# EKF Estimation of Stride Width from Individual IMU-Based Foot Trajectories

*EECS 568: Mobile Robotics*

*Team 20*


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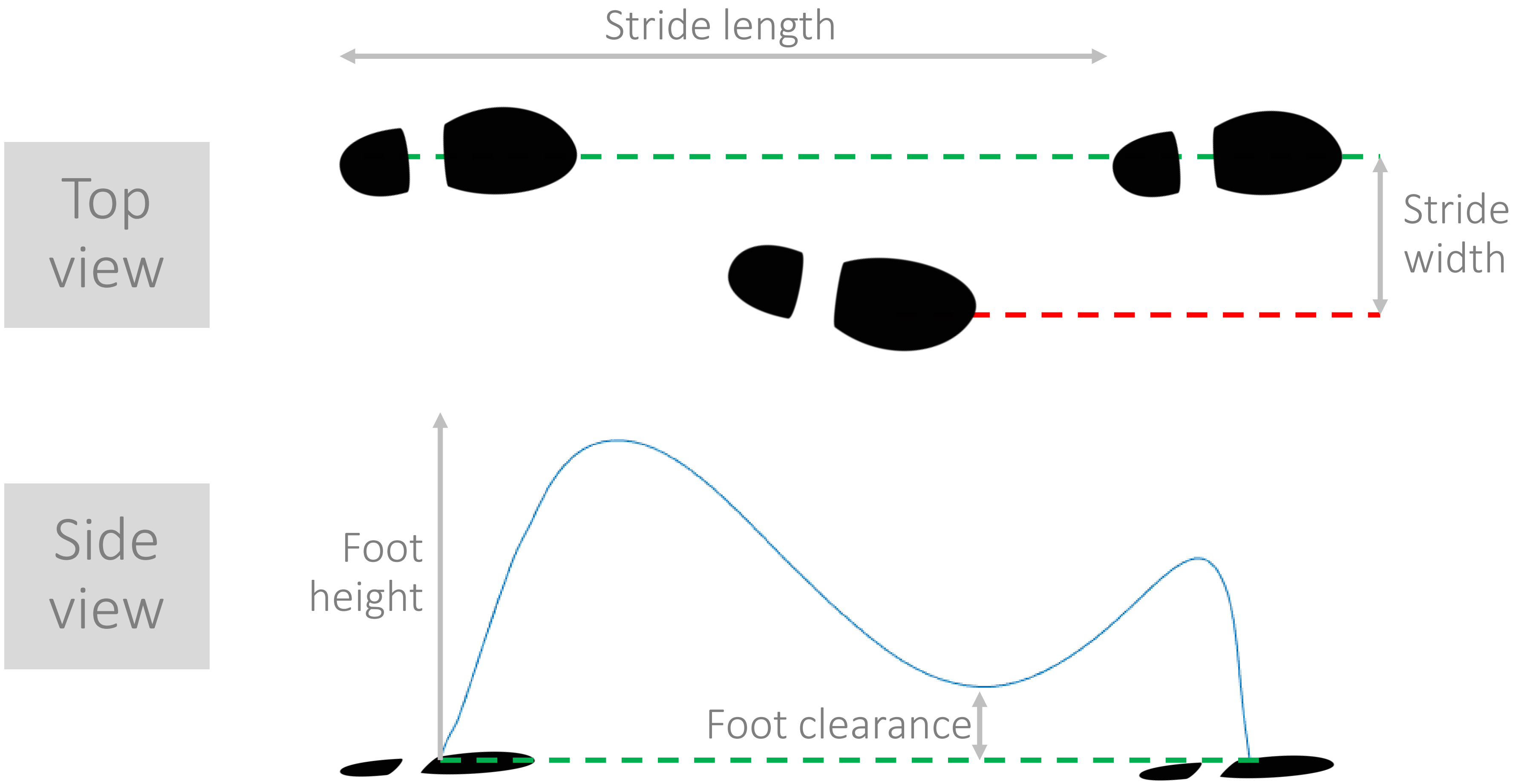
# Motivation

# Stride Metrics



# Individual Foot Trajectory Estimation

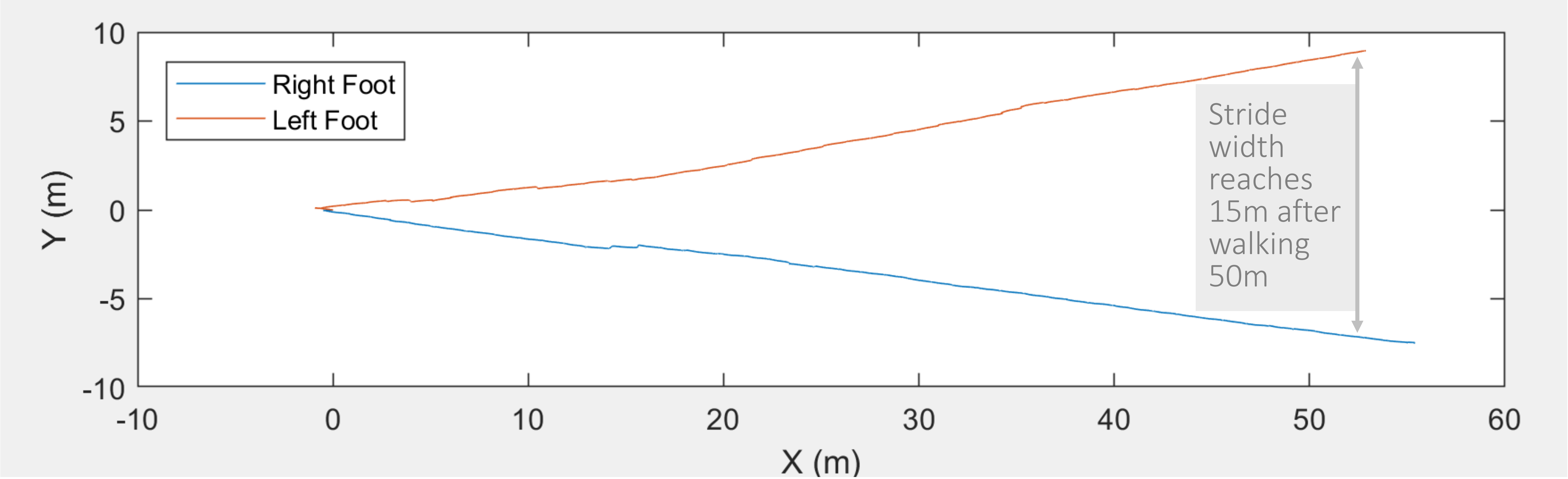
- Integrate foot-mounted IMU data to estimate position
  - Subject to integration drift error
  - Can eliminate integration drift by employing zero-velocity updates (ZUPTs)

- ZUPT-based Foot Trajectory Estimation
  - Each time foot is on the ground, assume it reaches zero velocity
  - Use this assumption to correct for integration drift each stride
  - Demonstrated good accuracy for individual stride metrics (~2% error in total distance travelled) [1]

[1] Ojeda and Borenstein, J. Nav., 2007.

# Individual Foot Trajectory Estimates

- No way for right and left foot IMUs to know where each other are
- Use range measurement to fuse individual foot trajectory estimates



# Models

State

$$\mu = [x_R, y_R, \theta_R, x_L, y_L, \theta_L]^T$$

Control

$$u = [\Delta x_R, \Delta y_R, \Delta\theta_R, \Delta x_L, \Delta y_L, \Delta\theta_L]^T$$

Action Model

$$\mu_t = \mu_{t-1} + \begin{bmatrix} \Delta x_R \cos(\theta_R + \Delta\theta_R) - \Delta y_R \sin(\theta_R + \Delta\theta_R) \\ \Delta y_R \cos(\theta_R + \Delta\theta_R) + \Delta x_R \sin(\theta_R + \Delta\theta_R) \\ \Delta\theta_R \\ \Delta x_L \cos(\theta_L + \Delta\theta_L) - \Delta y_L \sin(\theta_L + \Delta\theta_L) \\ \Delta y_L \cos(\theta_L + \Delta\theta_L) + \Delta x_L \sin(\theta_L + \Delta\theta_L) \\ \Delta\theta_L \end{bmatrix}$$

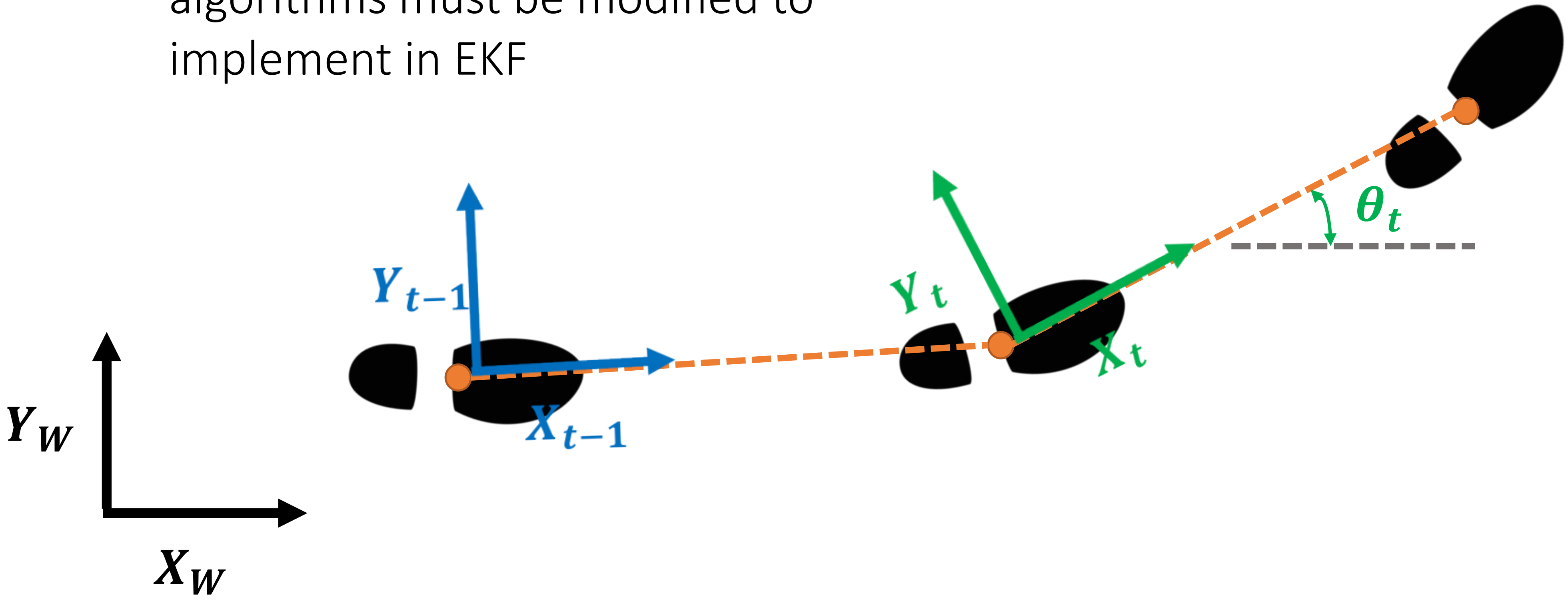
Measurement Model

$$z = \begin{bmatrix} (x_R - x_L)\sin\theta_L - (y_R - y_L)\cos\theta_L \\ (x_R - x_L)\cos\theta_L + (y_R - y_L)\sin\theta_L \end{bmatrix}$$

# Control Input

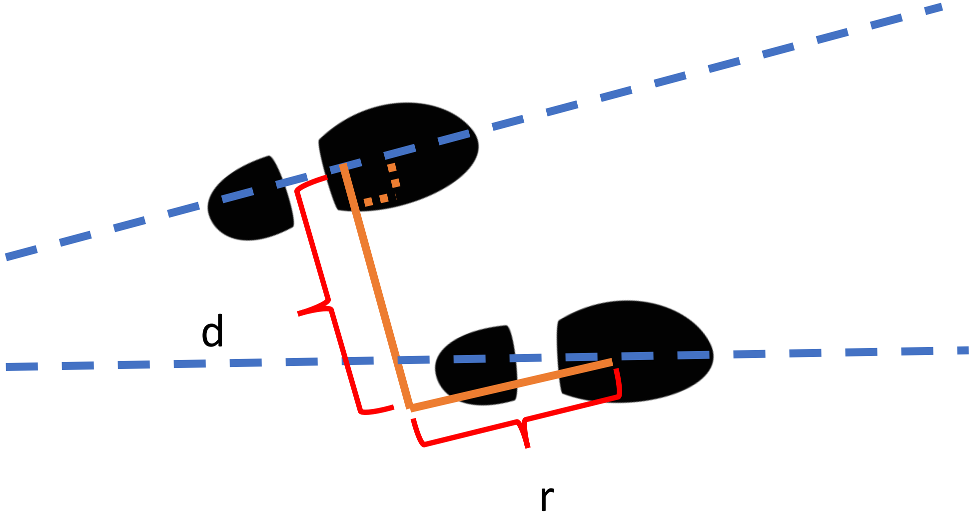
$$u = [\Delta x_R, \Delta y_R, \Delta\theta_R, \Delta x_L, \Delta y_L, \Delta\theta_L]^T$$

- Raw outputs of ZUPT algorithms must be modified to implement in EKF



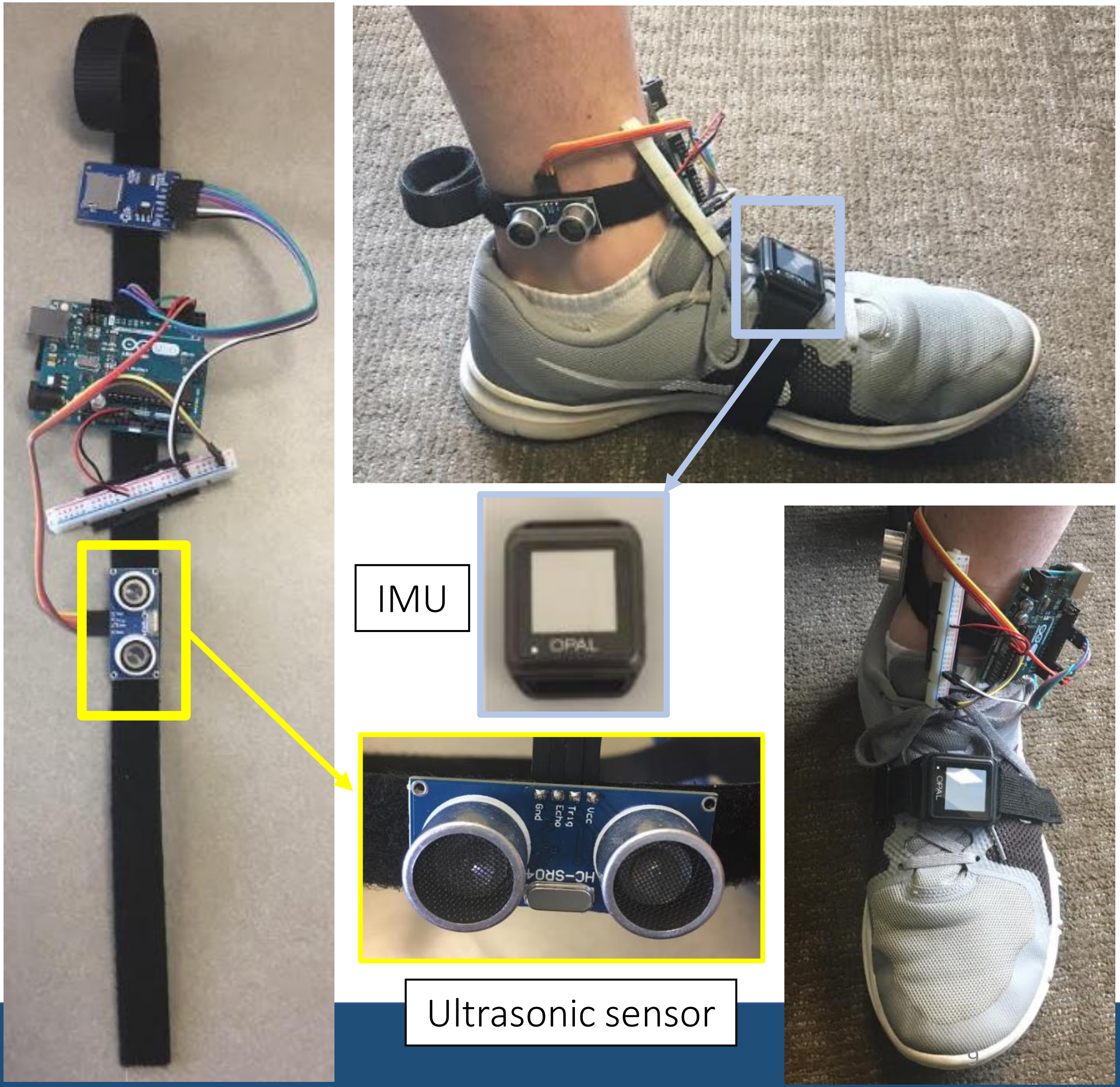
# Measurement Model

$$z = \begin{bmatrix} d \\ r \end{bmatrix} = \begin{bmatrix} (x_R - x_L)\sin\theta_L - (y_R - y_L)\cos\theta_L \\ (x_R - x_L)\cos\theta_L + (y_R - y_L)\sin\theta_L \end{bmatrix}$$

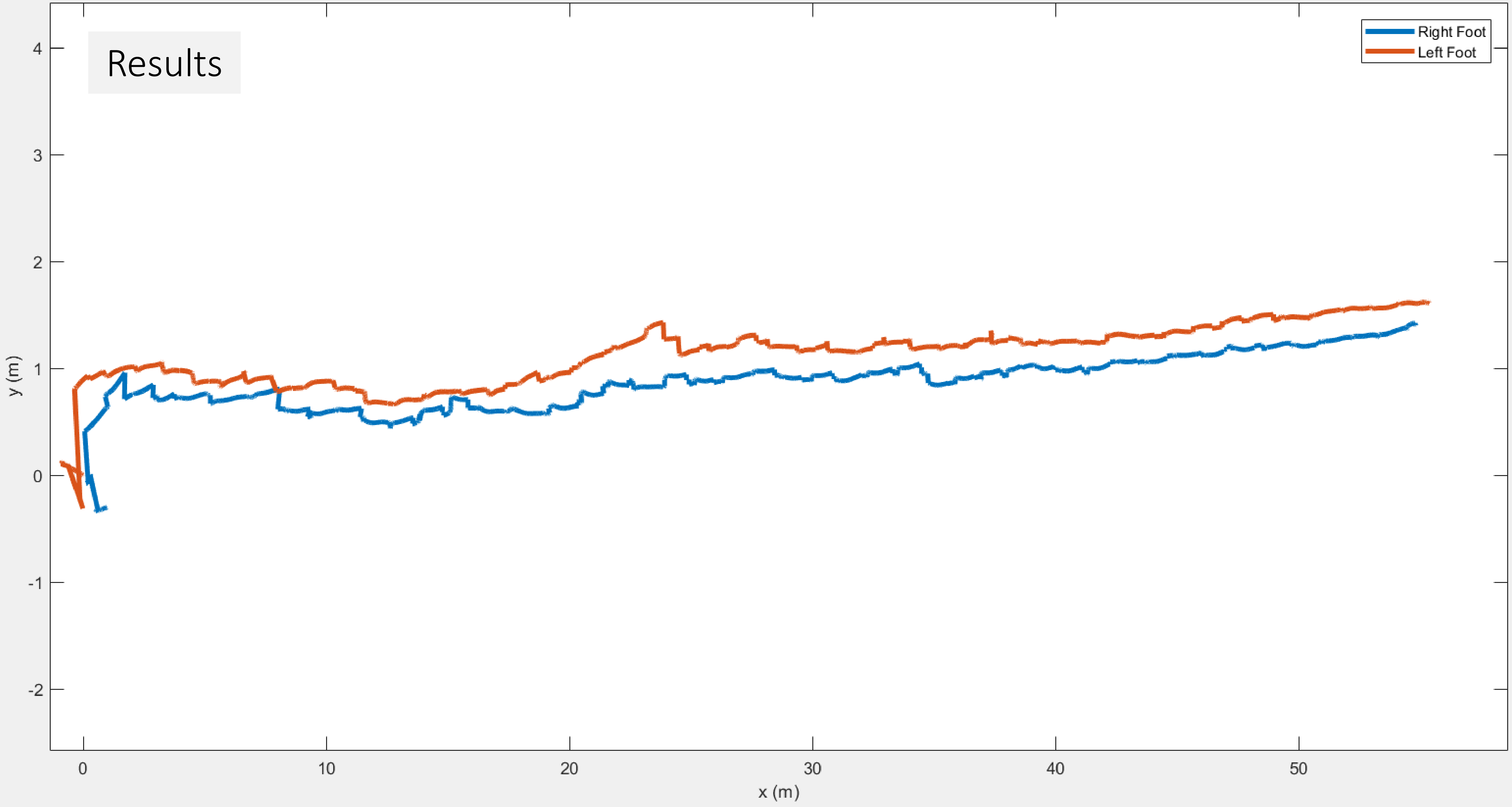


# Experimental Setup

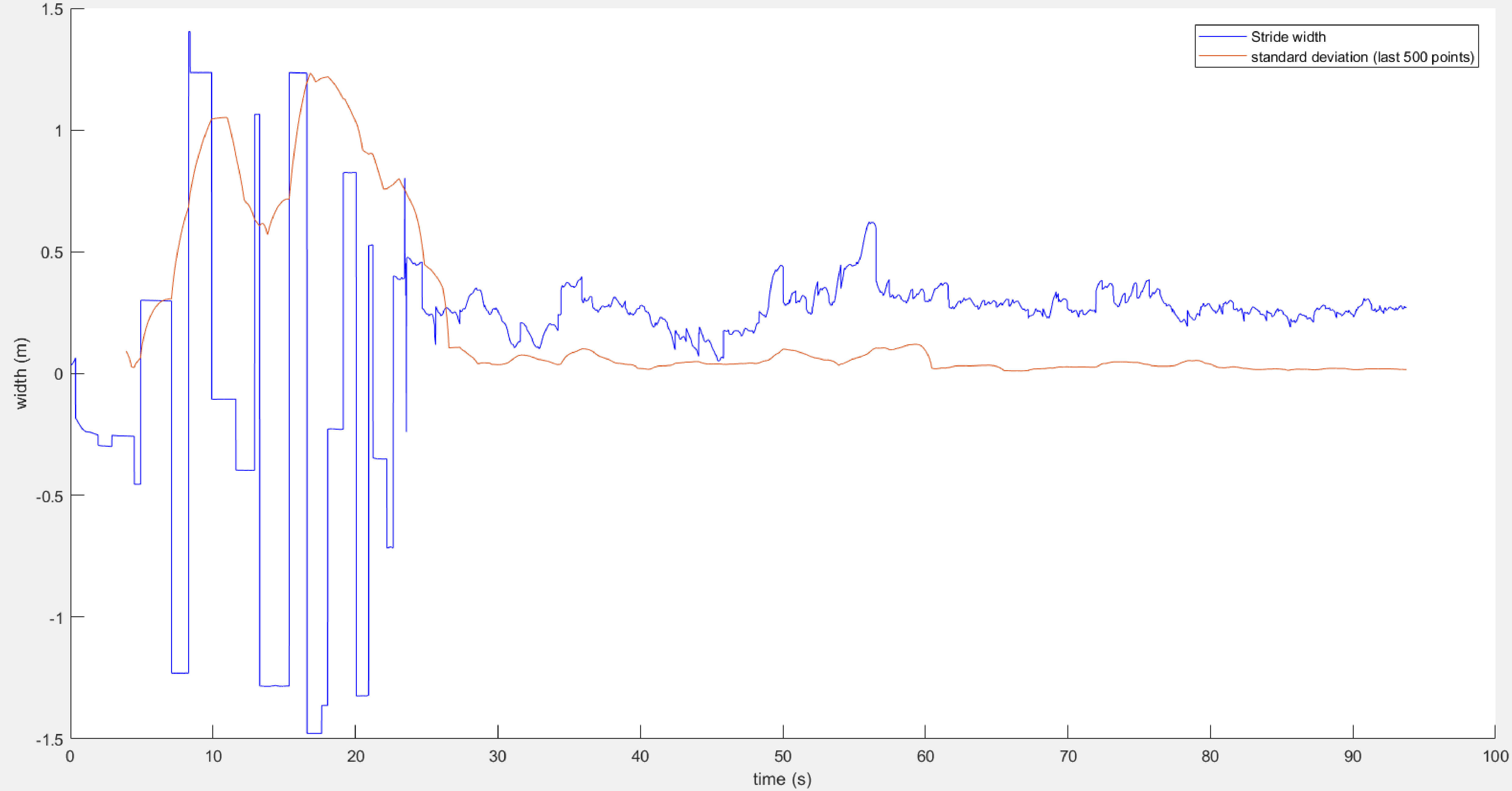
- Ultrasonic sensor to obtain instantaneous distance between two feet (hooked up to Arduino)
- IMU to measure human kinematics
- Walked ~50m down hallway with consistent stride width

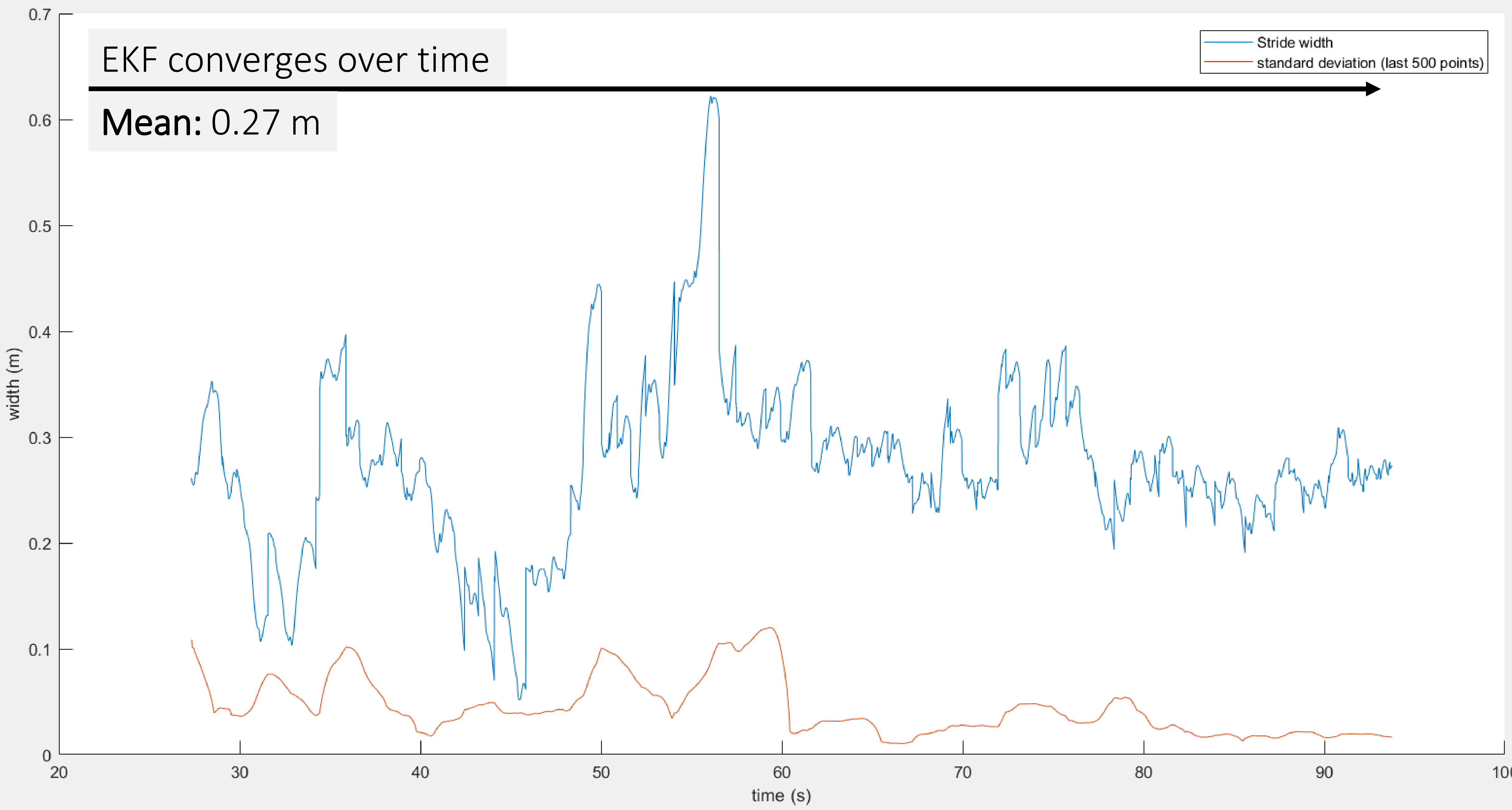


# Results




Right Foot
Left Foot
y (m)
x (m)
4
3
2
1
0
-1
-2
0
10
20
30
40
50
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
24.5
25
25.5
26
26.5
27
27.5
28
28.5
Screenshot is saved to clipboard!
Paste Ctrl+V to paste copied image
1607x876 px, 36 KB
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
48
49
50
51
52
53


Stride width
standard deviation (last 500 points)
1.5
1
0.5
0
-0.5
-1
-1.5
width (m)
0
10
20
30
40
50
60
70
80
90
100
time (s)


EKF converges over time
Mean: 0.27 m
Stride width
standard deviation (last 500 points)
width (m)
time (s)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
20
30
40
50
60
70
80
90
100

# Upcoming Work

- Longer walking trial to demonstrate good long-term accuracy after convergence
- Test performance with turning
- Look into ways to improve initial estimates for faster convergence

Thank You

# Citations

Slide 2


- https://www.active.com/running/articles/25-rules-every-runner-should-follow
- https://www.quora.com/How-does-running-affect-a-soldiers-performance-in-modern-warfare
- http://www.lifealert.com/