Ubiquitous and Mobile Computing
CS 525M: AutoGait: A Mobile Platform that Accurately Estimates the Distance Walked

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Introduction/Motivation:

What was the main problem addressed?

- Many mobile apps require location and motion information as a fundamental building block of their system, and they need it to be both accurate and energy efficient.
- GPS based systems are expensive in energy use, unreliable indoors, and not very accurate (8m).
- DGPS is accurate (10cm) but requires special HW
- Accelerator-based dead reckoning systems (counting steps, tracking time, and assuming fixed stride) are unable to provide accuracy.

Introduction/Motivation:
Why is the problem solved important?

- Accurate estimation of distance walked is a critical enabler for many mobile applications
  - Pedometers (Navigation and Health monitoring)
  - Indoor navigation systems (Escort system presented earlier this semester)

Introduction/Motivation:
How will the solution be used eventually?

- The solution will provide, on both phone and dedicated HW:
  - More accurate pedometer operations tracking how far someone has walked
  - More precise locations of a user to any app needing to locate individuals, whether indoors or outdoors
  - Longer mobile operations because of reduced need to charge a device depleted by GPS use

Introduction/Motivation:
What will be learned?

- The authors wish to show that the constant stride length used in conventional systems is the major source of error in distance and location determinations.
- The authors wish to prove that their system can dynamically determine stride length, and when combined with a step counting system, provide much more accurate distance and location determinations.
- The authors also hope to demonstrate that their system can self calibrate using only occasional GPS access.

Related Work:
What else has been done to solve this problem?

- Previous class paper on the Escort system.
  - Escort uses a fixed stride length, dead reckoning system
  - Accumulating location drift error was a significant problem.
  - A fixed audio beacon served as a local origin and used to generate corrective path and location information that allowed location to within 8m within a building.
- RF based fingerprinting
  - *WiFi (Actually Cell Towers) – The bus arrival esti*mator
  - RFID tagging – Connecting Conference attendees
  - Bluetooth

Related Work:
What else has been done to solve this problem?

- One paper proposed using double integration of raw accelerometer data to determine distance. The Escort paper showed that double integration introduces a growing and substantial error in location.
- Calibration of walking profiles generated on a treadmill.
- Solutions using DGPS. Fine for guiding semi-autonomous farm equipment, but not for light mobile equipment.
- Ultrasound sensors to measure stride length. Additional sensors, and issues with interference and noise.

Related Work:

How is the approach proposed in this paper different or novel?

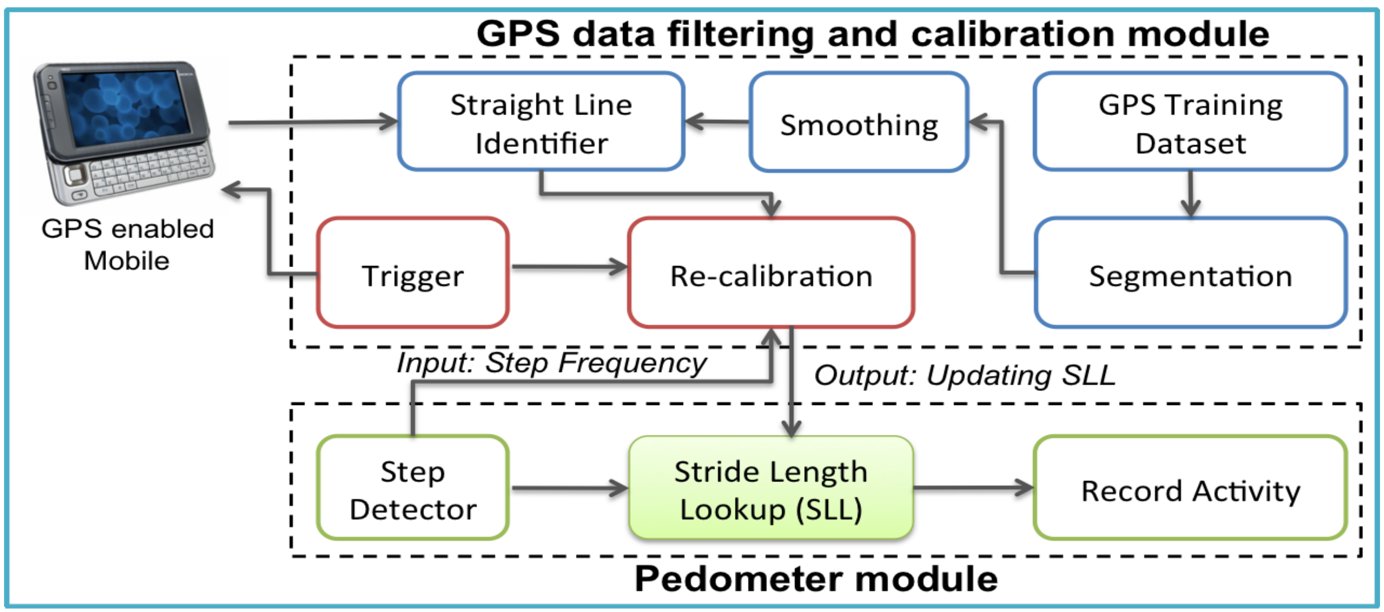
- Breaks with assumptions employed in other systems:
  - Stride length is not constant for all walking modes – AutoGait learns and uses a stride length to walking speed relationship
  - Stride length for an individual changes over time – AutoGait opportunistically recalibrates itself to account for changing characteristics of user
- Does not depend on additional infrastructure at locations like audio beacons, DGPS, etc.
- Limits GPS use to calibration, not for all location operations
- The approach does use an **external** Bluetooth connected step sensor (and raises questions about the reliability of a phone's accelerometer to detect steps).

Methodology
Approach and Design

- The prototype system was implemented on a Nokia N810 using Linux Python
- Step sensing was accomplished with SmartShoes.
  - Each shoe had a MicroLEAP computing unit
  - Shoes detected steps via pressure sensors
  - Sensor data reported to phone via Bluetooth.
- They chose not to use the phone’s accelerometer to detect steps.
  - Accelerometer based commercial products missed slow speed steps.
  - Traded off from a simpler design to gain more reliability.
  - Pressure sensor provides a sequence of boolean values. Extracting steps from the boolean sequence may also have been simpler.

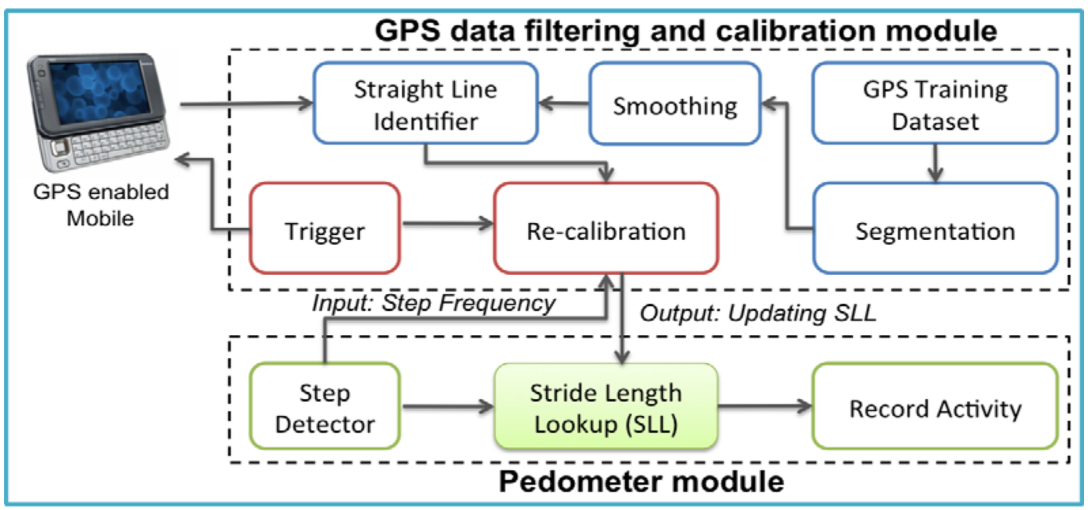
Methodology
Approach and Design

- The architecture divides cleanly into 2 lightly coupled components:
  - A pedometer module
  - A GPS data filtering/calibration module



Methodology
Approach and Design

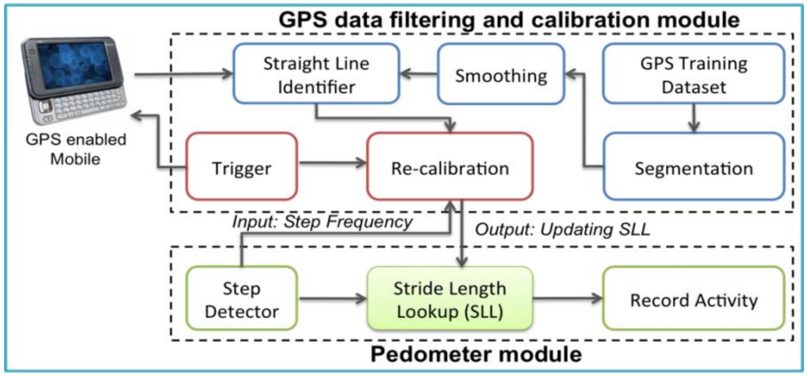
- The pedometer module:
  - Detects steps & determines step frequency
  - Uses step frequency to obtain the stride length
  - Records the step activity and dead reckoned distance.
  - Provides step frequency information to the GPS module during calibration/training phase of the system



Methodology

Approach and Design

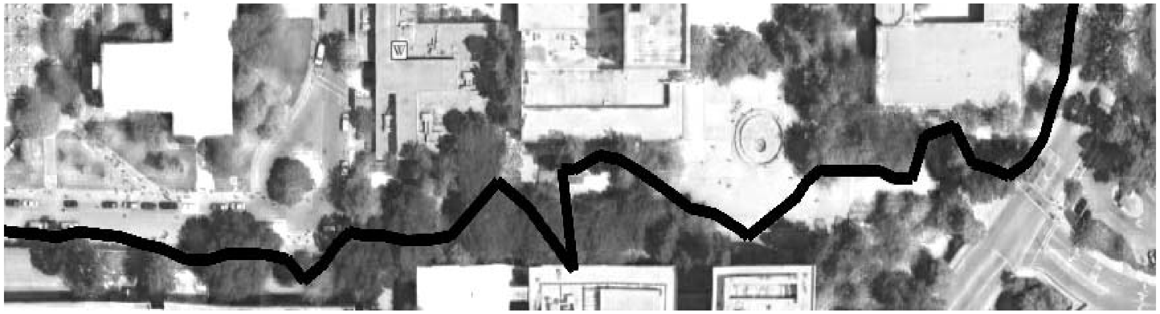
- The GPS data filtering/calibration module:
  - Generates SLL during calibration
    - Captures and processes GPS/step data (GPS position every 10 steps)
    - Smoothes high frequency noise from location and heading data
    - Determines usable data with segmentation/straight-line operations
    - Generate stride length tables.
  - Provides stride length data to the pedometer module

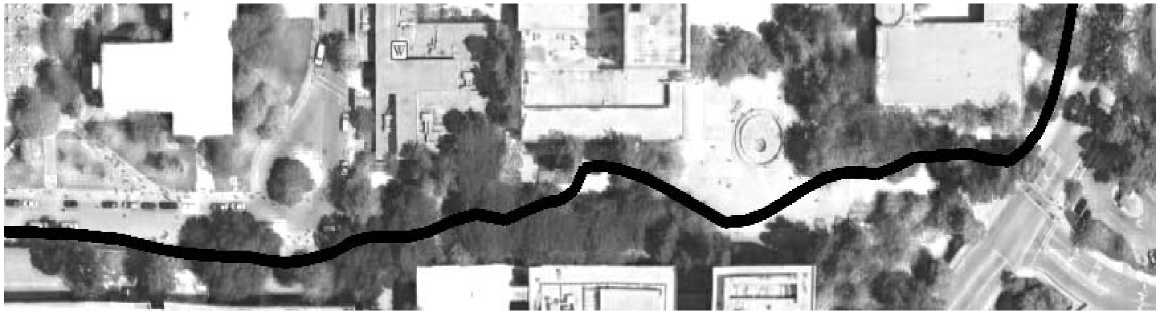


Methodology

AutoGait Calibration – Filter GPS Data

- GPS is noisy and inaccurate. Remove high frequency noise from GPS coordinates via convolution (essentially a moving average technique). Smoothes the path.

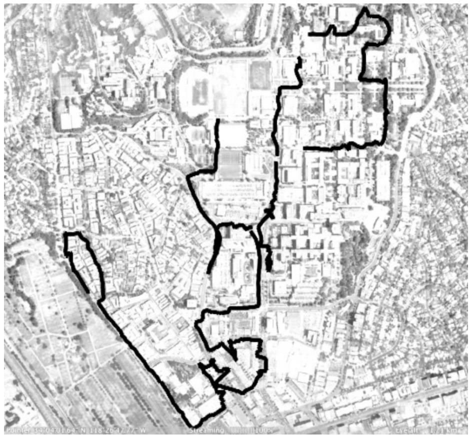




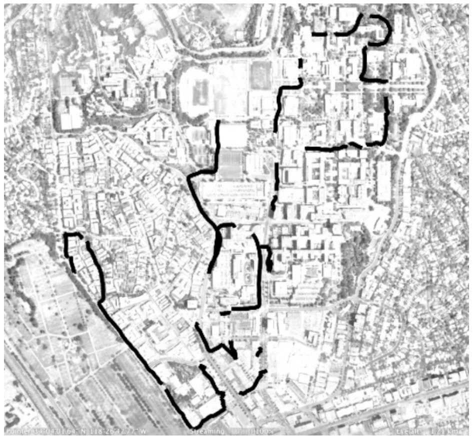
Methodology

AutoGait Calibration – Filter GPS Data

- From GPS data, remove non usable data segments (not moving, in car, segment too short (GPS error may exceed segment length)etc.
- Break into individual line segments when heading change thresholds are exceeded.



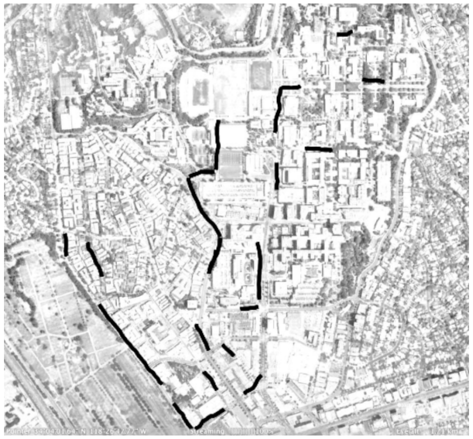
Raw GPS Data



Segmentation

&

Smoothing



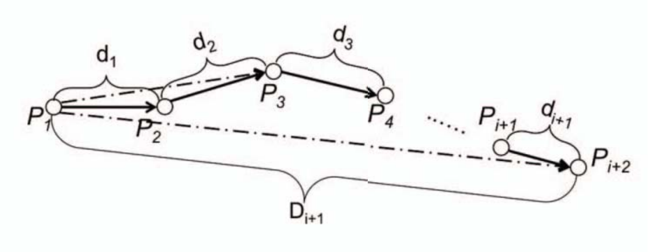
Heading Change

Filtering

Methodology

AutoGait Calibration

- For each line segment, average step frequencies, then estimate stride length by:
  - End-to-end: (distance between line segment end points P_1-P_{i+2})
  - Sum up : Sum of individual points (edges d_1,d_2, …) of segment

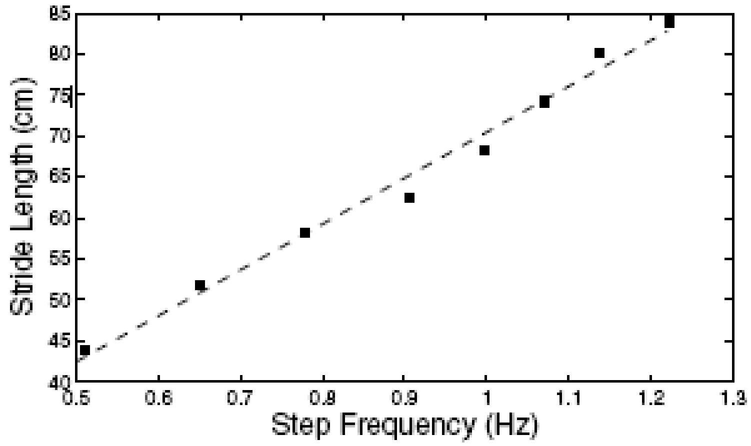


- Determine average stride length (end-to-end underestimates, sum up over estimates)
- Determine stride frequency/stride length equation from least squares fit of usable line segments.
- Opportunistically (when outdoors) perform recalibration.
- Reduce recalibration occurrences as stable parameters develop.

Results

Verification experiments

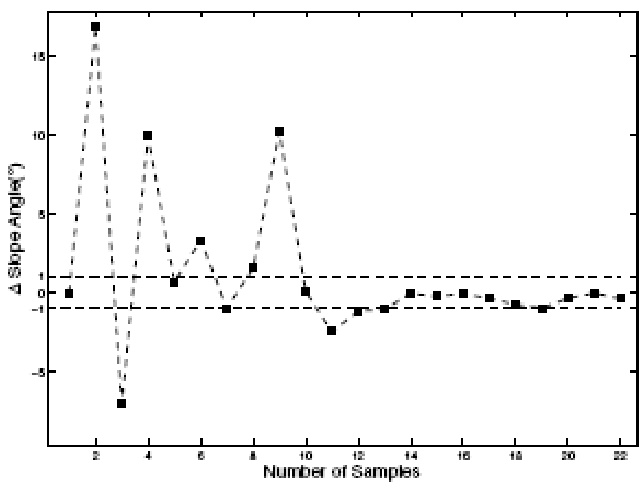
- Linear Relation verification on Treadmill:
  - The system is based on the premise that there is a linear relation between stride length and step frequency
  - Experiment done on treadmill with one participant changing speeds every 200 steps.
  - Linear relation seen in plot

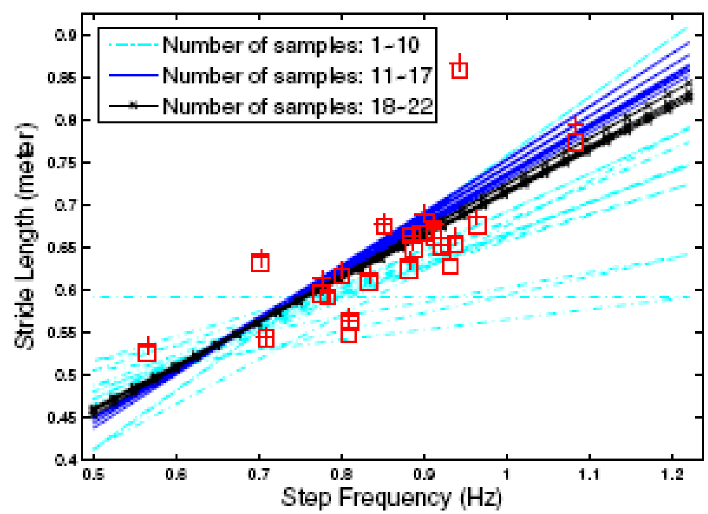


Results

Verification experiments

- Identifying Straight-Line Segments & Calibration:
  - Calibration of stride length and step frequency by GPS was tested with prototype. Participant casually walked route 6 times (seen in Slide 14).
  - Processing the line segments, the plot shows that stable calibration was achieved with 17 samples (when angle variation between lines is within 1 degree, calibration is assumed done).

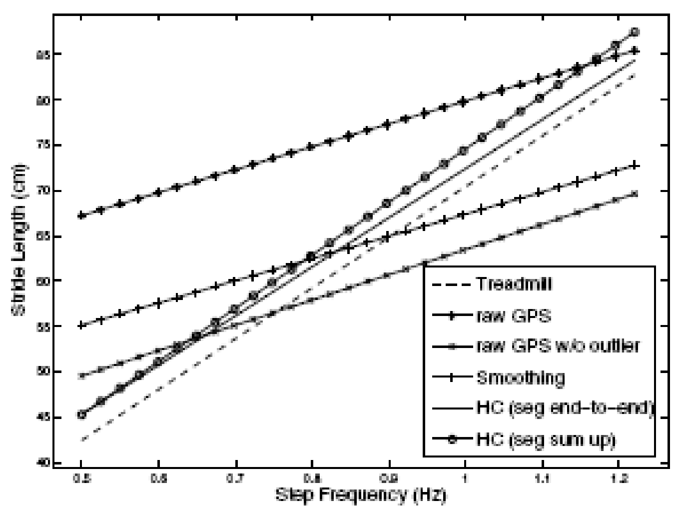




Results

Verification experiments

- Effectiveness of GPS filtering:
  - The stride length lookup relation was calculated with variations of GPS filtering and plotted. A treadmill plot was used as the assumed correct standard.
  - The full filtering treatment gave very good agreement. The slight discrepancy from the standard is related to an effect seen in another study, where ground strides are slightly longer than treadmill strides.



Results

Verification experiments

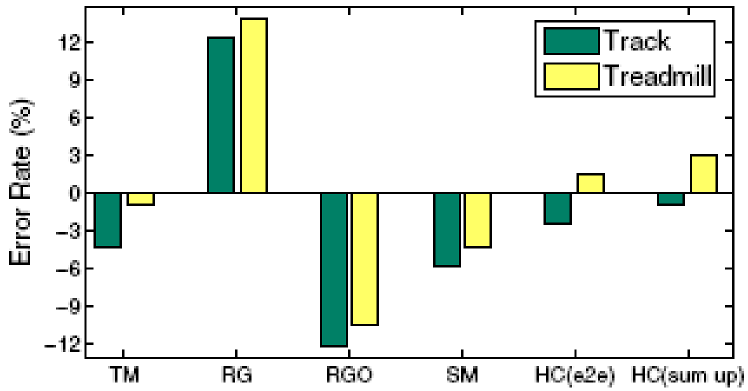
- Validation of SLL Accuracy:
  - A participant walked a mile on both a tread mill and ground (4 laps of a smooth track), at 3 different speeds, and error rates calculated. The error rate is the amount of deviation from 1 mile.
  - The table shows the error rate for AutoGait vs. a constant stride (as used by most pedometers).

Speed		Slow	Moderate	Fast
Distance (m)		400	800	400
Lap Time (min:sec)		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%
Const. Stride Length (0.7m)	Est Dist (m)	502.6	834.4	341.6
	Error Rate	-25.7%	-4.3%	14.6%

Results

Verification experiments

- Validation of SLL Accuracy (continued):
  - Once again, various GPS filtering steps were skipped, and the errors shown in the graph.
  - This illustrates the necessity of the various filters working together
  - SM (smoothing alone) distorts sharp corners which are smoothed out. To avoid this, we should use only straight line segments.
  - Sum up has less error then end to end on the track, because it accounts for small zigzags, that end to end does not see.



Results

Verification experiments

- Benchmark studies
  - The participant also wore commercial products while walking the 4 laps around the track.
  - The commercial products use different methods to determine stride length.
  - Their errors were much larger, because they assume constant stride length for different speeds, or miscounted steps at certain speeds (accelerometers could not detect softer forces at slow speeds).

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

400m test	**Without Calibration**			**With Calibration**		
Speed	Slow	Mod	Fast	Slow	Mod	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%

NIKE+ SHOES TEST RESULT

Results

Verification experiments

- Multiple Users
  - Three participants tried the AutoGait system while walking the 4 laps around the track, to prove that it was able to be personalized (using sum up method).
  - Despite walking the same track, there were variations in the number of segments detected.
  - The SLL equation parameters (alpha, beta) generated by the calibration were quite different, demonstrating the need for individual profiles in a pedometer. The errors were between 1 and 1.4%

Participant	A	B	C
α (SLL)	0.453	0.064	0.539
β (SLL)	0.23	0.612	0.2156
Segments Found	15	18	14
Est Dist (m)	1577.5	1579.4	1616.9
Error Rate	-1.41%	-1.29%	1.06%

Discussions/Conclusions/Future Work

- The AutoGait System delivers what was promised.
  - The authors demonstrated a system which can calibrate step frequency (speed) to stride length for individual users, significantly reducing error in determining distance walked.
  - The system opportunistically calibrates itself when GPS is available.
  - It can reduce the frequency of calibration if it detects the SLL is in stable over a period of time (reduce GPS usage and you save battery charge).

Discussions/Conclusions/Future Work
Lessons Learned

- There may be shortcomings in some standard sensors in phones. The authors rejected the built in phone accelerometers as a method to detect steps, because they were not reliable in low G (slow walking) cases. They chose instead to use external sensors to detect steps.
- The standard set of phone sensors can be extended via Bluetooth (and WiFi) with external mote type systems like MicroLEAP.
- GPS is noisy, and requires filtering/smoothing techniques.

Discussions/Conclusions/Future Work Issues

- The authors warn that accelerometers can miss low acceleration events (slow steps). The goal of this system is improved accuracy and this can impact that goal. They propose 2 solutions:
  - An auto-regression model to predict the number of missed steps and effect of step frequencies based on recorded history.
  - Discard segments that have a signature of missing steps.
- Investigate data processing algorithms for accelerometer data to determine steps from that data.

Discussions/Conclusions/Future Work Extensions

- The authors are considering a future study for the case of running. The step frequency vs. stride length relations are likely different (parabolic, for example) for running vs. walking, so AutoGait would need to detect whether a running or walking SLL should be employed.
- The authors would like to validate that the linear step frequency/stride length relation is truly age independent as claimed by another study, by evaluating it with diverse age groups.
- Account for stride length when for walking uphill (it shortens) and downhill (it lengthens).

Discussions/Conclusions/Future Work
Final Comments on paper

- Simple architecture of phone software
- Simple nature of the algorithms used.
- Low error rates, compared to commercial products.
- The need for the Bluetooth connected sensors complicates solutions, since they are not just software on a standard platform.
- On the other hand, the ability to extend a system with external sensors offer interesting solutions when the standard sensor set on a mobile device fail to provide required capabilities.

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Thank You!

Questions?