AutoGait: A Mobile Platform that Accurately Estimates the Distance Walked

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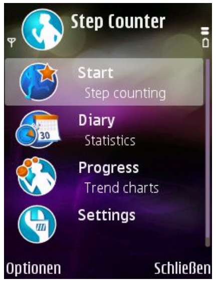
Outline

- Motivation
- Intro to AutoGait & Our Approach
- Prototype Implementation
- Experiment Results
- Summary and Future Work

Pedometers & Applications



- ❑ Can be applied to various applications
  - Pedestrian Dead Reckoning for Indoor Navigation and Outdoor Trajectory Tracking
    - RF-based localization requires infrastructure
    - 3G localization is not accurate
    - GPS doesn’t work indoor environment and consumes lots of battery
  - Activity/Health Monitoring
    - Monitoring Ambulatory Activity
  - etc.

Limitations of existing approaches

- Manual calibration
  : Inconvenient, Erroneous, Tedious

- Use of constant stride length
  : Seriously biasing estimation results

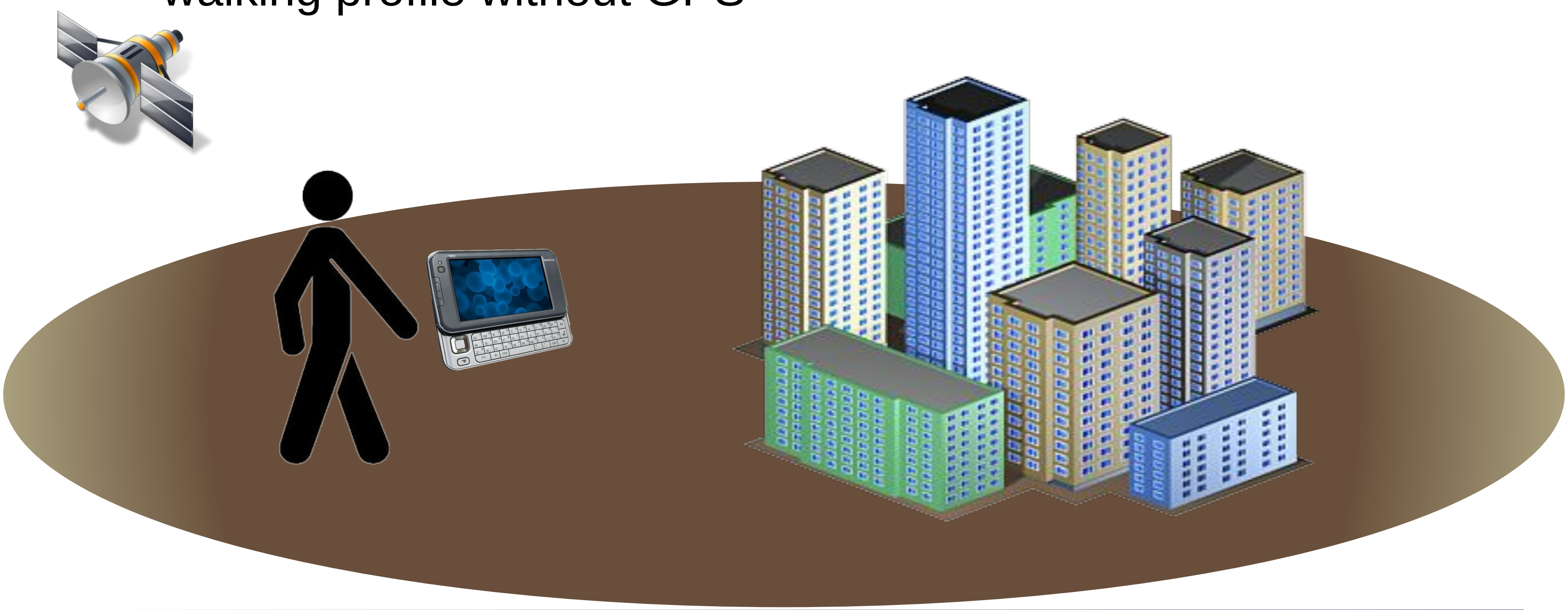
Why accuracy is important?

- Small error in each step could result in a huge difference in estimating total distance walked
  - Experiment results: actual distance walked: 400m, vs. Omron pedometer: 496.3m in slow speeds and 341.6m in fast speeds
  - [5] K. De Cocker, G. Cardon, and I. De Bourdeaudhuij, “Validity of the inexpensive Stepping Meter in counting steps in free living conditions: a pilot study”, Br J Sports Med, vol. 40, no. 8, pp. 714–716, 2006.
- For some applications like indoor navigation/pedestrian dead reckoning system, a few meters of error could account for location misprediction.

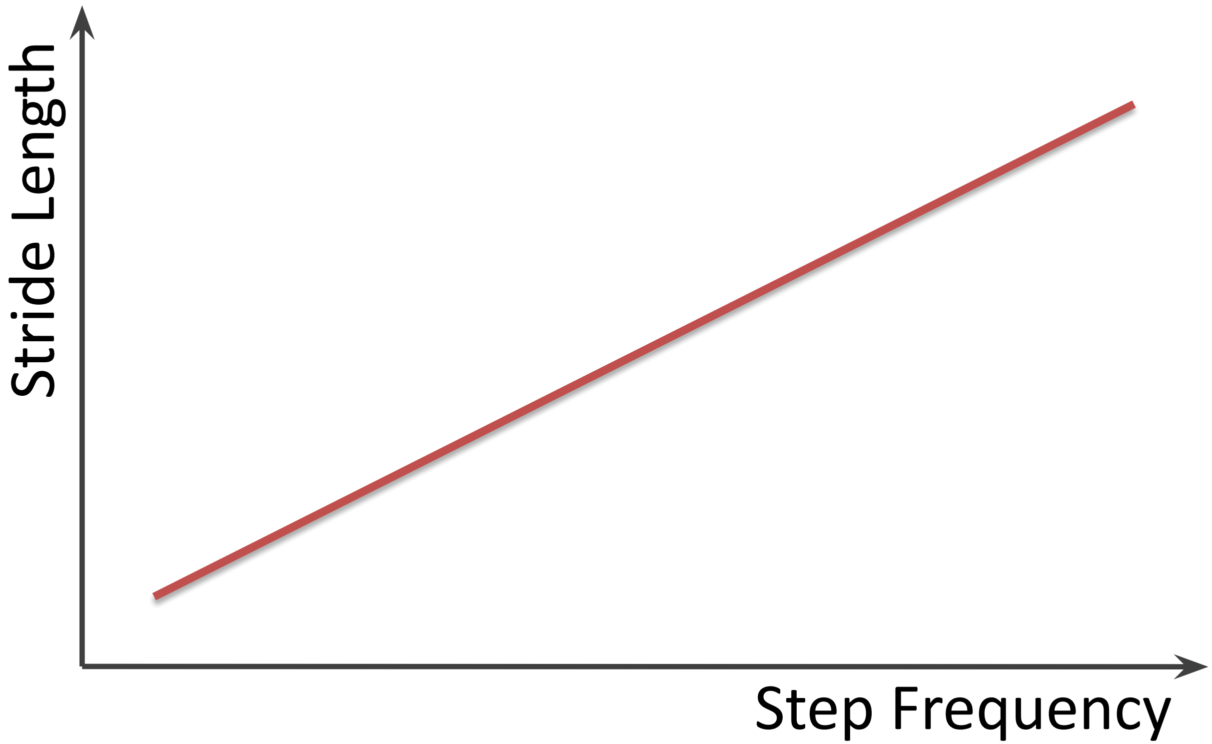
The Goal of AutoGait

A mobile platform that

- *autonomously* discovers a user's walking profile when the user walks outdoors by utilizing the mobile's GPS and the step detector
- *accurately* estimates the distance walked using the calibrated walking profile without GPS

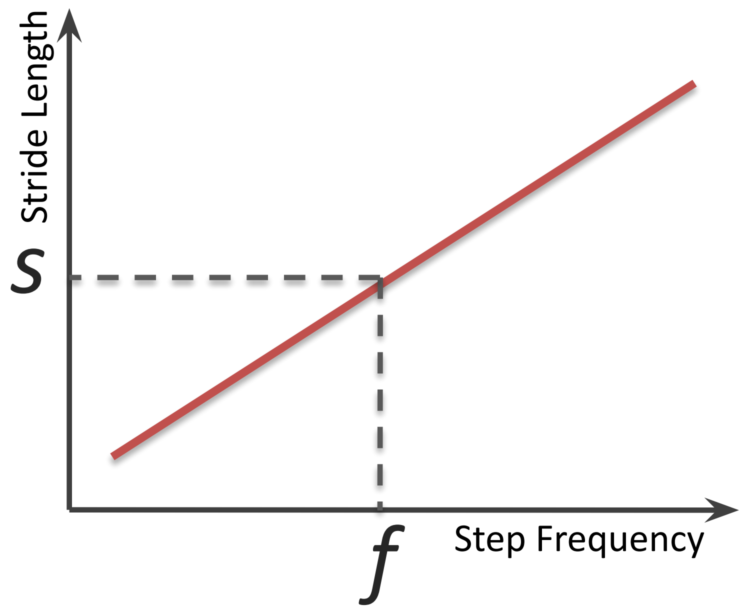


Walking Profile – Variable Stride Length



Physiologists found there is a linear relationship between step frequency and stride length

Estimating Distance Walked

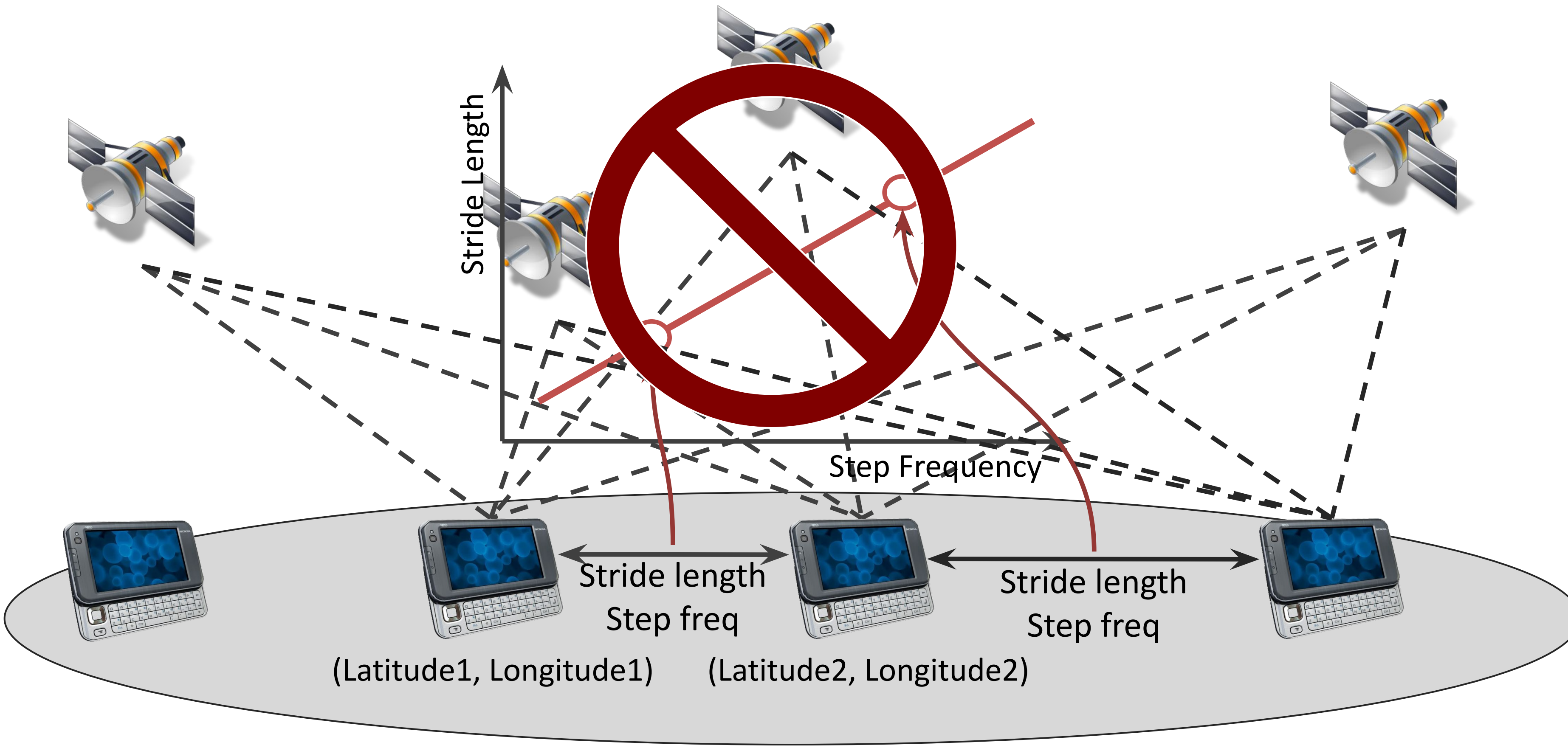


<u>Walking profile</u>

$s = \alpha \times f + \beta$

1. Measure the step frequency (f_i) for each step
2. Calculate the stride: $s_i = \alpha \times f_i + \beta$
3. Add s_i to the cumulative distance walked (D): $D_{new} = D_{old} + s_i$

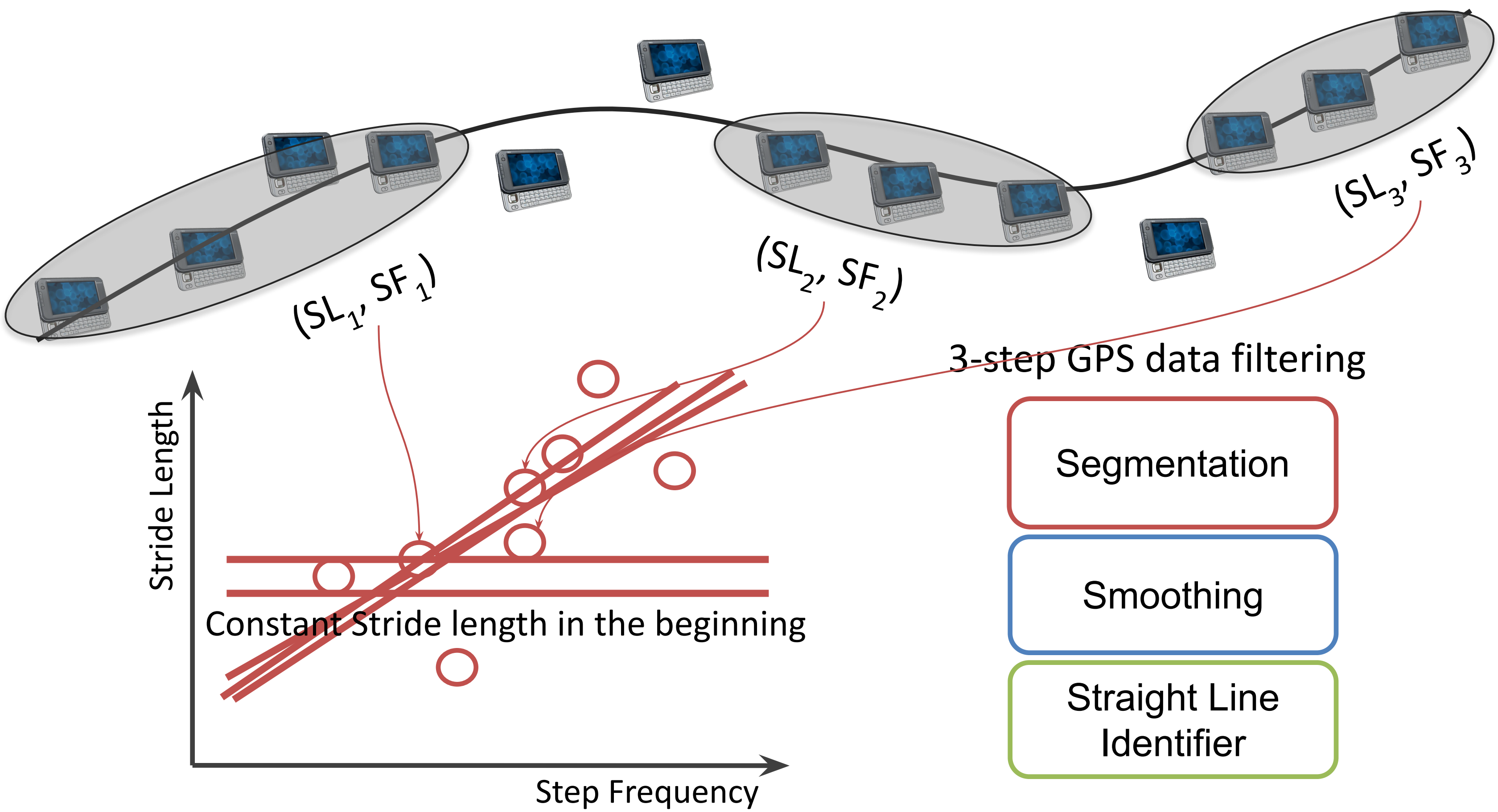
Problem when calibrating with GPS in Mobile Device



GPS in mobile devices have the error range of 5 to 10 *meter*.

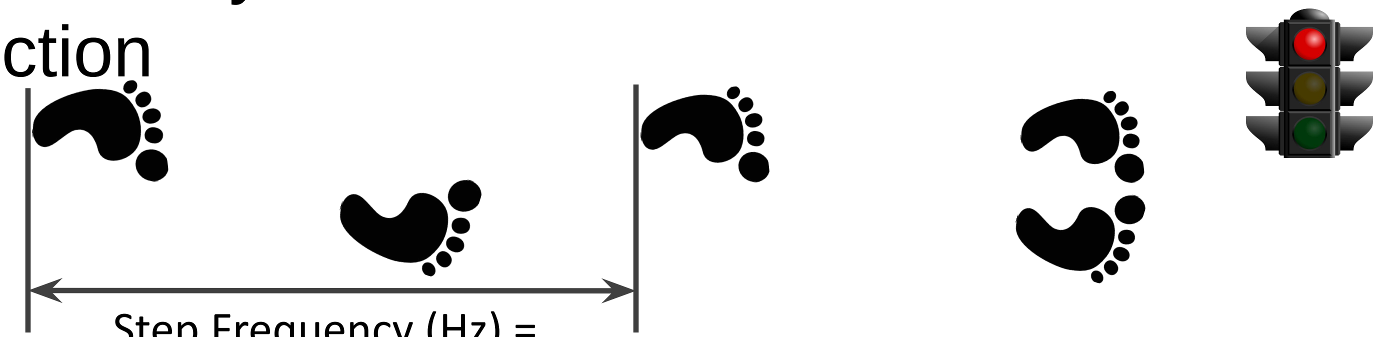
Our Approach

For each cluster, we compute average stride length (SL) and step frequency (SF).



Step 1: Segmentation (Pre-process)

✓ Immobility Detection



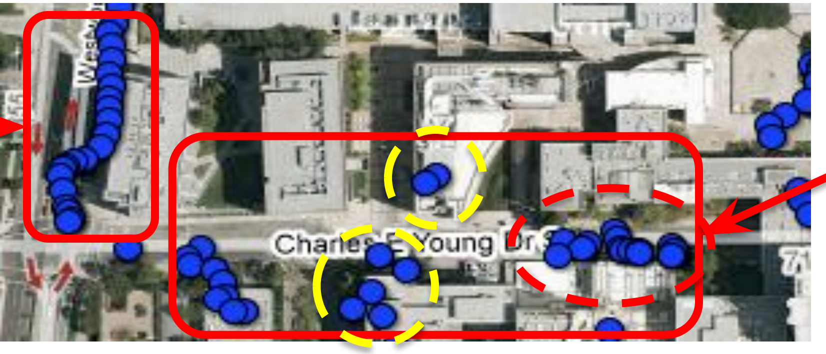
Step interval becomes larger when a user stops.

- Remove edge of two consecutive GPS readings if it contains a step interval is greater than (mean + 3 X standard deviation) of the total step interval

Step 1: Segmentation (Pre-process)

✓ Unrealistic Movement Detection

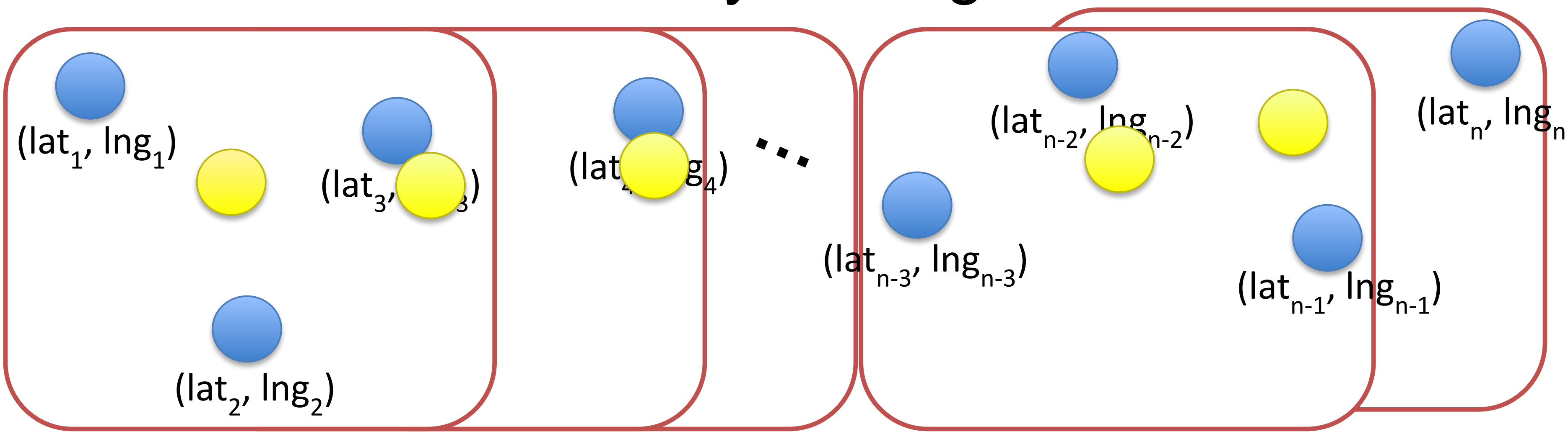
- Environmental obstacles generate sudden jumps in GPS traces
- Remove noisy samples
  1. Speed between two consecutive GPS readings > (mean + 2*standard deviation) of the total speed
  2. Remove sub-segment if it contains a few GPS coordinates



Speed becomes larger when a GPS coordinate jumps due to noise.

Step 2: Smoothing

- Convolution is used for the smoothing
- Each GPS coordinate in the segment is smoothed with only its neighbors



$$(conv\_lat_1, conv\_lng_1) = ((lat_1+lat_2+lat_3)/3, (lng_1+lng_2+lng_3)/3)$$

$$\vdots$$

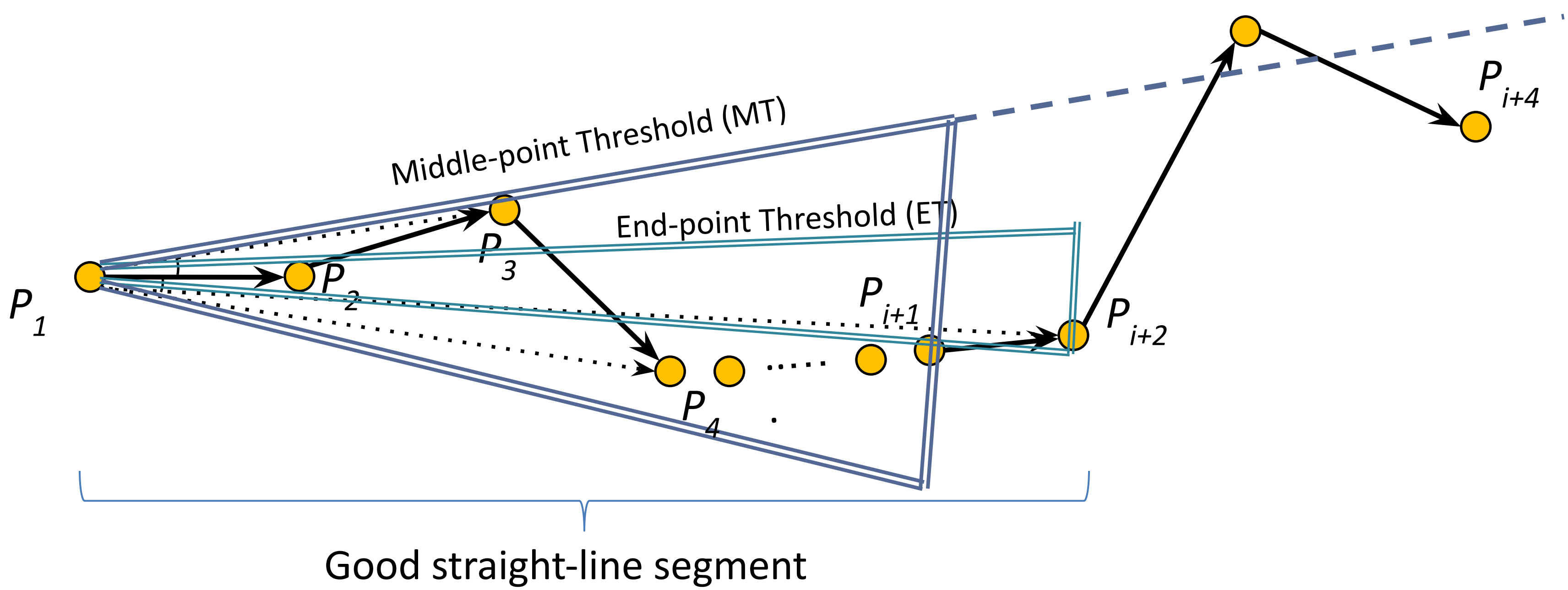
$$(conv\_lat_{n-2}, conv\_lng_{n-2}) = ((lat_{n-2}+lat_{n-1}+lat_n)/3, (lng_{n-2}+lng_{n-1}+lng_n)/3)$$

Step 2: Smoothing

- However -
  - Some of noisy GPS readings still remain
  - Smoothing makes sharp corners dull and round

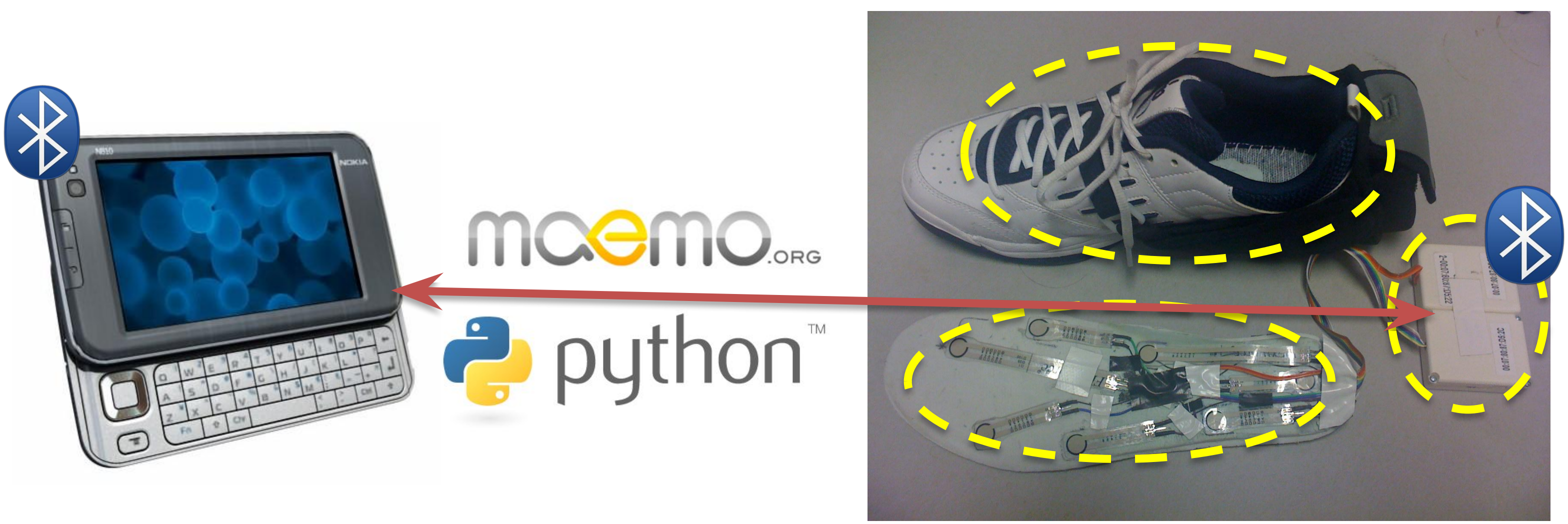
Step 3: Straight-Line Identifier

- Heading Change-based filtering: focus only on walking patterns in straight-line roads
- C_i: Δ angle between edge (P_1, P_2) and edge (P_1, P_{i+2})
- Find max i where $C_1 \ldots C_{i-1} < MT$, $C_i < ET$

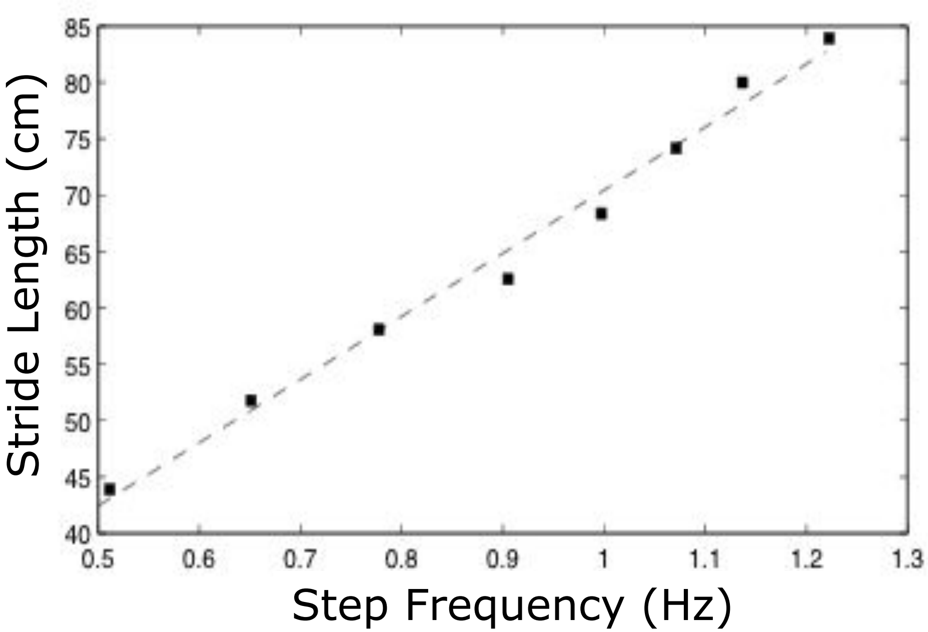


Prototype Implementation

- Nokia N810 using Linux Python and GPS
- Pedometer Implementation
  - Pressure Sensors in UCLA SmartShoe platform
  - MicroLEAP acquires sensor data and transfers it using Bluetooth



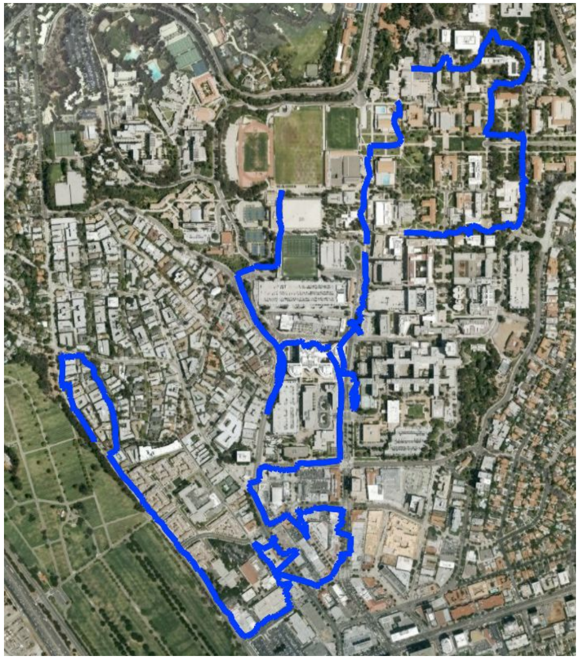
Linear Relationship Verification



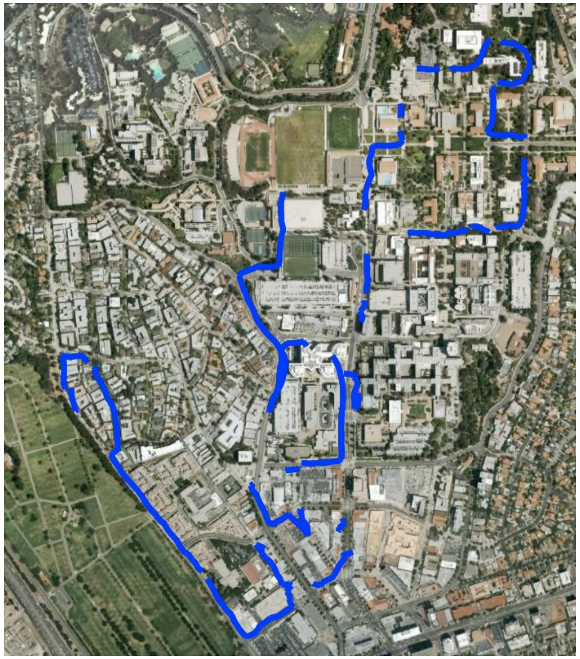
Speed (mph)	Frequency (Hz)	Stride length (cm)
1.0	0.51	43.90
1.5	0.65	51.79
2.0	0.78	58.07
2.5	0.91	62.55
3.0	0.10	68.37
3.5	1.07	74.17
4.0	1.14	80.00
4.5	1.22	83.93

- Measured on a treadmill
- Two hundred steps per each speed
- A line generated using the linear regression
- Sample points are very close to the line

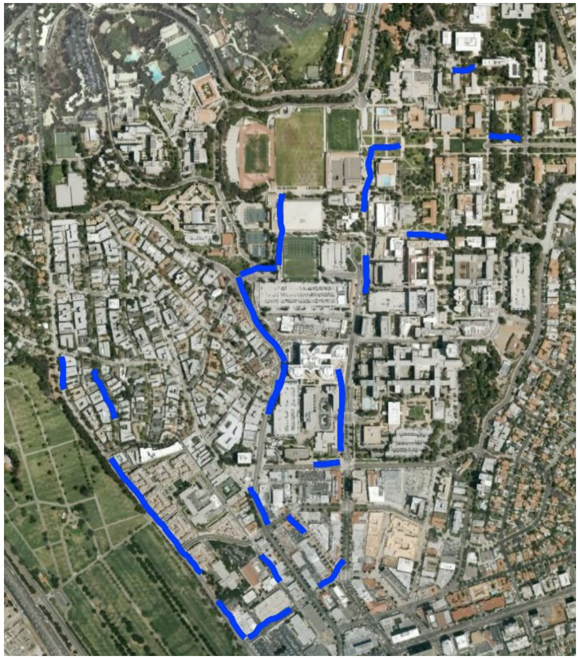
Identifying Straight-Line Segments



(a) Raw GPS Data



(b) Effect of Segmentation and Smoothing

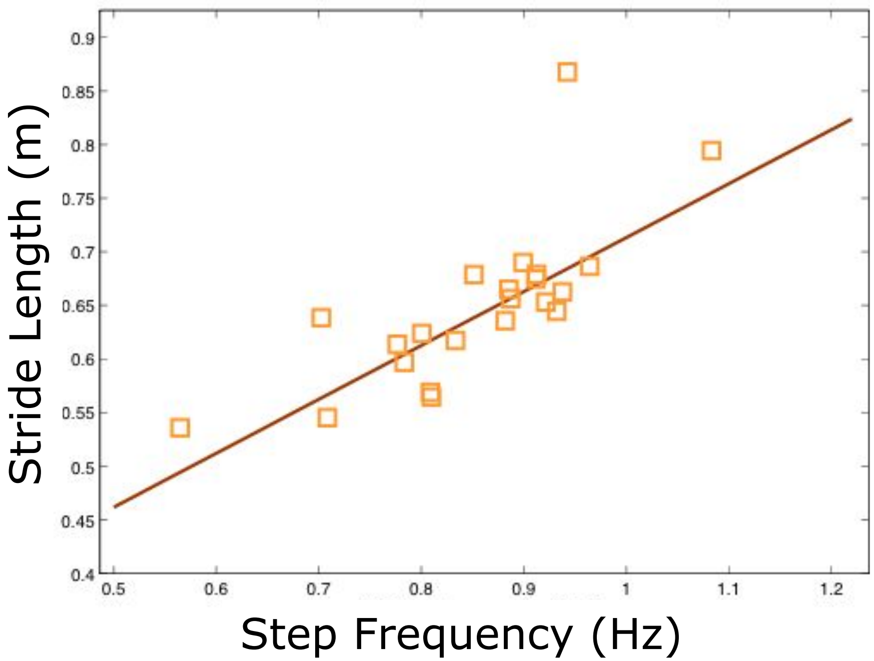


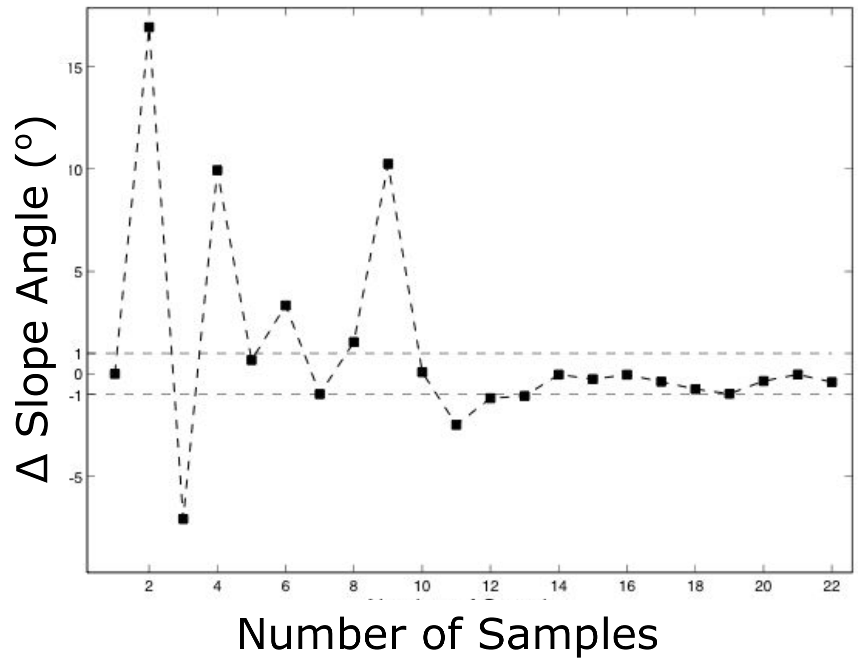
(c) Heading Change based Filtering

- A dataset obtained by walking near the UCLA campus
- 6 routes (trials), 26 straight lines were detected

Linear Profile Calibration

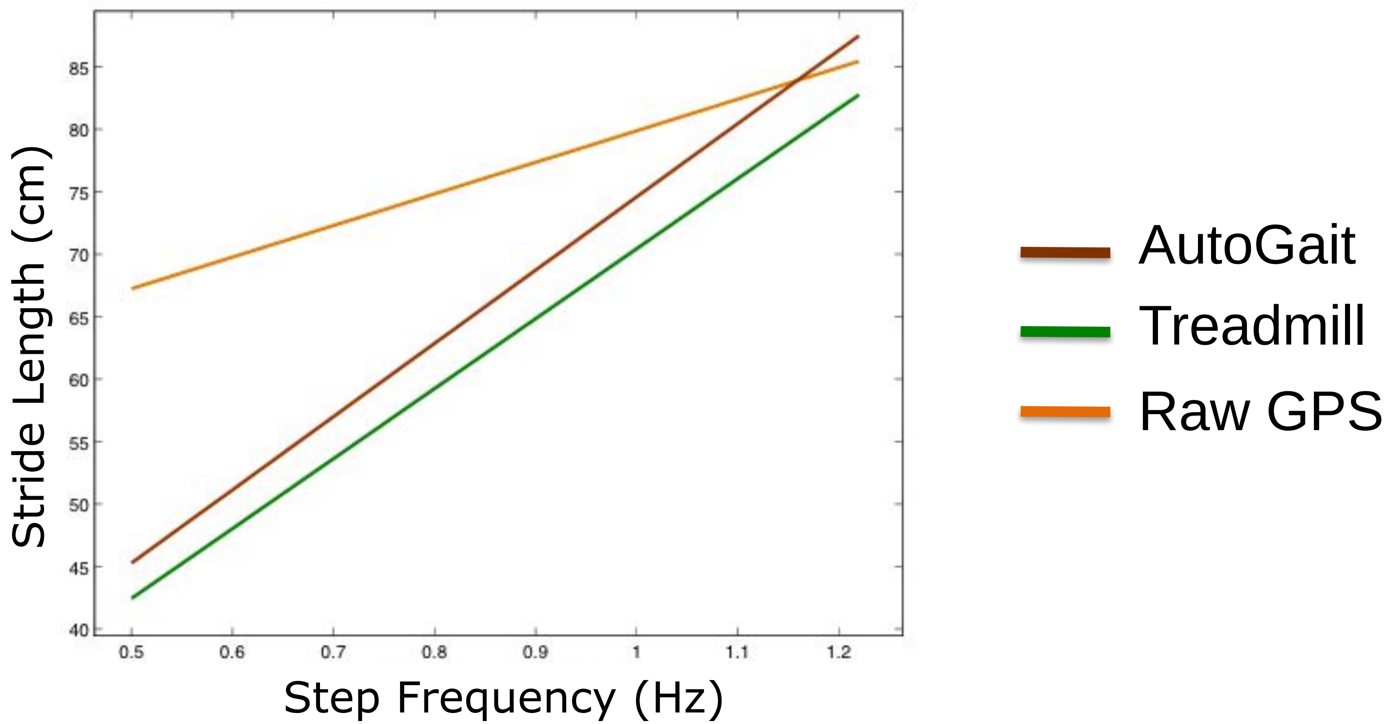
- As number of samples increase, the slope variations gradually converge.
- We terminate the calibration process when the slope variation sequentially stays within ±1^{o} over multiple time periods.
- Once the calibration is done, the system turns off the GPS module and uses the calibrated profile to estimate the distance walked.





Effectiveness of GPS Filtering

- The lines generated by AutoGait and Treadmill are following similar slope
- AutoGait is above the Treadmill because the stride length increases when the user walks on the ground compared to the treadmill
  - H. Stolze, J. P. Kuhtz-Buschbeck, C. Mondwurf, A. Boczek-Funcke, K. Jhnk, G. Deuschl, and M. Illert, “Gait analysis during treadmill and overground locomotion in children and adults,” *Electroencephalography and Clinical Neurophysiology/Electromyography and Motor Control, vol. 105, no. 6, pp. 490 – 497, 1997.*
- The raw GPS significantly overestimates the stride length due to the noise



Validation: Field Test

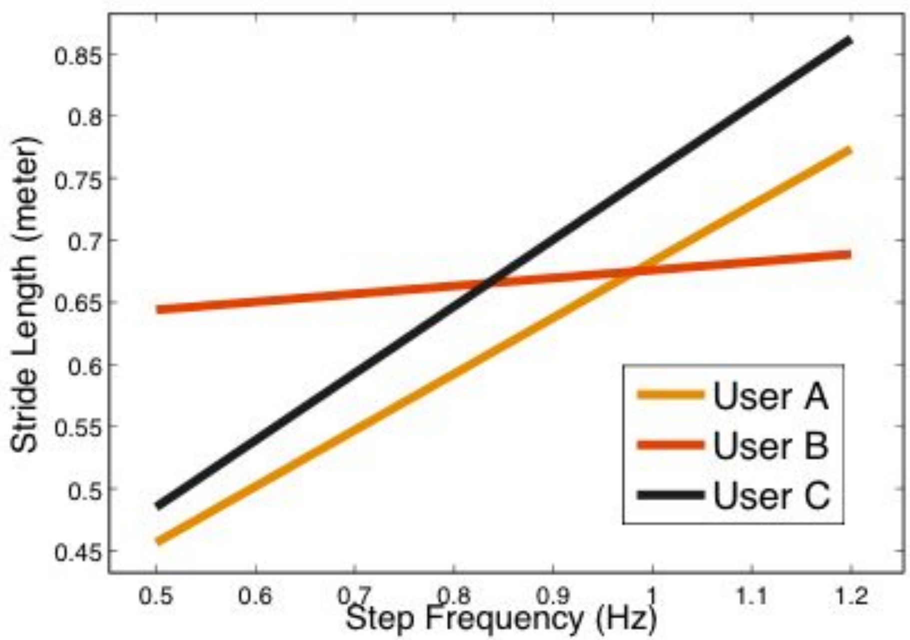
- AutoGait outperforms the constant stride length-based method both at slow speeds and at fast speeds.
- Considering the state of arts such as Nike+Apple Shoe or Omron pedometer uses the constant stride length, AutoGait can enhance the accuracy.

Speed		Slow	Moderate	Fast
Distance (*m*)		400	800	400
Lap Time		9:56	11:52	3:45
# of Steps (Ground truth)		718	1192	488
AutoGait	Est Dist (*m*)	395.9	795.4	396.3
	Error Rate	**1.02%**	**0.58%**	**0.93%**
Constant Stride Length (70 *cm*)	Est Dist (*m*)	502.6	834.4	341.6
	Error Rate	**-25.7%**	**-4.3%**	**14.6%**

Testing on Multiple Users

- ❑ Three people participated (A, B, and C)
- ❑ Walking Profile Calibration:
  - Casually walked around the UCLA campus
  - α and β are different for individuals – the profile should be personalized
- ❑ Validatic
  - Walke

Particip	C
α (SL	0.539
β (SL	).2156
Est Dist	l616.9
Error R	1.06%



Summary and Future work

- Developed a mobile platform that autonomously find the variable stride length, which can be used to accurately estimate the distance walked
- Implemented prototype using Nokia N810
- Extensive experiments significantly lower the error rates, achieving more than 98% accuracy in our testbed scenarios
- Future work
  - Outdoors and indoors detection
  - Consideration of physiological factors
    - In case of running
    - Walking uphill and downhill - Altitude

Thank you

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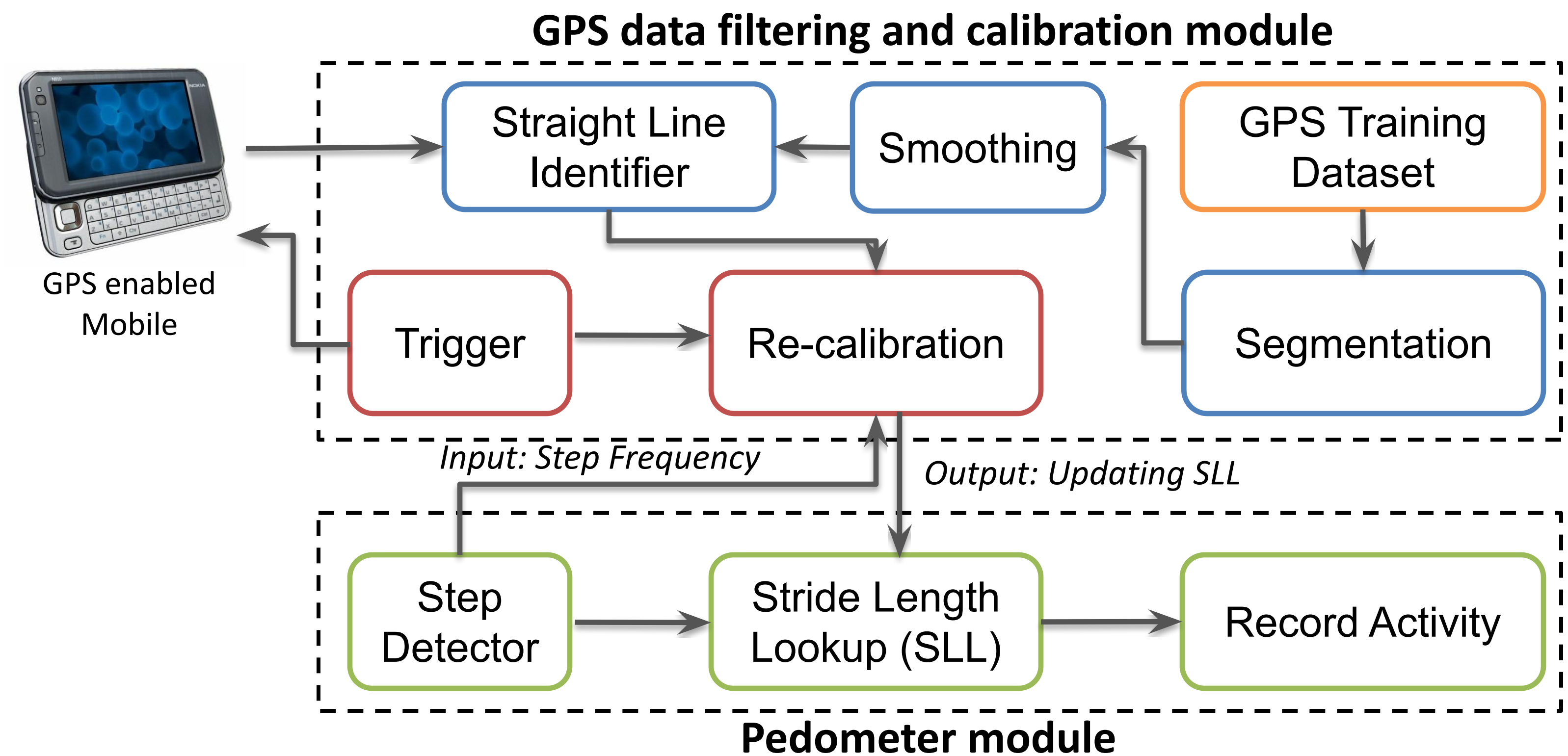
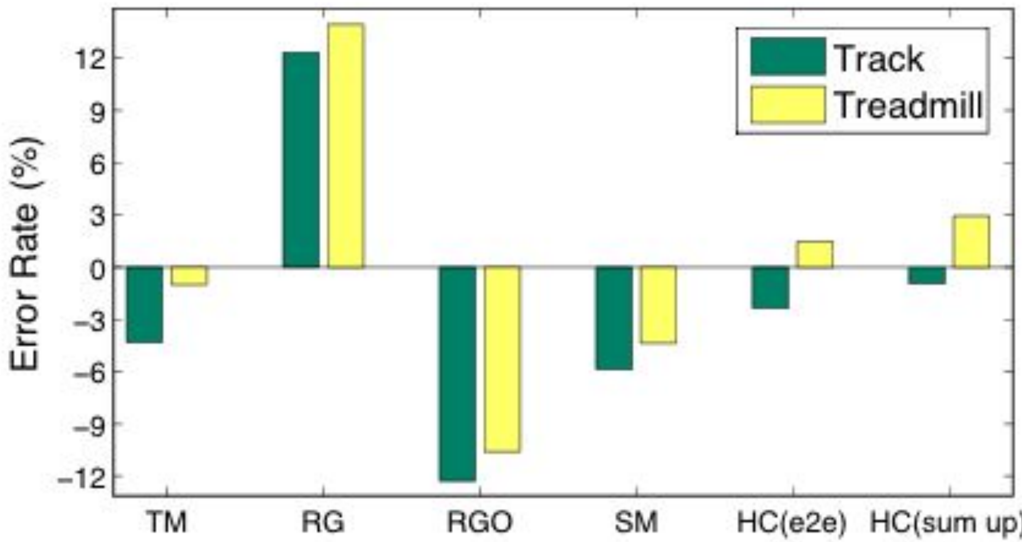
Appendix

AutoGait Architecture

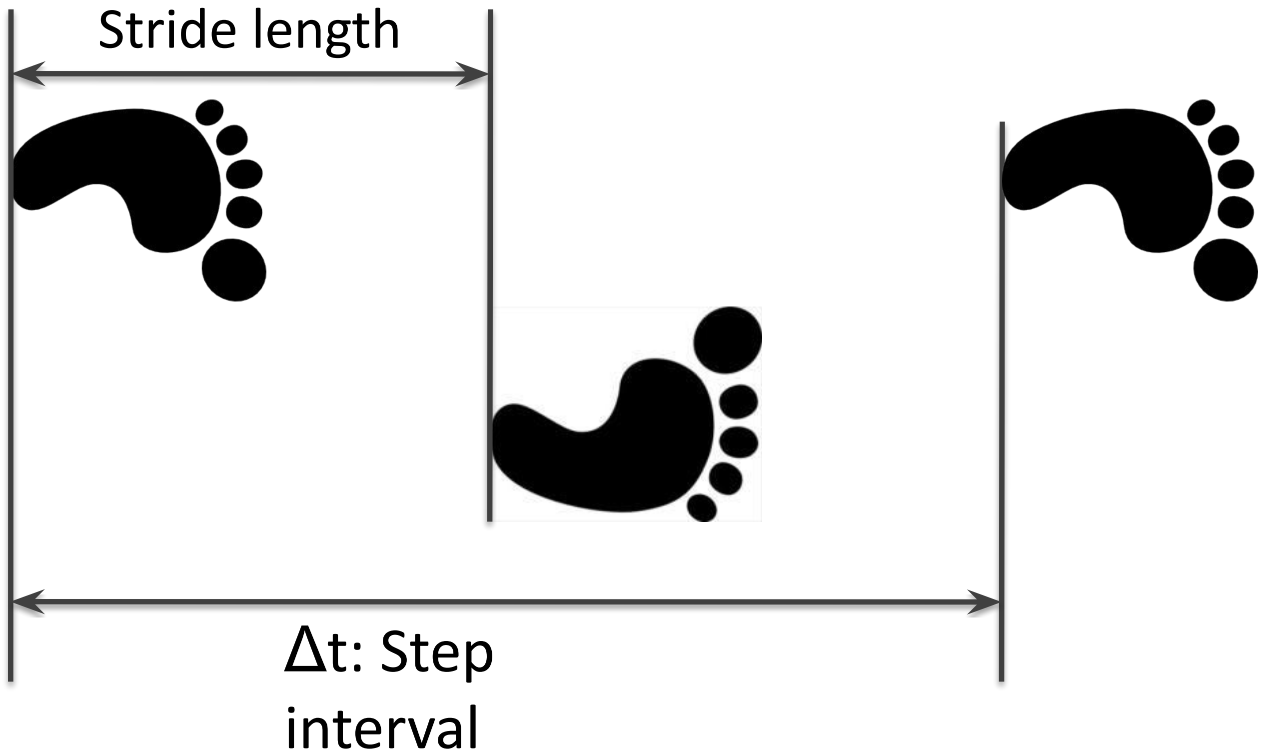


Validation: Field Test (1)



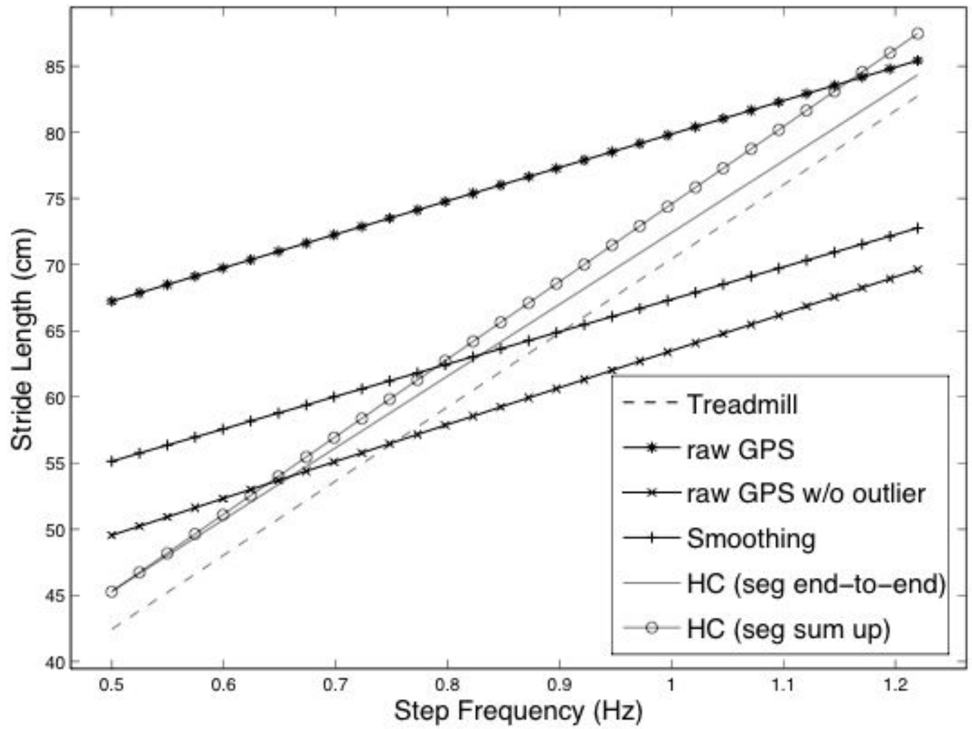
- High error rates for RG and RGO
- SM underestimates the distance traveled
- The *sum up* method performs two times better than the *end-to-end* method in the track test
- The *sum up* method works four times better than TM in the track test, but the TM performs three times better than the *sum up* method in the treadmill.
    - Implying the SLL should be discovered outdoors for a better estimation

Terms



Step Frequency = 1/Step interval

Effectiveness of GPS Filtering



- The lines generated by two HC methods are above the Treadmill but they are following similar slope
- Two HCs are above the Treadmill because the stride length increases slightly when the user walks on the ground compared to when the treadmill
- The raw GPS significantly overestimates the stride length

Benchmark Studies

	Omron Pedometer (HJ-720ITC)			Nokia Step Counter		
Speed	Slow	Moderate	Fast	Slow	Moderate	Fast
Found Steps	709	1190	488	266	1051	456
Est Dist (*m*)	496.3	833	341.6	181.7	717.8	311.4
Error Rate	-24.08%	-4.13%	14.6%	54.6%	10.3%	22.1%

400 m Test	Without Calibration			With Calibration		
Speed	Slow	Moderate	Fast	Slow	Moderate	Fast
Lap Time	8:41	5:08	3:26	8:21	4:59	3:34
Est Dist (*m*)	160	460	390	290	410	360
Error Rate	-60%	15%	-2.5%	-27.5%	2.5%	-10%

- ❑ Accelerometer based pedometer may not detect the steps at slow speeds.
- ❑ The Nike shoes use a constant stride length for estimating the distance walked.

Discussion & Future Studies

- Low-acceleration problem of Accelerometer-based pedometers
- Outdoors and Indoors detection
- AutoGait on Indoor Navigation Systems
- Consideration of Physiological Factors