Enhancing Human-Robot Synchronization

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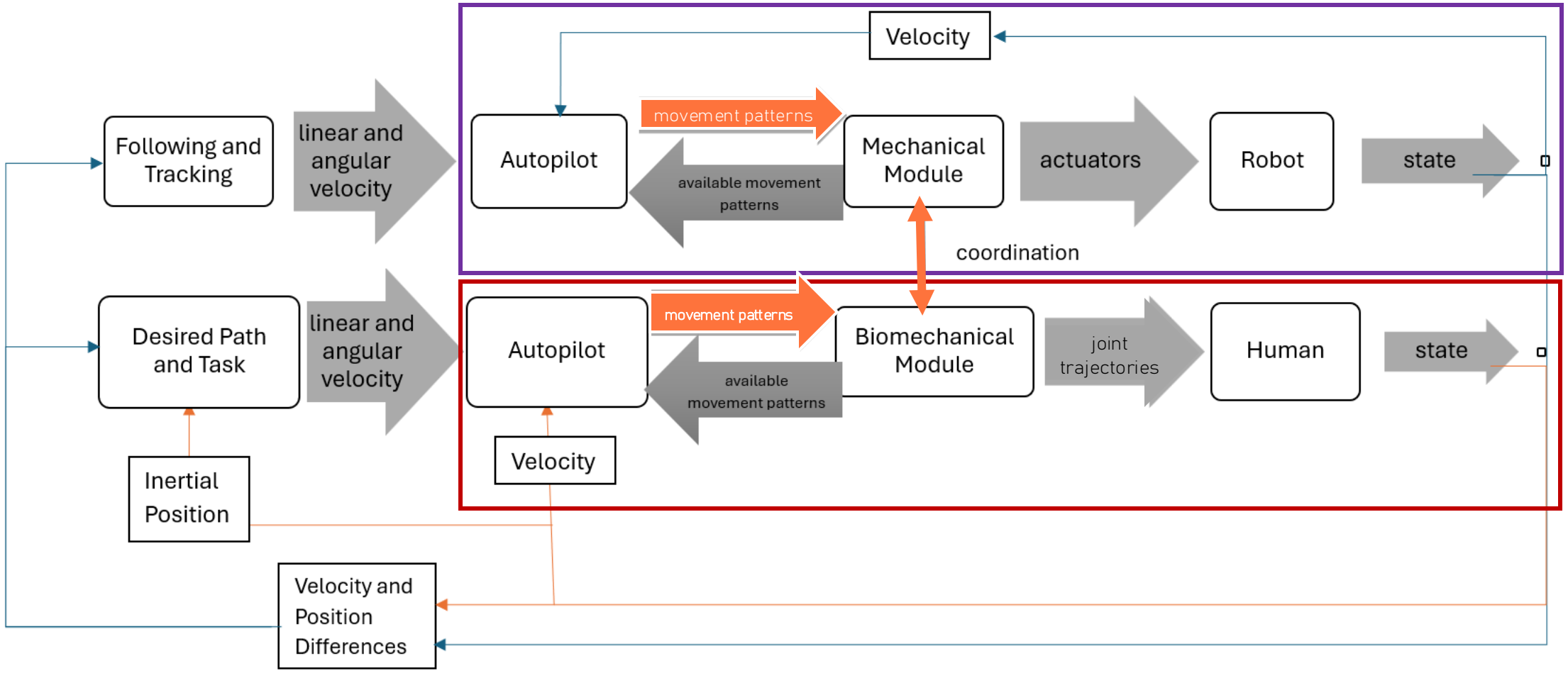
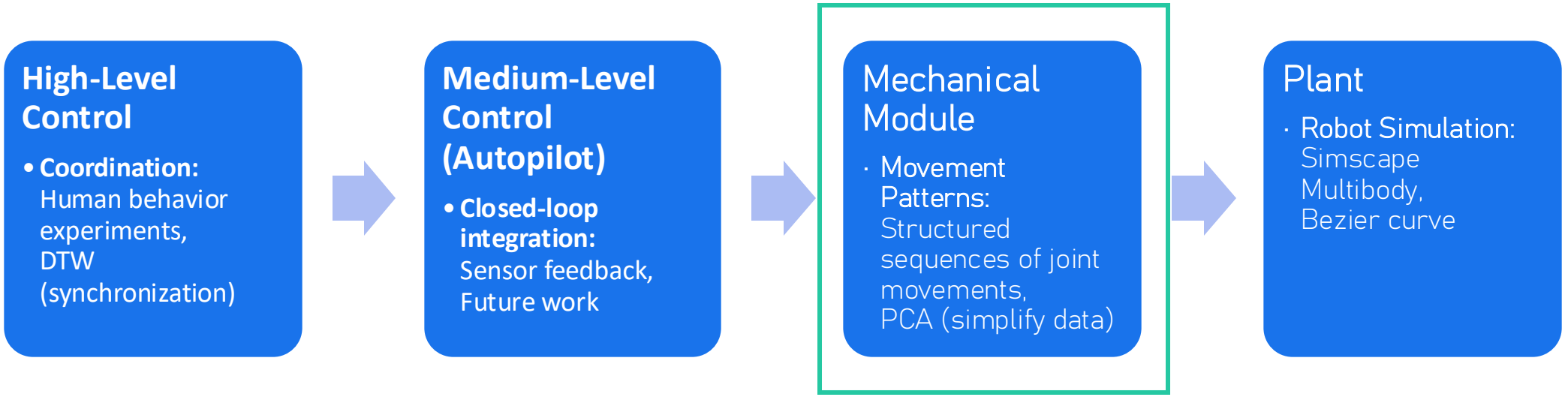
2025 IAAC GSC'25

Movement synchronization in human-robot interaction

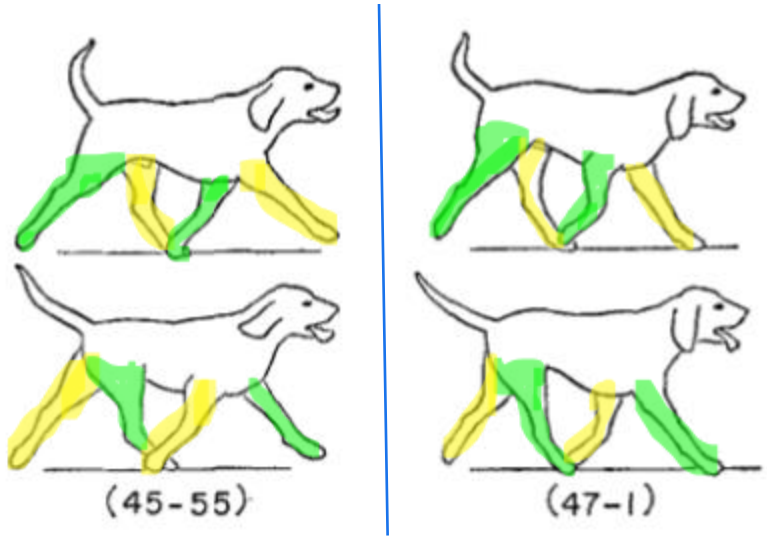
Hierarchical approach



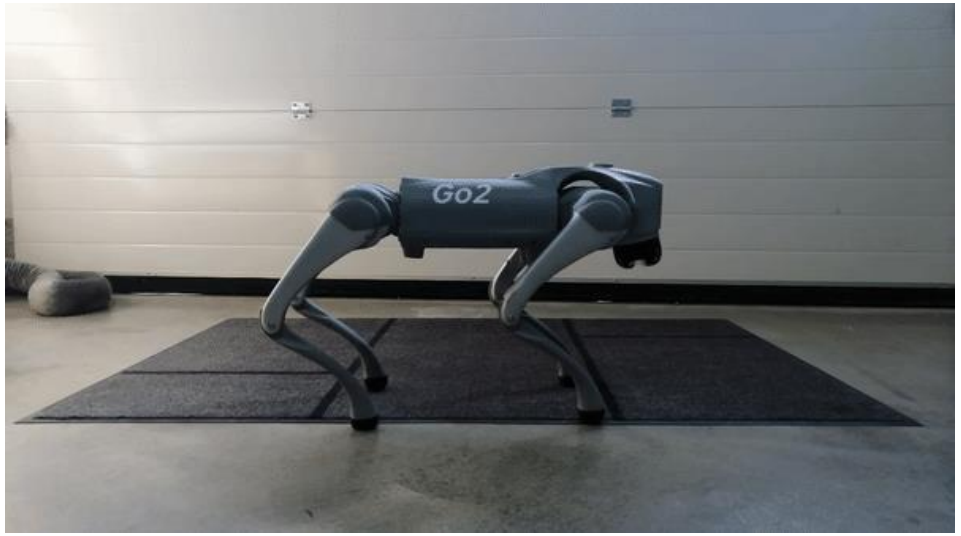
Roadmap


High-Level Control
• Coordination: Human behavior experiments, DTW (synchronization)
Medium-Level Control (Autopilot)
• Closed-loop integration: Sensor feedback, Future work
Mechanical Module
· Movement Patterns: Structured sequences of joint movements, PCA (simplify data)
Plant
· Robot Simulation: Simscape Multibody, Bezier curve

Movement patterns of a quadruped robot



Trotting Pacing

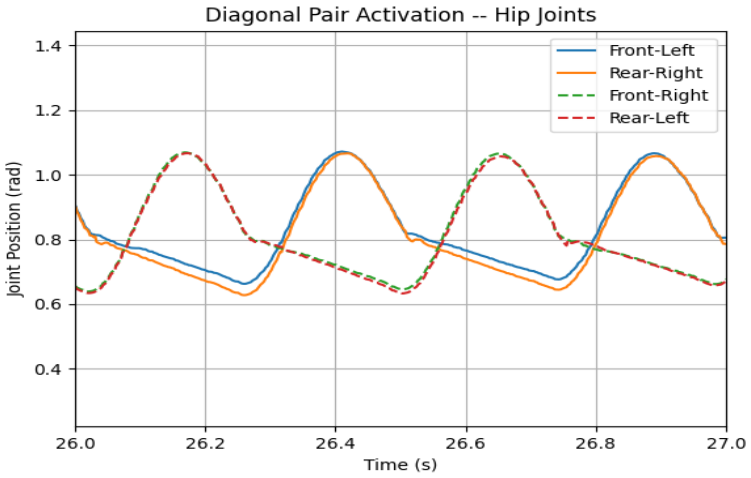


MILTON HILDEBRAND, 1986

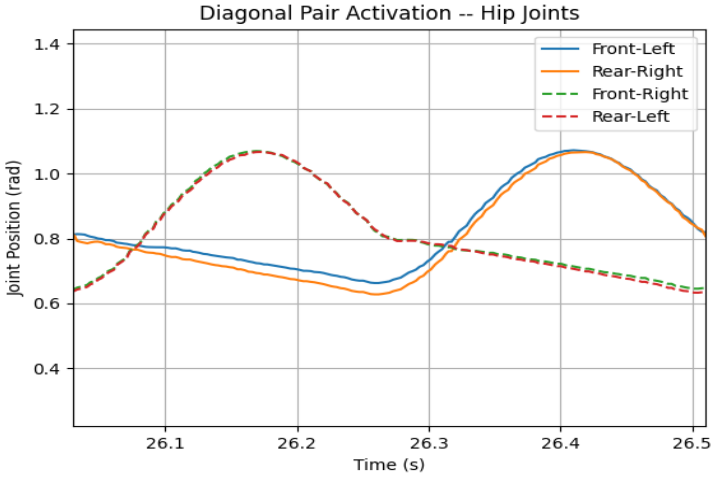
Unitree Go2

Weight (with battery)	15 kg (+8 kg payload)
Speed	0~3.5m/s
Max Joint Torque	45N.m
Sensors	Super-wide-angle 3D LIDAR, HD Wide-angle Camera, Foot-end force sensor
Battery life	About 2-4h

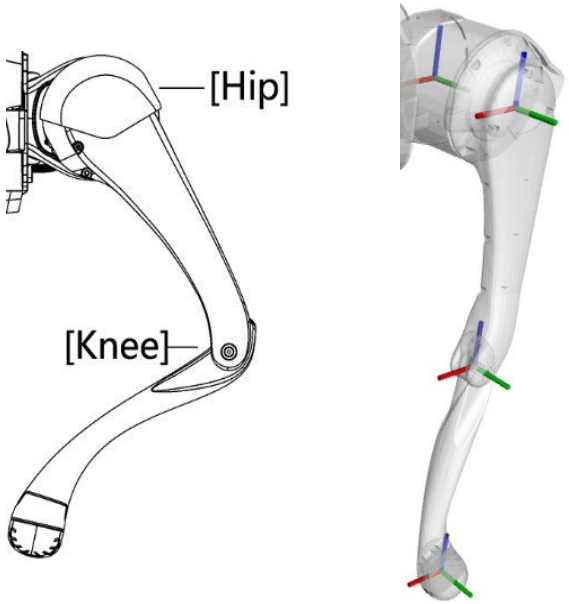
Movement patterns of Go2



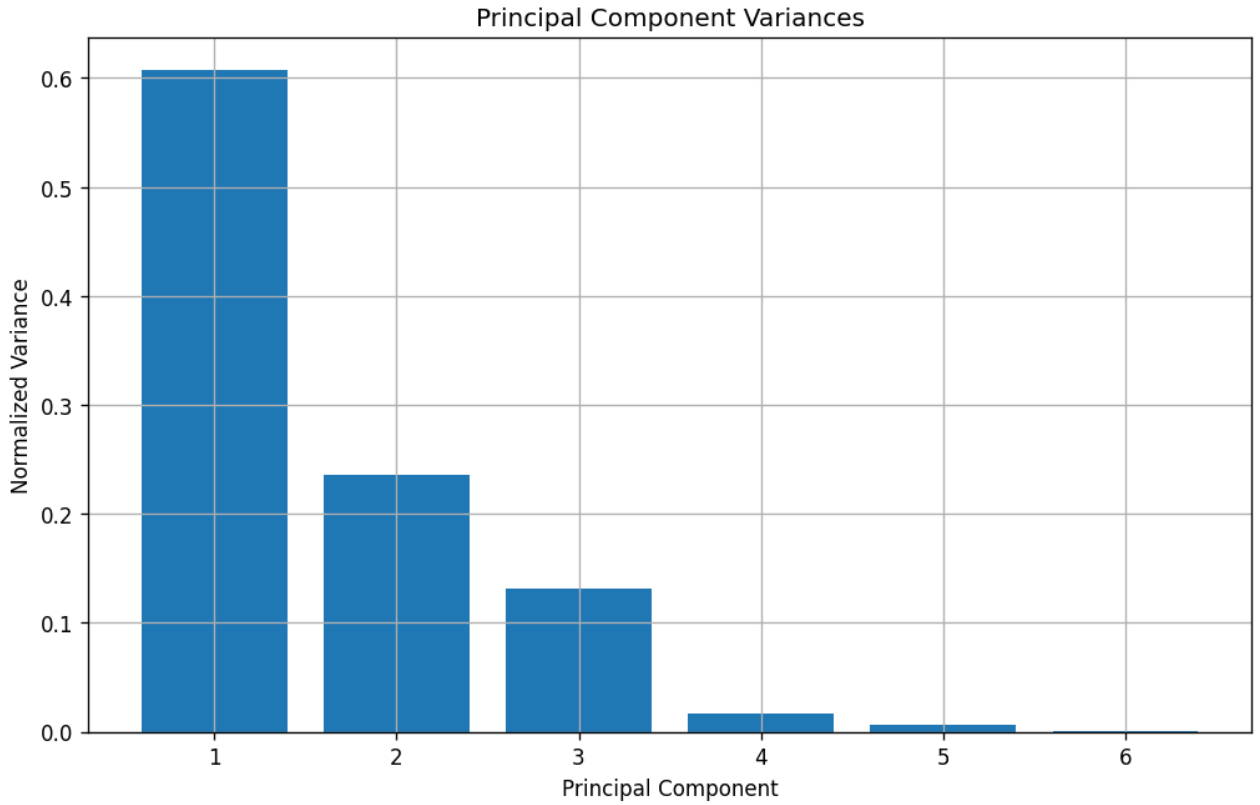
Trot gait



Step duration: 0.43 seconds



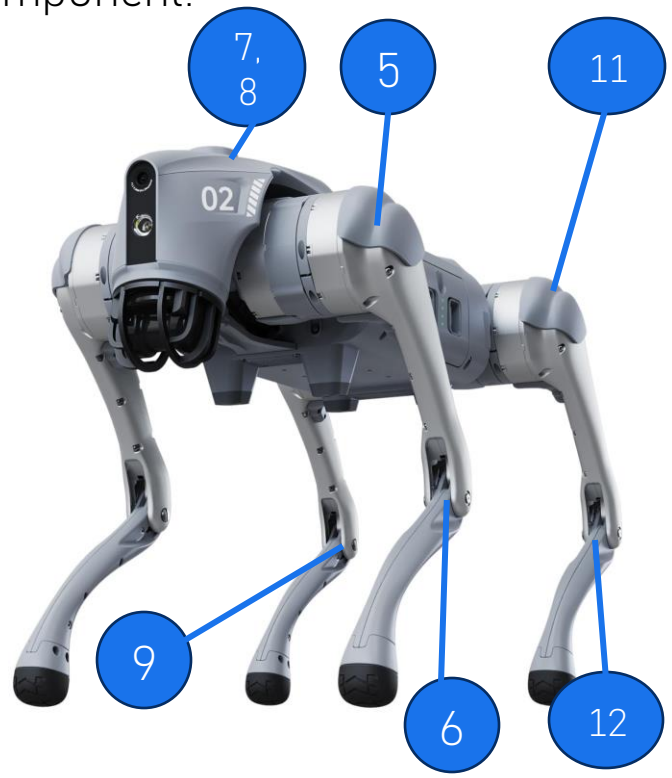
Principal Components Analysis (PCA)



First Principal Component:

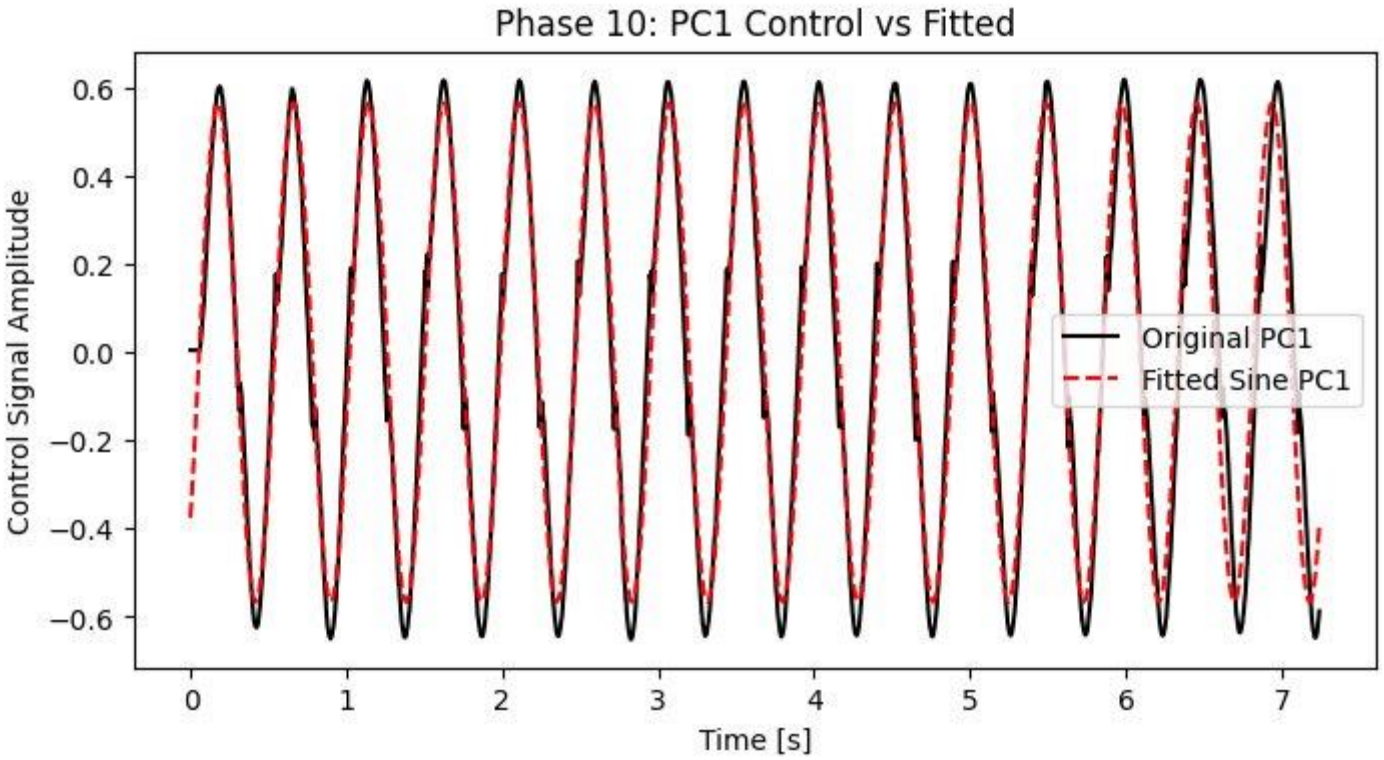
Motor 1: 0.01
Motor 2: 0.02
Motor 3: 0
Motor 4: 0.01
Motor 5: -0.32
Motor 6: -0.17
Motor 7: -0.69
Motor 8: -0.38
Motor 9: -0.25
Motor 10: -0.03
Motor 11: -0.16
Motor 12: 0.39

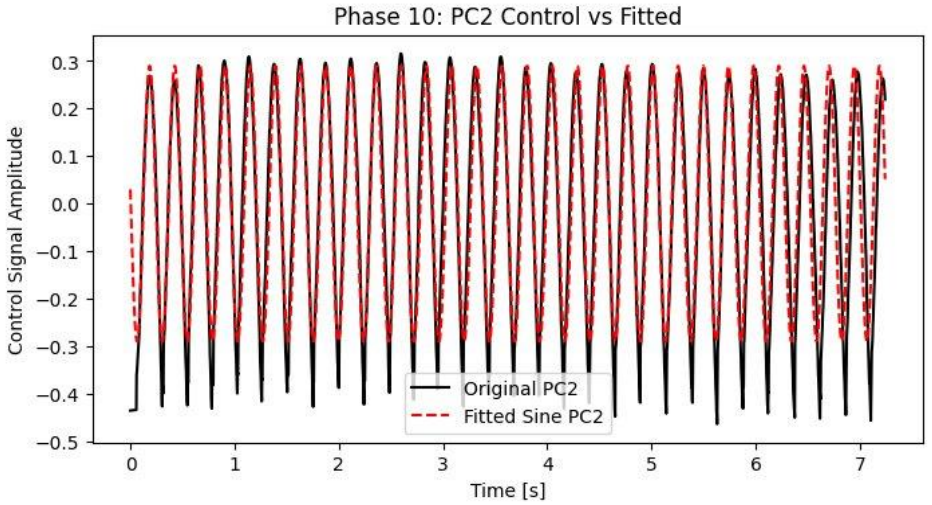
Rear right hip

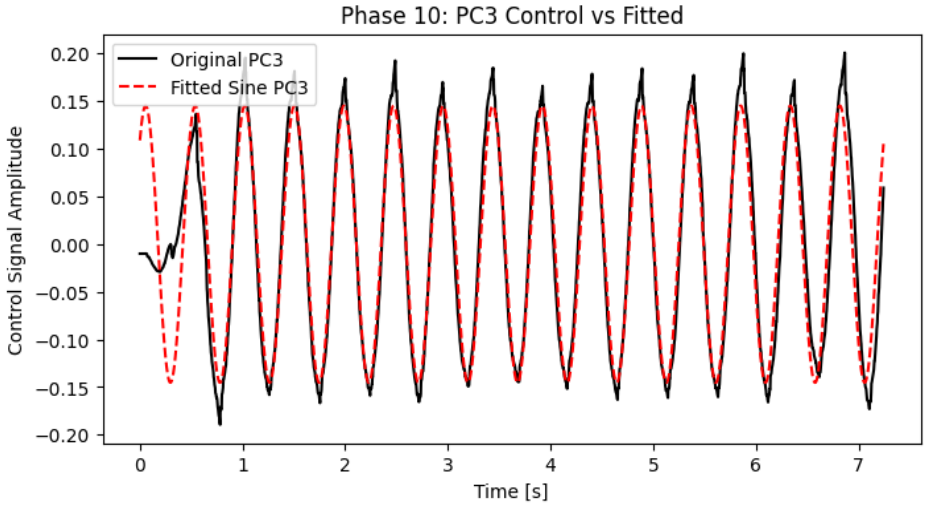


Reconstructed Signal

PCA reconstruction = PC_{score} · $eigenvectors^{T}$ + mean

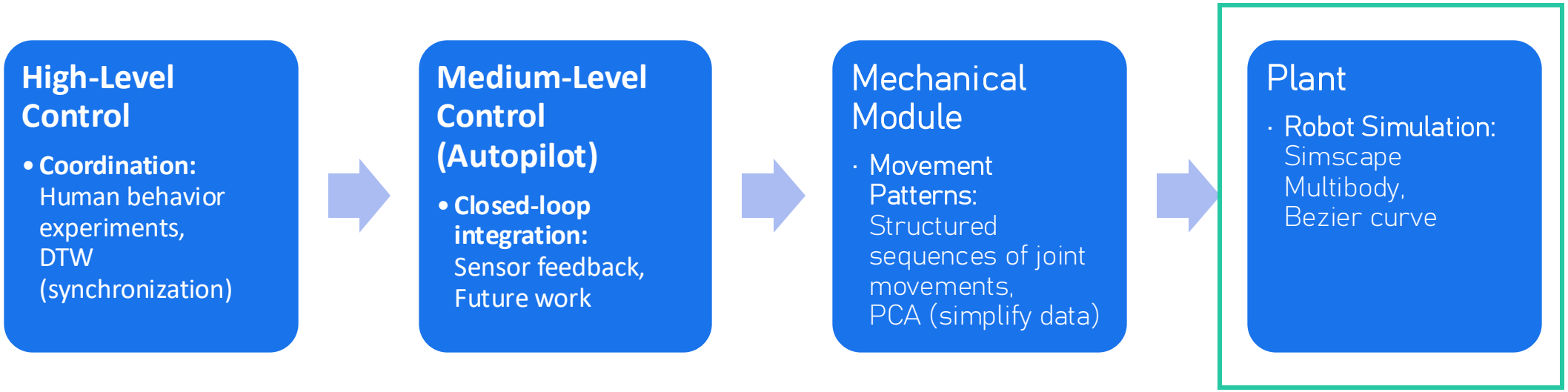






ANNA CLARKE ET AL, 2022

Roadmap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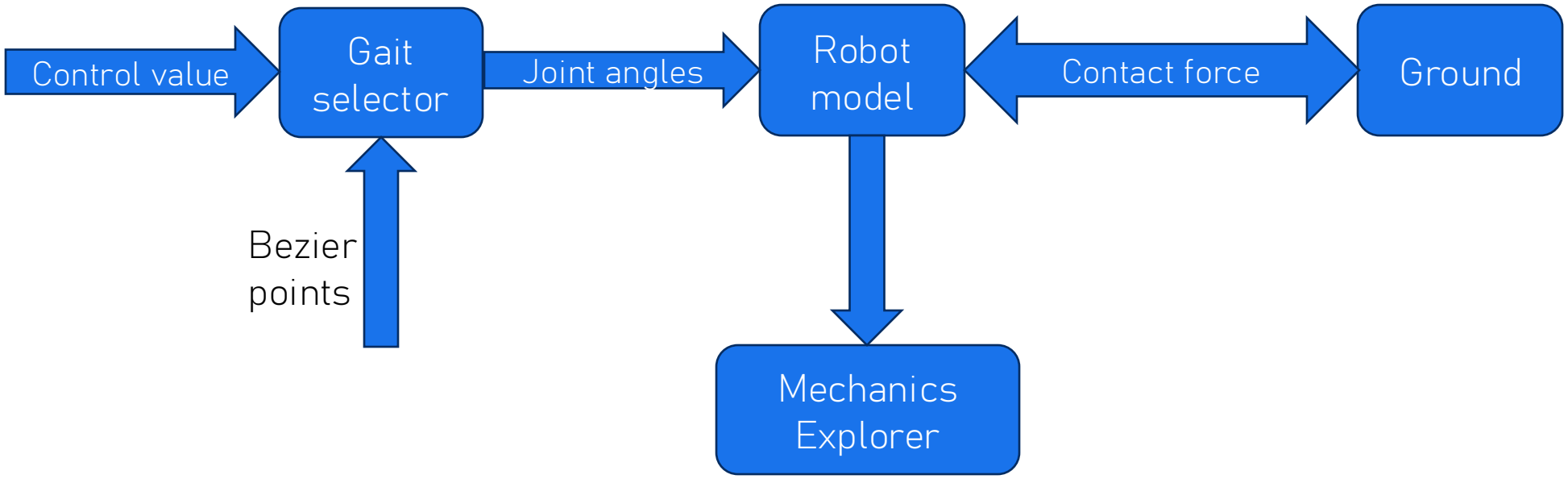
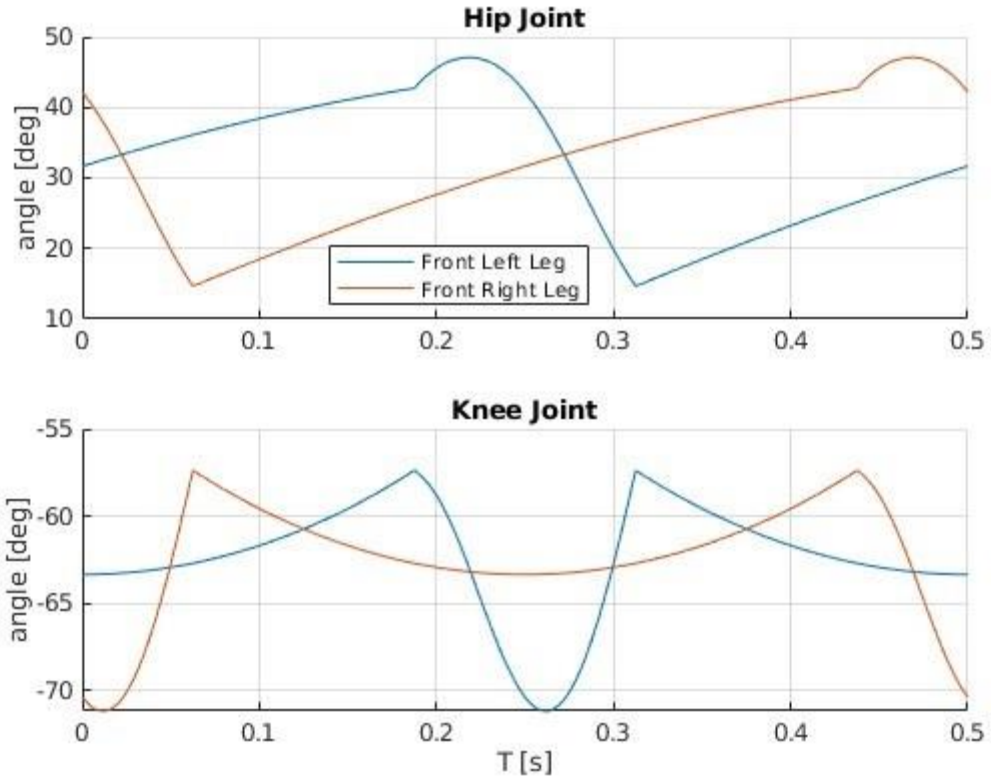
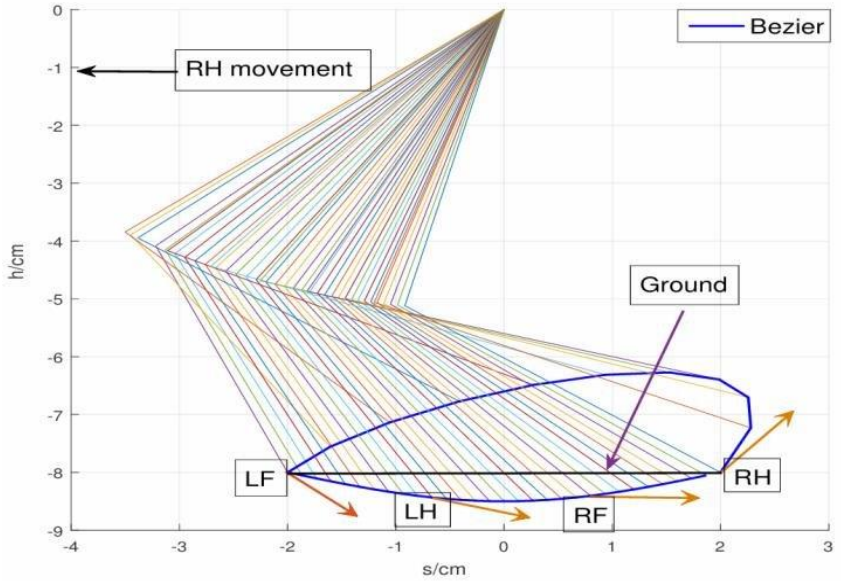
Robot Modeling



HTTPS://WWW.MATHWORKS.COM/PRODUCTS/SIMSCAPE-MULTIBODY.HTML

Foot Trajectory Design based on Bezier Curve



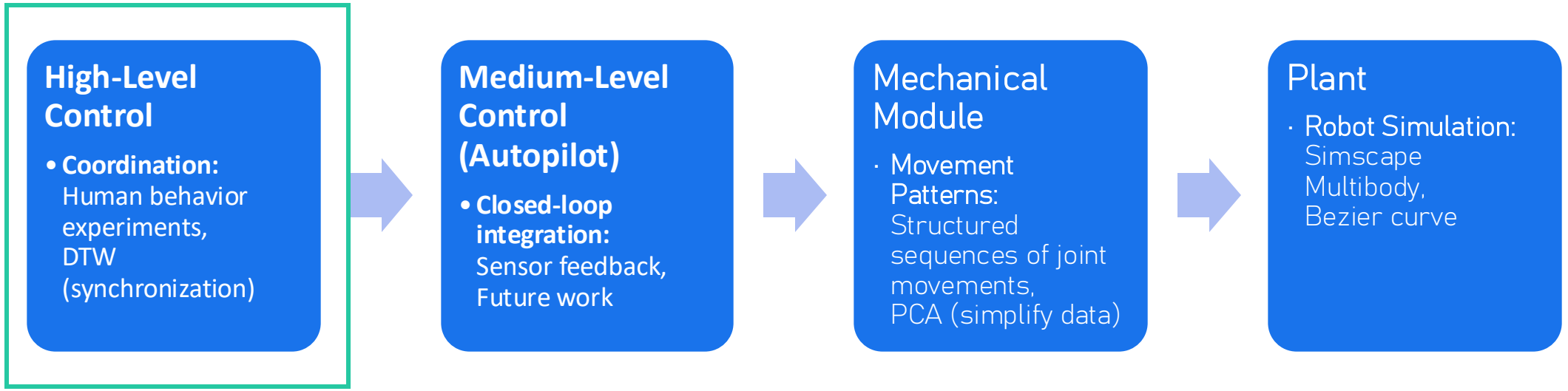


Inverse Kinematic

LIGUANG ZHOU ET AL, 2017

Simulating Robot Movement in Open Loop

Roadmap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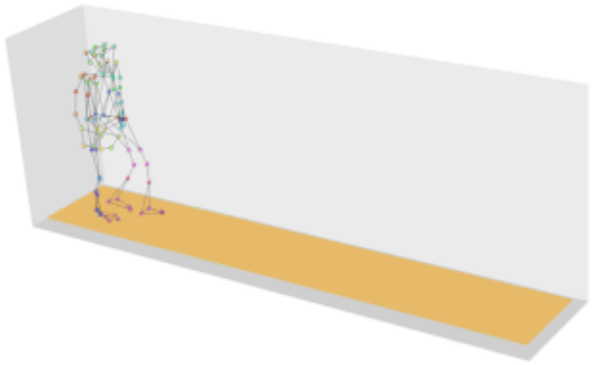
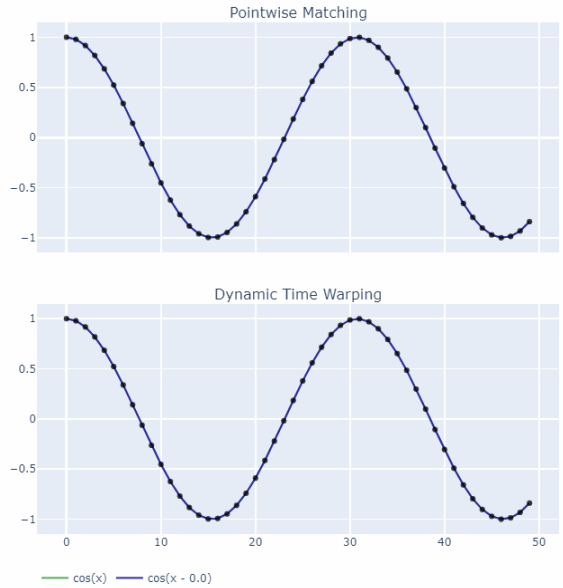
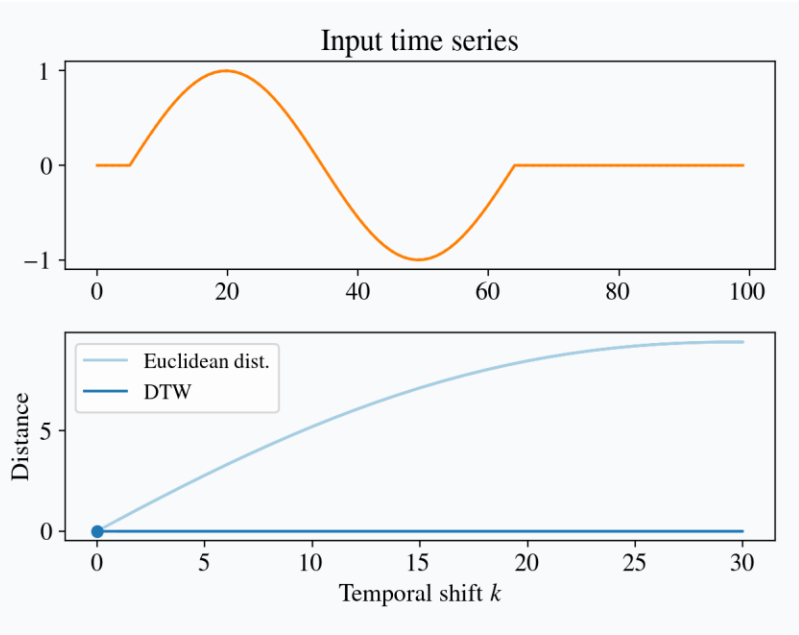
Dynamic Time Warping (DTW)

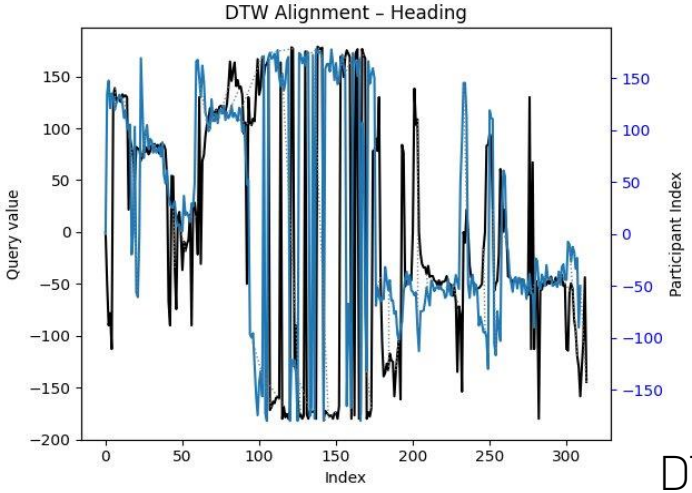




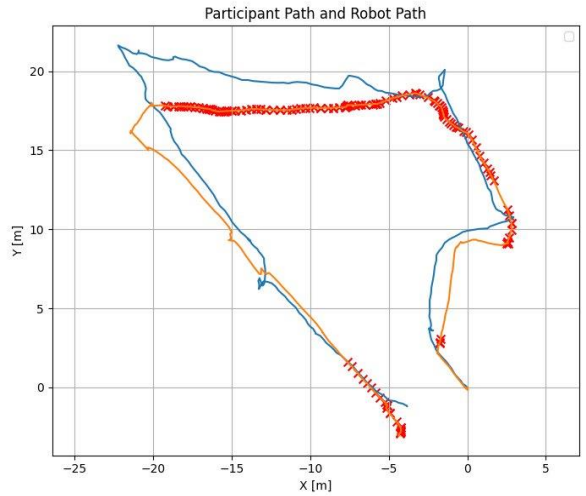


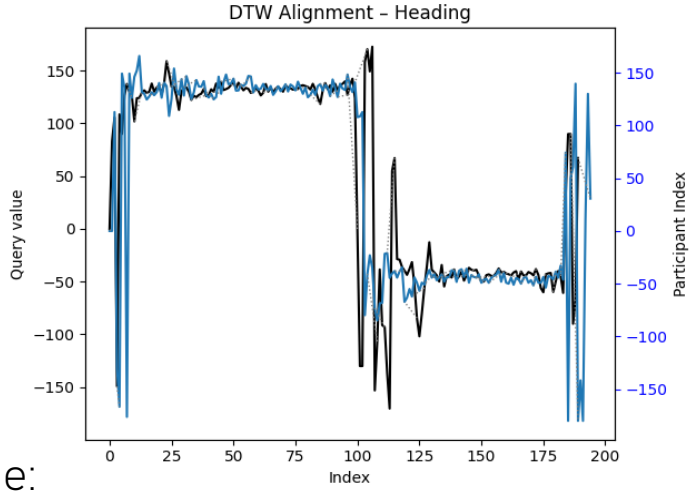
ROMAIN TAVENARD, 2021
DANNY GROVES, 2022

Analyzing data from initial field experiments

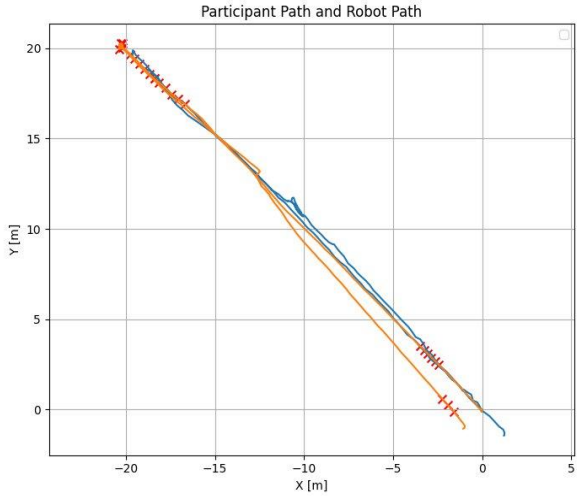


DTW value:
15068



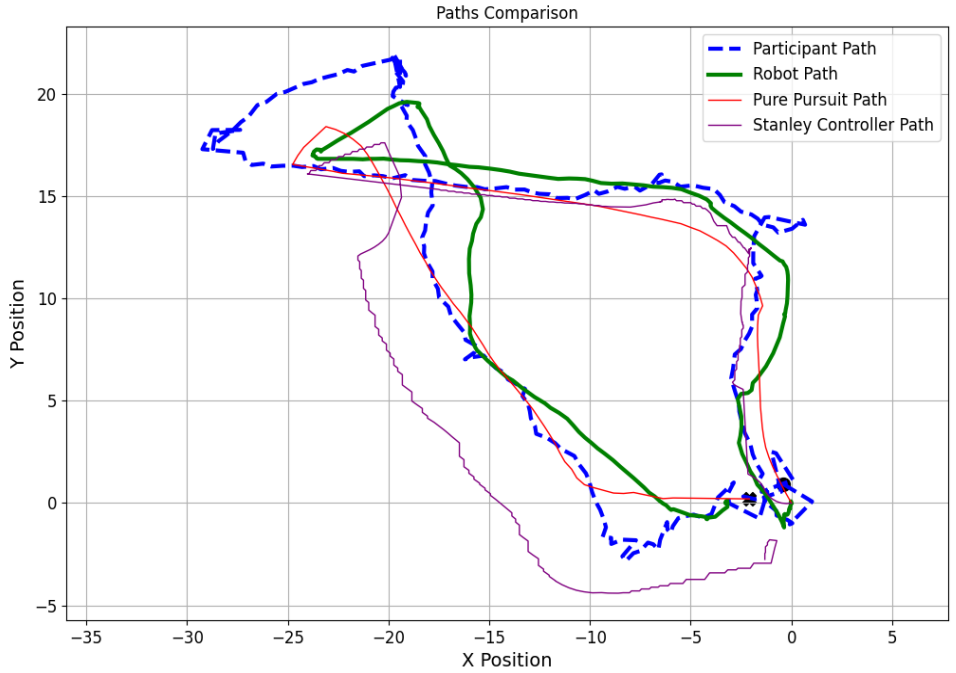


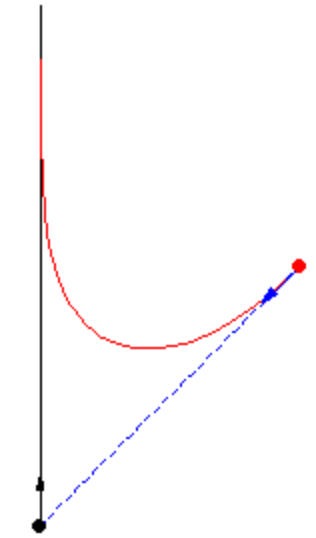
DTW value:
2946



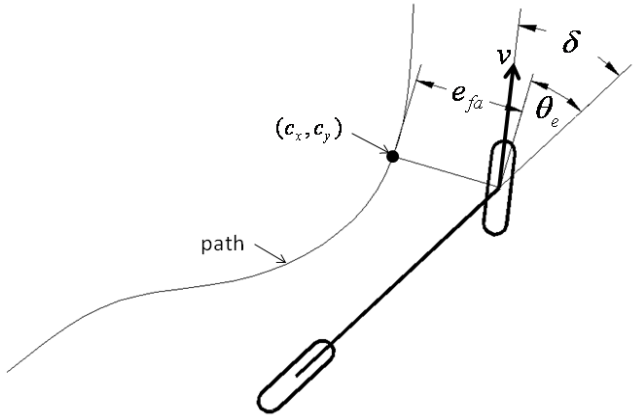
Analyzing high level of synchronization

	DTW value
Operator	21900
Pure-pursuit	4309
Stanley controller	4264





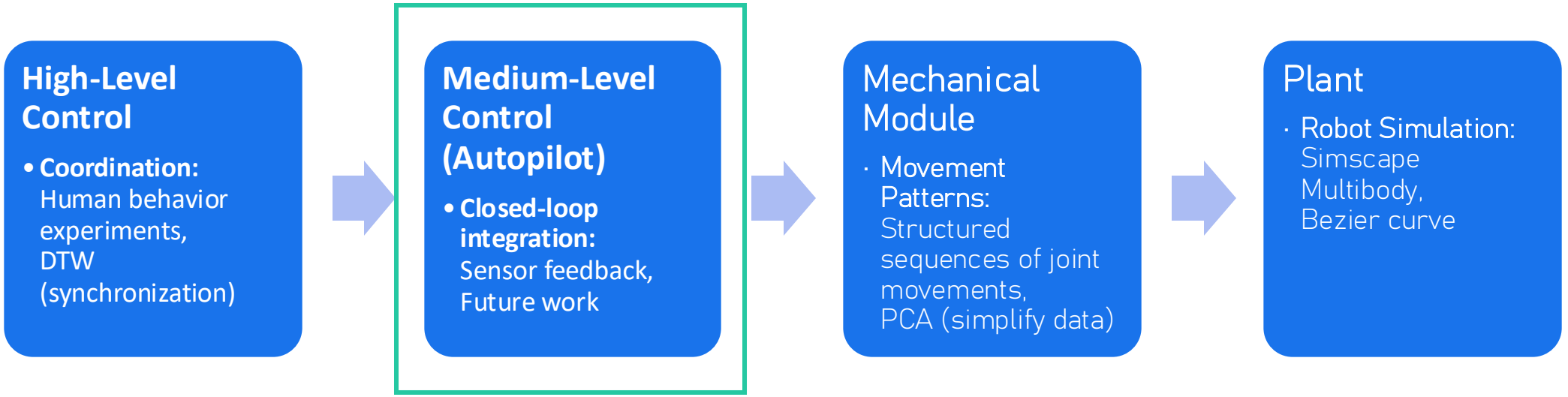
Pure Pursuit: Selects a "look-ahead" point to continuously guide the robot.



Stanley Controller: Minimizes both cross-track and heading errors.

JARROD M. SNIDER, 2009

Roadmap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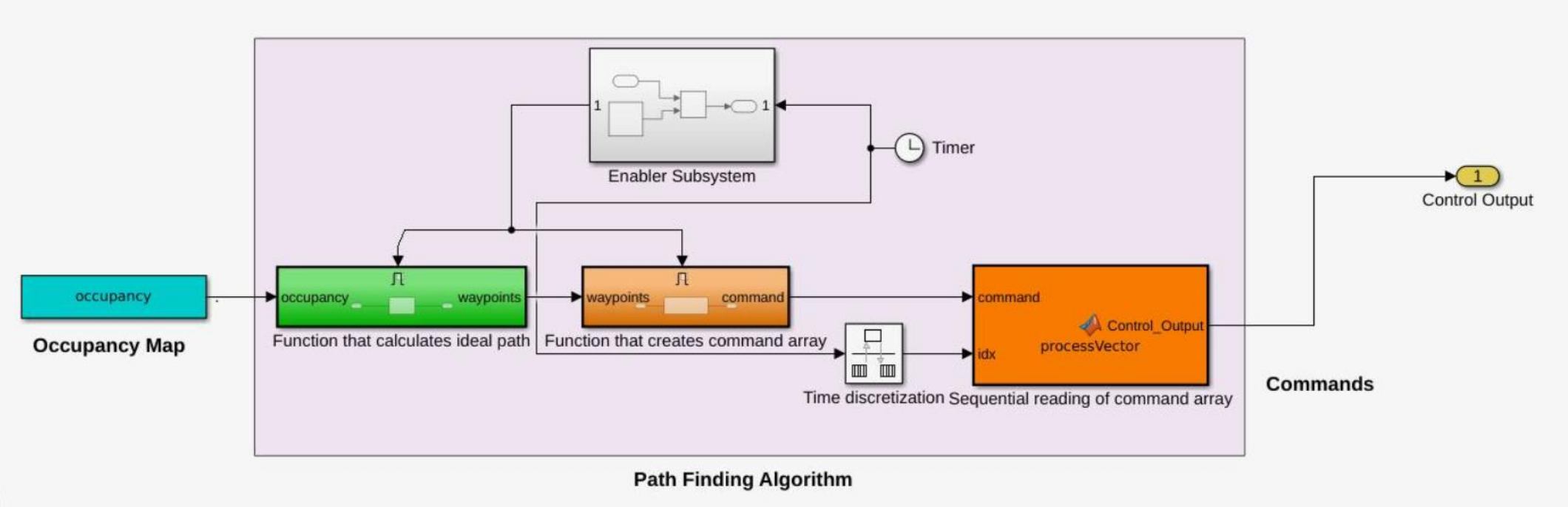
Work in Progress



Future Work

- Capture human movement data and extract movement patterns
- Real-time pattern matching
  Low-level feedforward control integration
- Evaluation and refinement