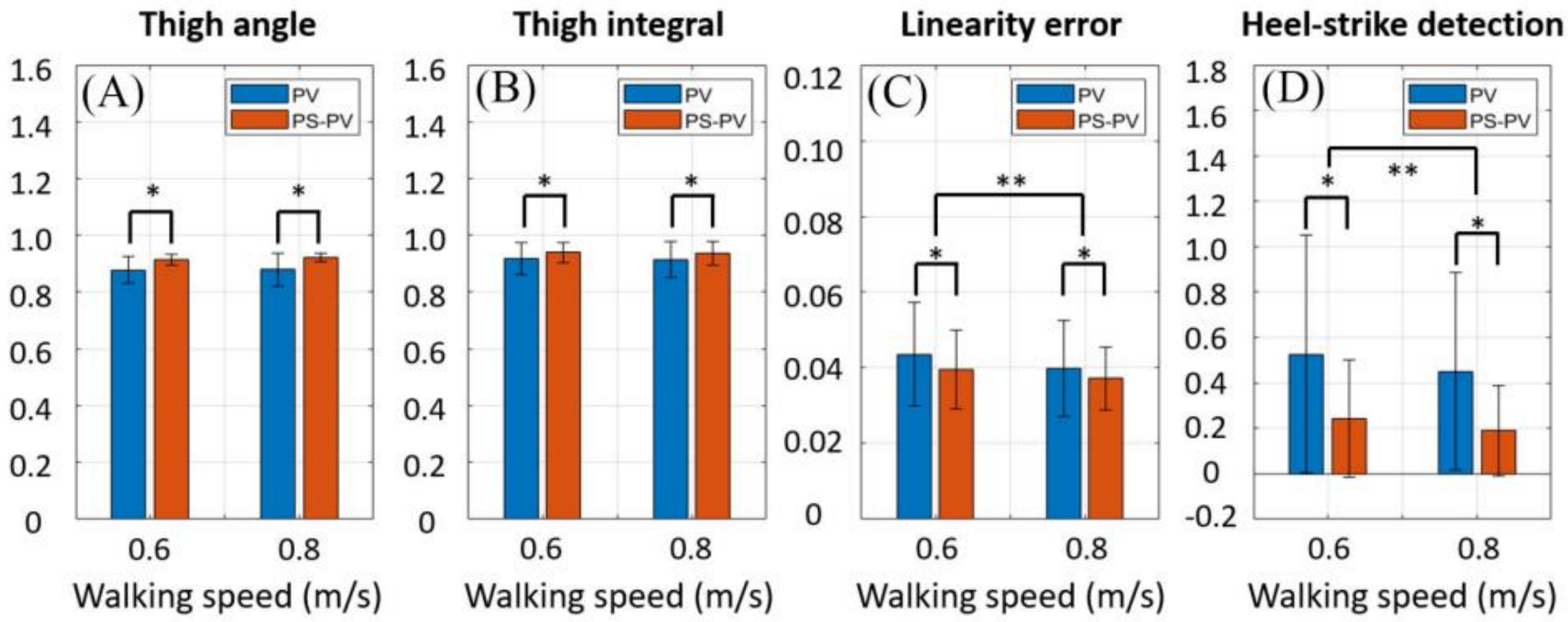
	Speed (m/s)	PV	PS-PV
Thigh angle correlation	0.5	0.862 ± 0.033	0.913 ± 0.014
	1.0	0.859 ± 0.037	0.935 ± 0.011
	1.5	0.783 ± 0.035	0.950 ± 0.008
	2.0	0.700 ± 0.036	0.949 ± 0.008
Thigh integral correlation	0.5	0.894 ± 0.036	0.988 ± 0.003
	1.0	0.876 ± 0.038	0.994 ± 0.002
	1.5	0.801 ± 0.035	0.993 ± 0.002
	2.0	0.720 ± 0.037	0.990 ± 0.002
Linearity error	0.5	0.040 ± 0.009	0.035 ± 0.007
	1.0	0.029 ± 0.006	0.024 ± 0.005
	1.5	0.025 ± 0.005	0.028 ± 0.007
	2.0	0.044 ± 0.007	0.046 ± 0.005
Heel-strike detection error	0.5	0.793 ± 0.760	0.736 ± 0.350
	1.0	0.706 ± 0.719	0.540 ± 0.272
	1.5	1.073 ± 0.949	0.667 ± 0.264
	2.0	2.063 ± 2.188	1.642 ± 0.411

Experiment and Results : Amputee Walking

University of Utah public biomechanics dataset :

K2(한정적인 보행) - 0.4,0.5,0.6,0.7,0.8 m/s

K3(자립보행 가능) - 0.6,0.8,1.0,1.2,1.4 m/s

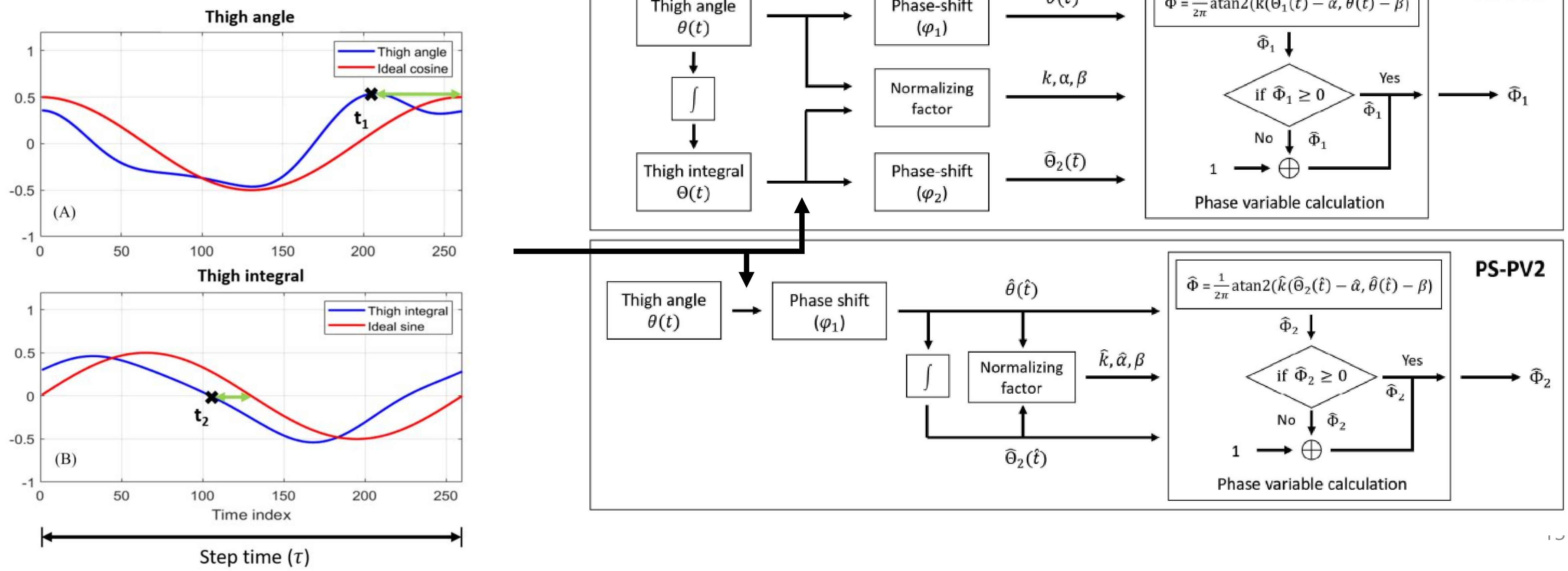


Three way Mixed ANOVA: group, walking speed, method

Experiment and Results :
Real-Time Phase Shifting Implementation

의족 가동 중 실시간 위상 지연 감지 필요

$$\varphi_1 = \tau - t_1, \quad \varphi_2 = \frac{1}{2}\tau - t_2$$



Real-Time Phase Shifting Implementation

$$\hat{\theta}(\hat{t}) = \theta(t + \varphi_1)$$

$$\hat{\Theta}_1(\bar{t}) = \Theta(t + \varphi_2)$$

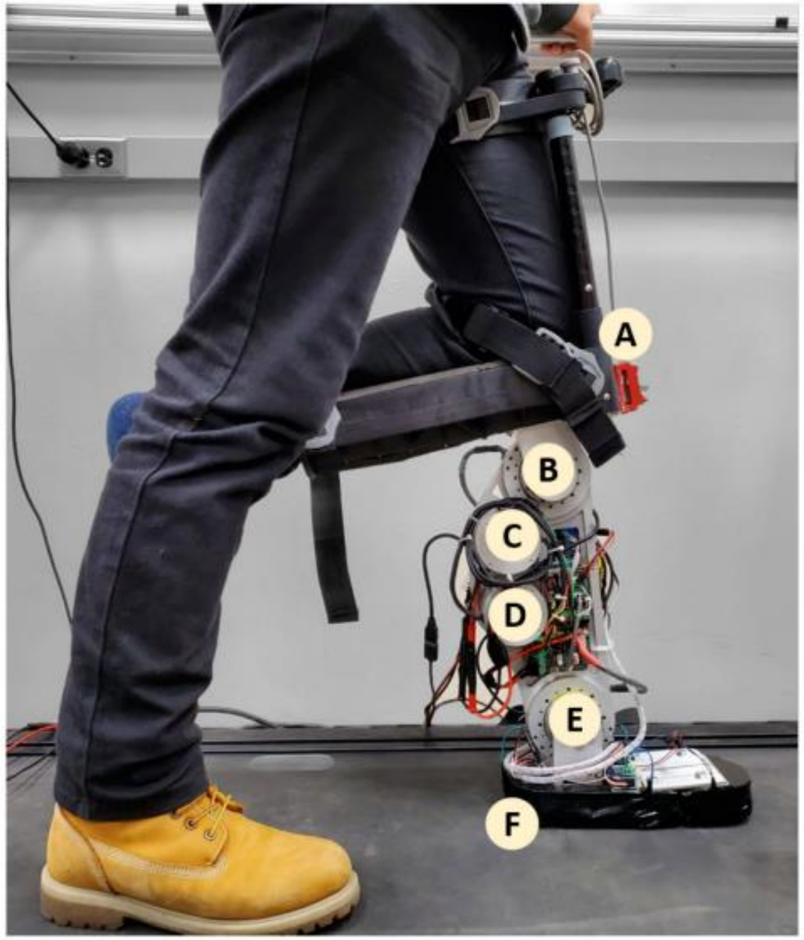
$$\hat{\Theta}_2(\hat{t}) = \int \hat{\theta}(\hat{t})\, d\hat{t}$$

$$\hat{\Phi}_1(t) = \frac{1}{2\pi} atan2(k(\hat{\Theta}_1(\bar{t}) - \alpha), (\hat{\theta}(\hat{t}) - \beta))$$

$$\hat{\Phi}_2(t) = \frac{1}{2\pi} atan2(\hat{k}(\hat{\Theta}_2(\hat{t}) - \hat{\alpha}), (\hat{\theta}(\hat{t}) - \beta))$$

$$\hat{k} = \frac{|\hat{\theta}_{max} - \hat{\theta}_{min}|}{|\hat{\Theta}_{2,max} - \hat{\Theta}_{2,min}|}, \qquad \hat{\alpha} = \frac{|\hat{\Theta}_{2,max} + \hat{\Theta}_{2,min}|}{2}$$

Real-Time Phase Shifting Implementation



A. IMU (Thigh)

B. Harmonic drive (Knee)

C. BLDC motor (Knee)

D. BLDC motor (Ankle)

E. Harmonic drive (Ankle)

F. FSR sensor (Heel)

IMU detect thigh motion

high resolution optical encoder

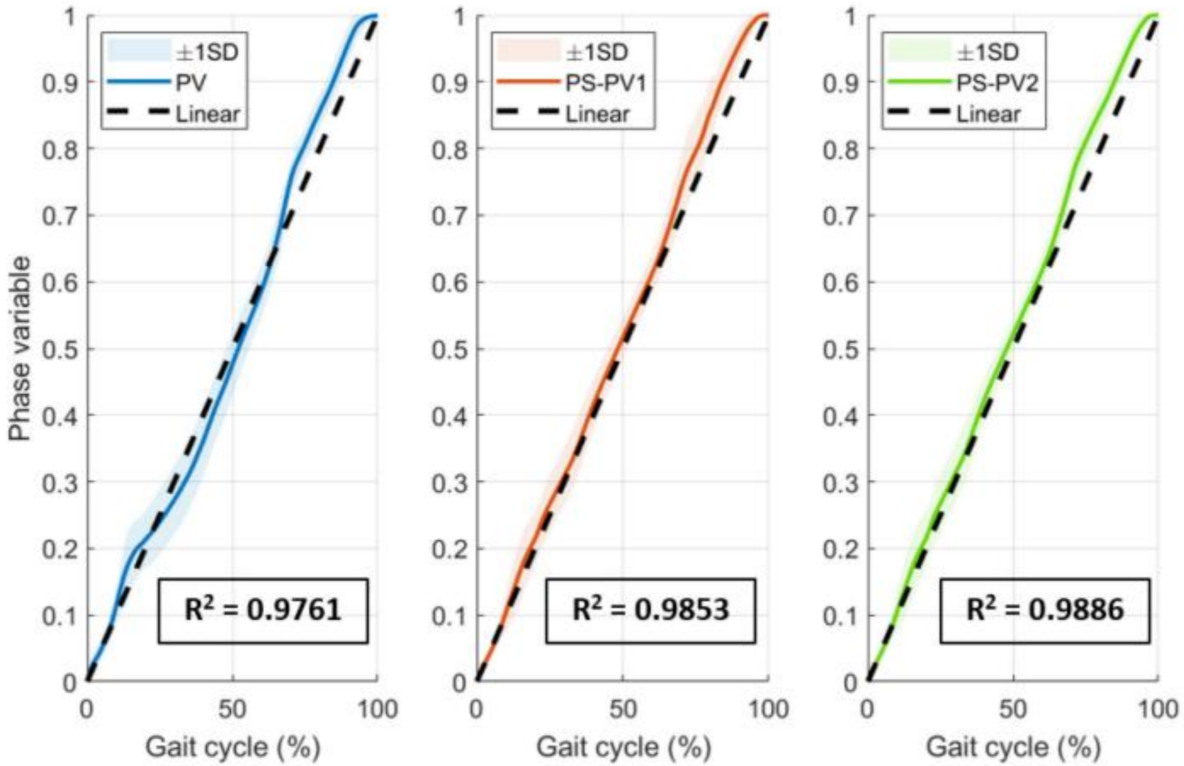
healthy young subject 1.7m 70kg.

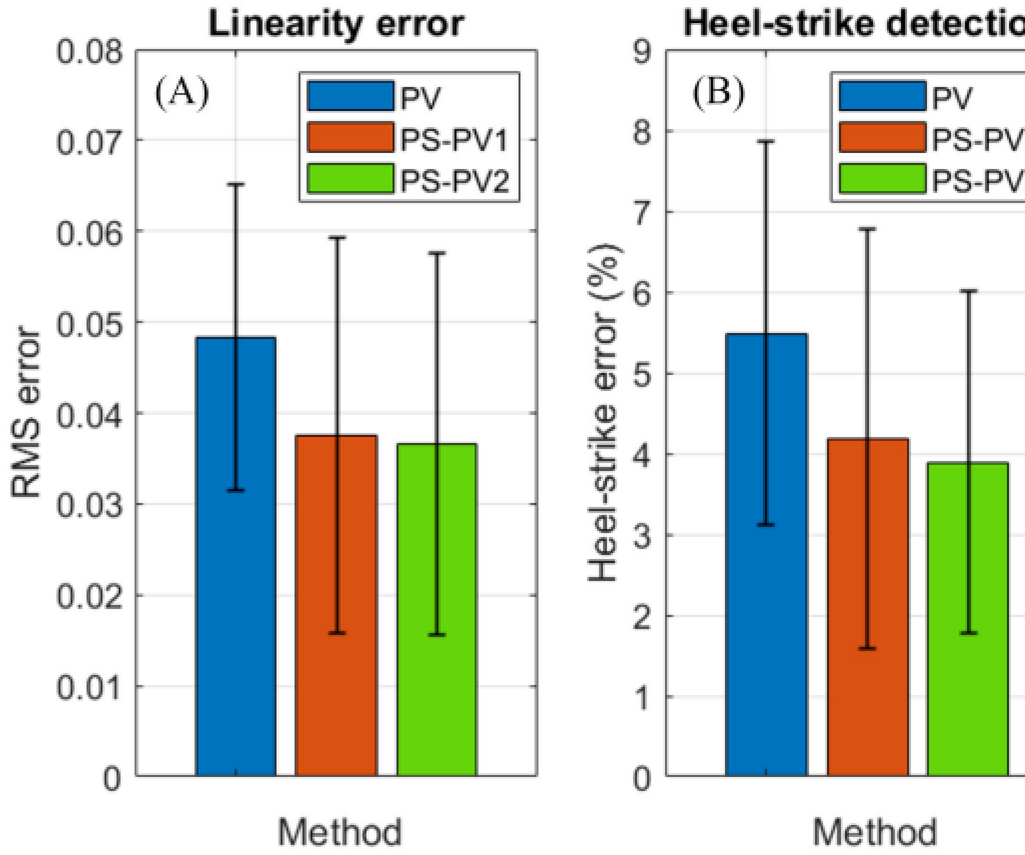
0.8m/m

handrailed treadmill

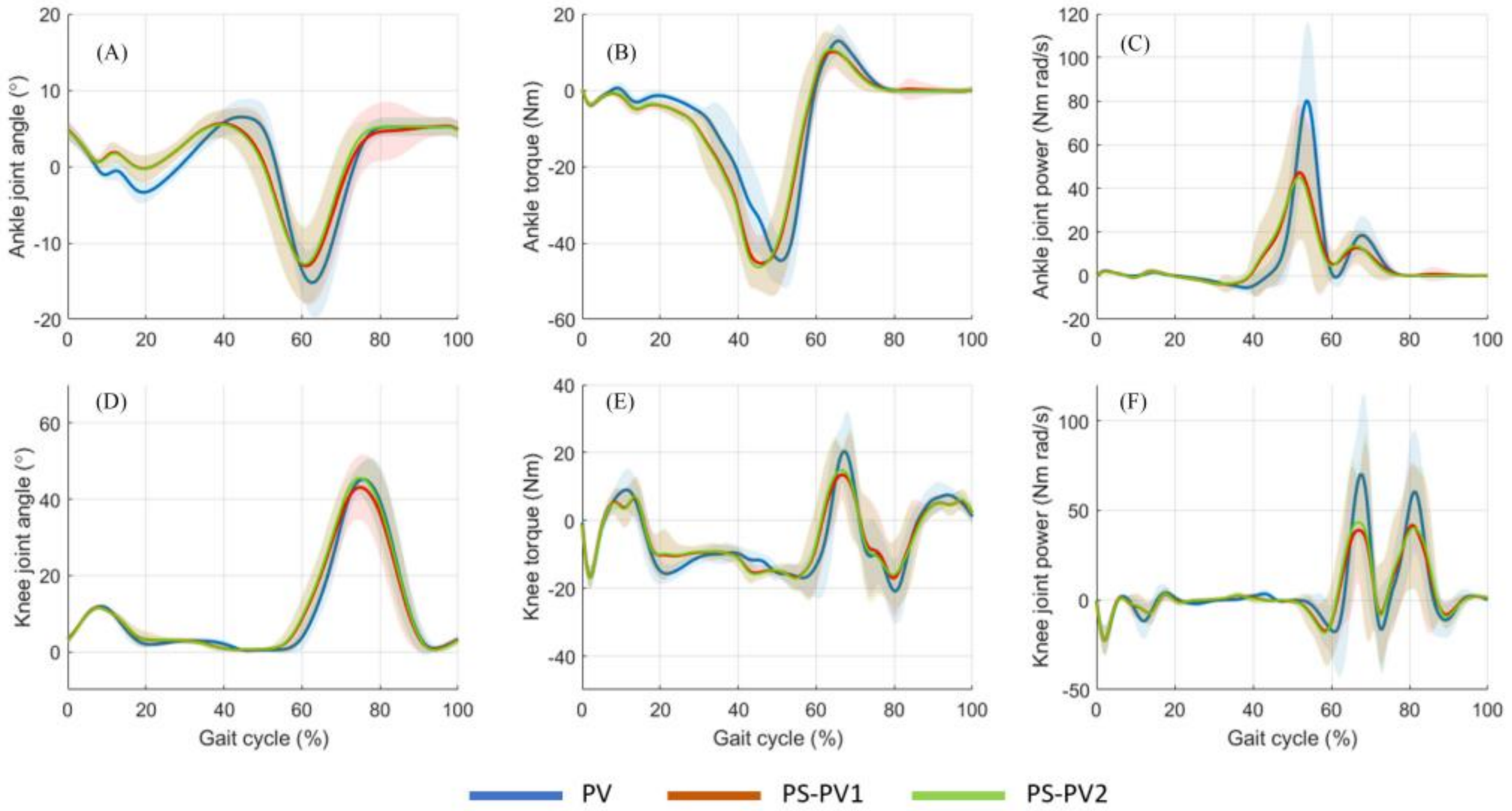
Real-Time Phase Shifting Implementation

	PV	PS-PV1	PS-PV2
Thigh angle	0.86 ± 0.03	0.89 ± 0.02	
Thigh integral	0.90 ± 0.05	0.90 ± 0.06	0.91 ± 0.05

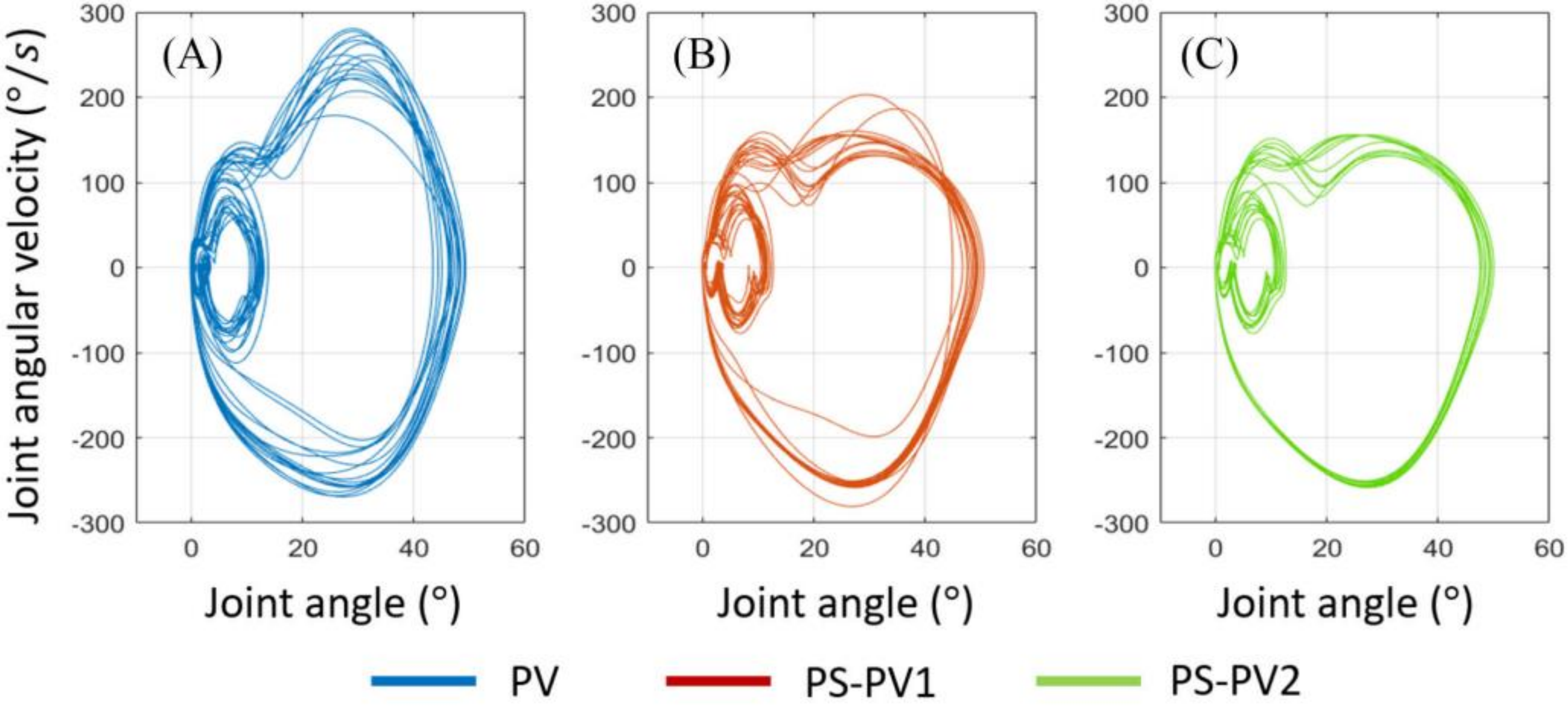




Real-Time Phase Shifting Implementation



Discussion


(A)
(B)
(C)
Joint angular velocity (°/s)
300
200
100
0
-100
-200
-300
0
20
40
60
Joint angle (°)
PV
PS-PV1
PS-PV2

limits

- torque limit - > 0.8m/s (slower than normal person)
- L-shape emulator -> difference between two limbs, slightly higher hip extension occur on prosthesis side.
- But still PSPV shows ideal cosine function
- PS is user specific -> learning based gait phase estimation model using proposed PSPV

Conclusion

- PSPV using user thigh angle information
- PS improve linearity and HS detection.
- Real time implementation performed.
- linear PV assist more controlled PO
- phase portrait: PSPV has fewer deviations from limit cycle.
- phase shifted thigh angle integral PV is better perform
- PSPV is more accurate gait progress detectopm amd thus robust walking

Q&A

Thank You

For Your Attention