



Mobile Robotics Lab

Personal Dead-reckoning (PDR) System for Firefighters

Presented by

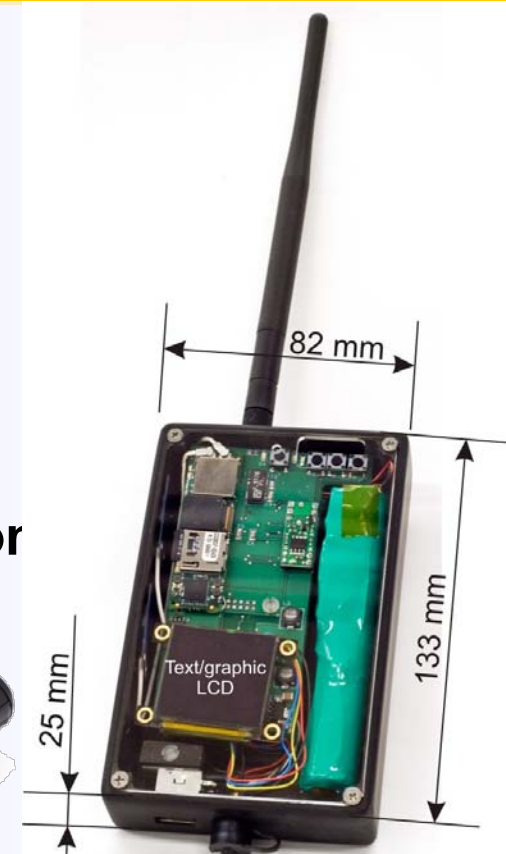
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26 years experience in GPS-free position estimation for mobile robots and pedestrians

Personal Dead-reckoning (PDR) System

- ◆ Uses in-heel Inertial Measurement Unit (IMU)
- ◆ Two key innovations:
 1. PDR removes drift from IMU's accelerometers
 2. PDR removes drift from IMU's gyros
- ◆ Performance:
 - Position errors: <math><1\%</math> of distance traveled
 - Heading errors: $\sim 0^\circ$ in walks of unlimited duration (at steady state, indoors)
 - Three modes of elevation estimation (typical Z-axis error: <math>< 1\text{ m}</math>)



Small-sized processor pack with built-in radio

PDR System - Implemented Features

IMU
inside

◆ PDR system works with

- walking backwards, sideways, or in any direction;
- crawling on hands and knees, in any direction;
- crawling up and down stairs on hands and knees;
- jogging, shuffling, hopping, skipping, dancing;
- firefighter-tested with cartwheels, Judo roll, even Moonwalk



Firefighter performing a Judo roll while PDR system keeps tracking

◆ Fast system initialization: <30 seconds (immediately prior to mission)

- Does not require setup of equipment on location

◆ Does not require any user-specific calibration

- Any user can just put on the boots, perform the 30-second initialization, and start walking
- Live demos today at 3:45 pm as part of Demonstrations & Exhibits II (Mid-Century Room)



Firefighter dragging victim while crawling

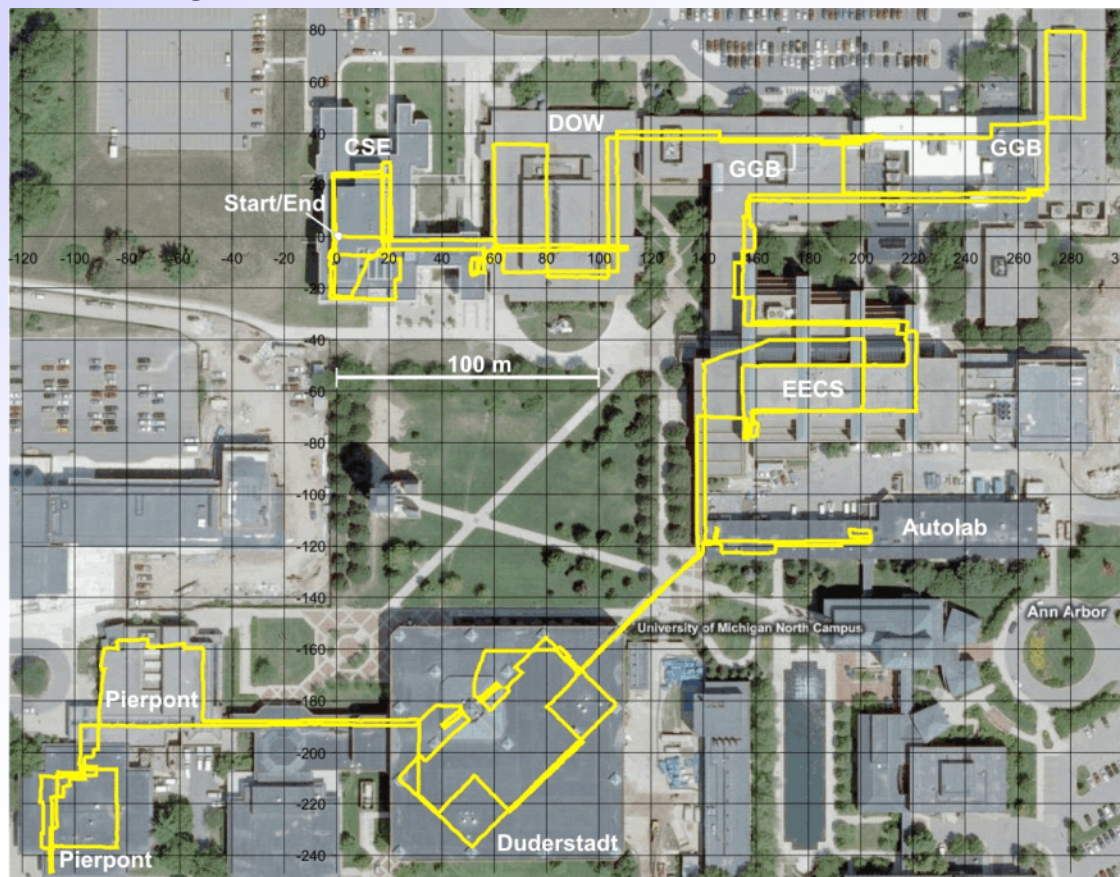
Innovative Technologies in The PDR System

1. Drift removal from accelerometers

- **Z**ero Velocity **U**Pda**T**es (ZUPT) applied to accelerometers
 - > IMU's velocity is zero on footfall
 - > If accelerometers say otherwise (e.g., due to drift), ZUPT corrects them

2. Drift removal from gyros

- ZUPT doesn't work for gyros, due to noise
- **Solution: Heuristic Drift Elimination (HDE)**
 - > Assumption: corridors are straight or intersect at 90°
 - > If gyro says otherwise (e.g., due to drift), HDE corrects gyro drift

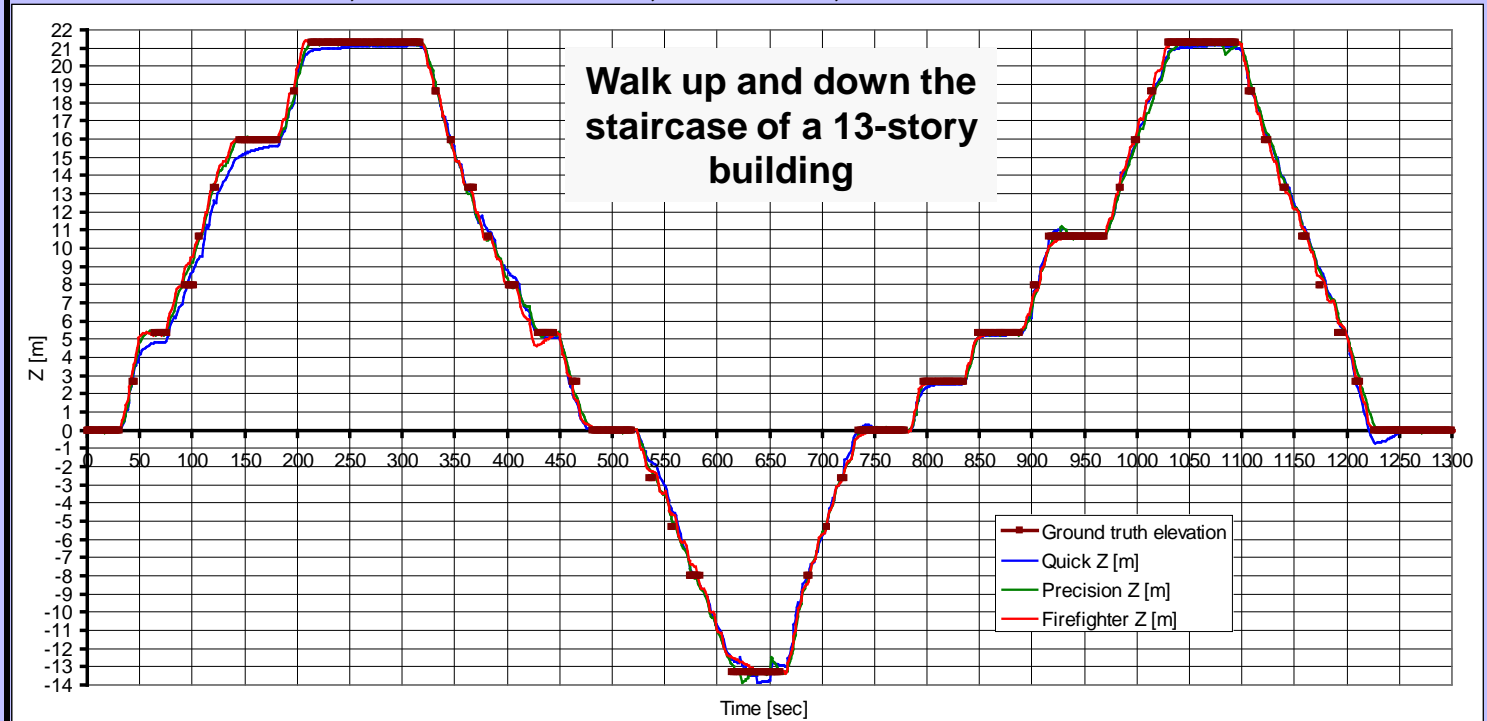


→
PDR-based trajectory of a 1-hour/2.5-mile walk through 7 interconnected buildings. Average heading error: $<1^\circ$. Final position error: 8 m (0.2% of distance traveled).

Elevation Estimates (Z-axis)

Mode	Advantages	Disadvantages
Quick Mode (QM)	Average errors: <1.0 m. No need for floor height measurements.	Uses barometer – therefore not compatible with pressurization techniques
Precision Mode (PM)	Average errors < 0.2 m.	Requires measurement of floor heights and uses differential barometer
Firefighter Mode (FM)	Works without barometer. Average errors: <1.5 m.	Reliability decreases in high risers. Requires measurement of floor height.

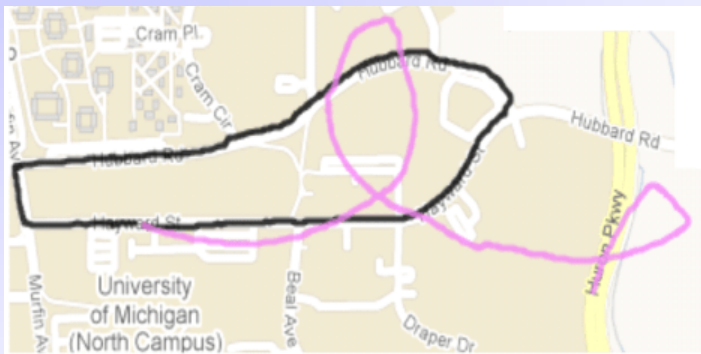
Test Set Walk D4HT, Duration: 22 min, Floors: 13, vertical distance traveled: 108 m



UC_{error} = 1.98 m	QM_{error} = 0.23 m	PM_{error} = 0.14 m	FM_{error} = 0.20 m
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Urban Locator (UL) Mode for Police & First Responders

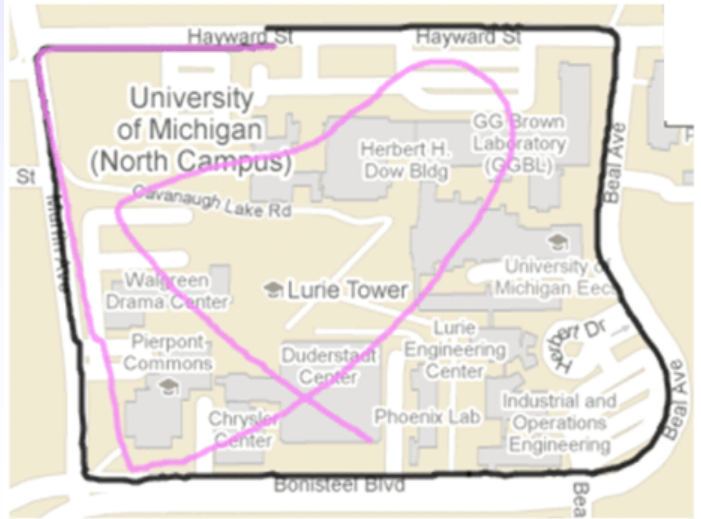
- ◆ PDR system can track walking emergency responders in GPS-denied urban environments.
- ◆ Same features as original PDR system, except that UL mode is optimized for urban streets, not buildings.



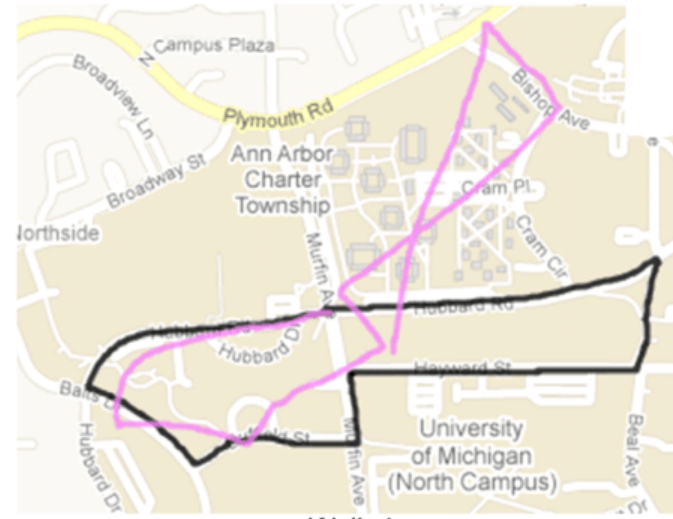
Walk 1



Walk 2



Walk 3



Walk 4

Examples of PDR system tracking a person walking along urban streets.
 Pink trajectory: Raw IMU output.
 Black trajectory: PDR using UL mode.

San Miguel Fire District Testing, June 7, 2010

This video is available at
http://www.engin.umich.edu/research/mrl/PE_PDR_Video.htm



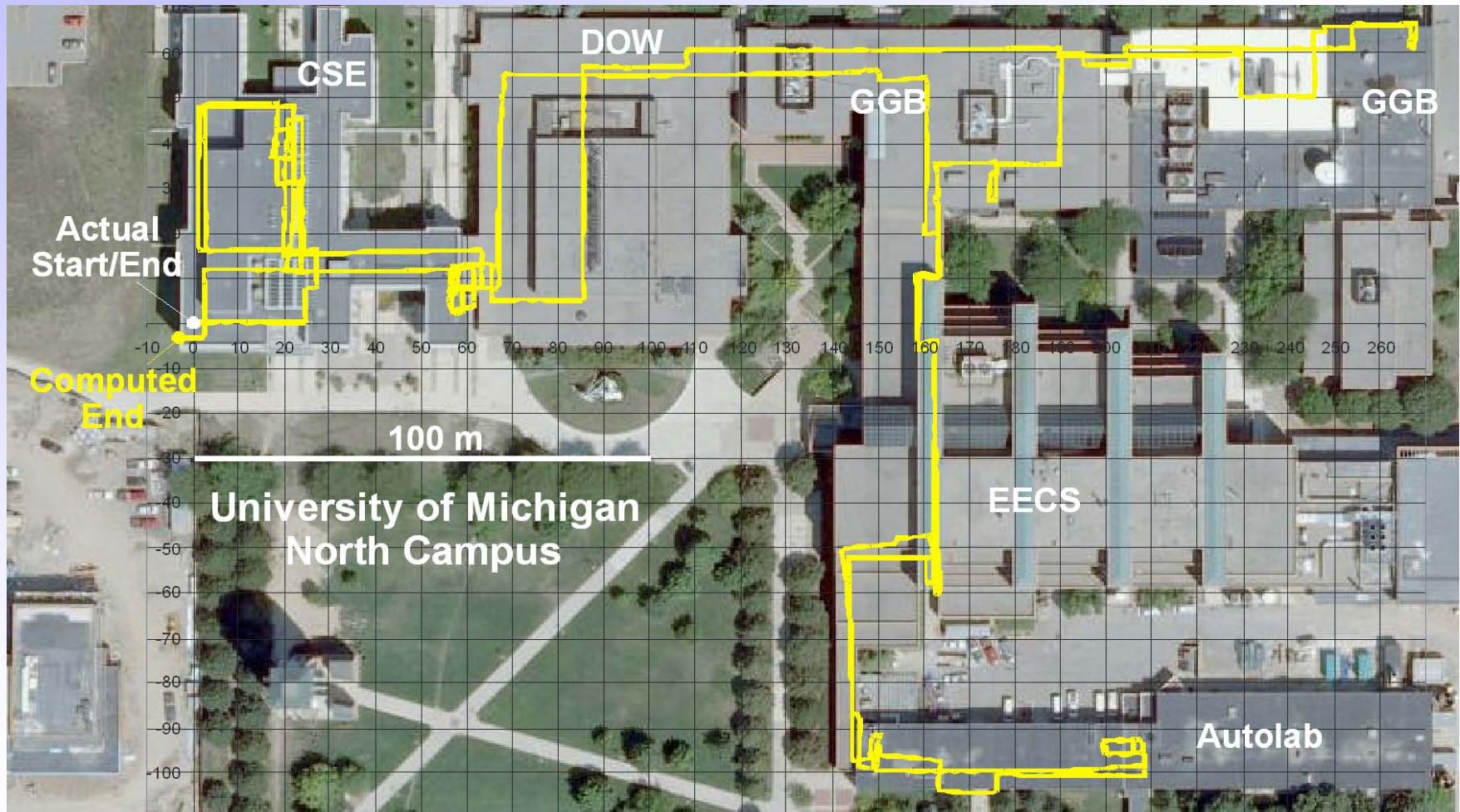
Summary

- ◆ **Proposed personal dead-reckoning (PDR) system**
- ◆ **Two key innovations:**
 1. **Removes drift from IMU's accelerometers**
 2. **Removes drift from IMU's gyros**
 3. **Measures elevation with excellent accuracy**
 4. **Work will every conceivable kind of legged motion, including crawling**
- ◆ **Results:**
 - **Position errors: <1% of distance traveled**
 - **Heading errors: ~0°**
(at steady state, indoors, in >99.5% of buildings)
 - **Three modes of elevation estimation**
(typical Z-axis error: < 1 m)

Backup Slides

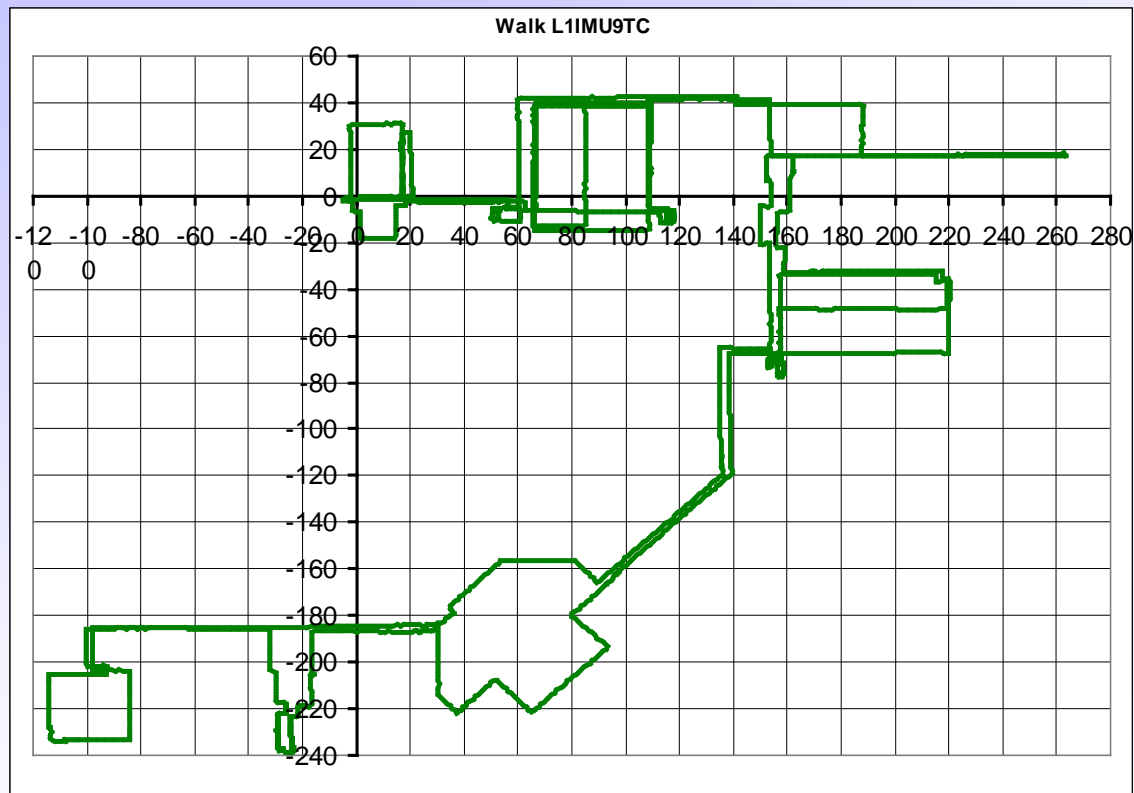
The following slides are not part of the oral presentation but may be useful in the Q&A session

More Experimental Data

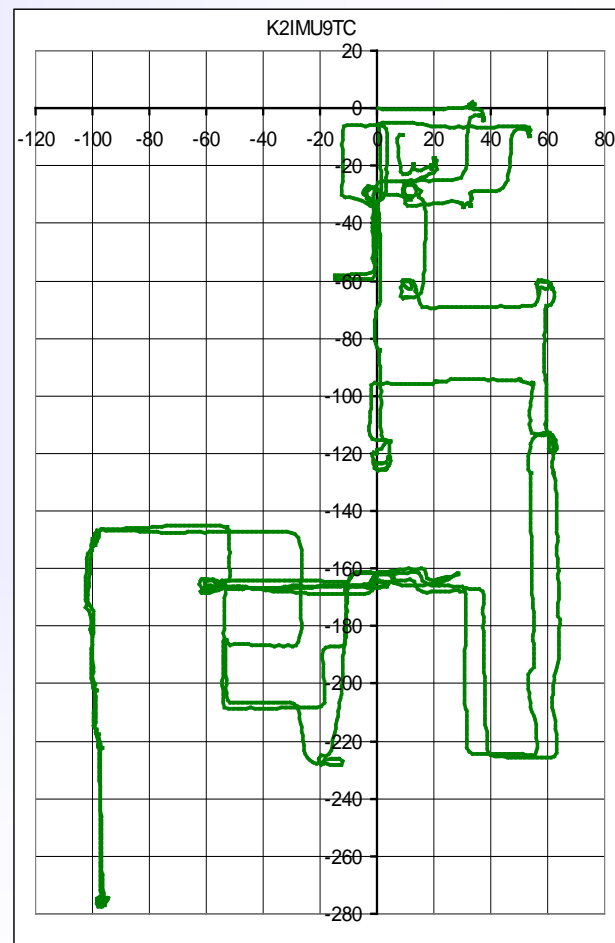


PDR-based trajectory of a 31-minute/1.1-mile walk through UM buildings, overlaid over a satellite photo. Average heading error: $<2^\circ$. Final position error: 4 m (0.22% of distance traveled).

More Long-duration Walks



Walk duration: 45 min, Distance: 3,000 m, Heading error: 1.7°,
Final position error: 3.3 m (0.11% of distance traveled)

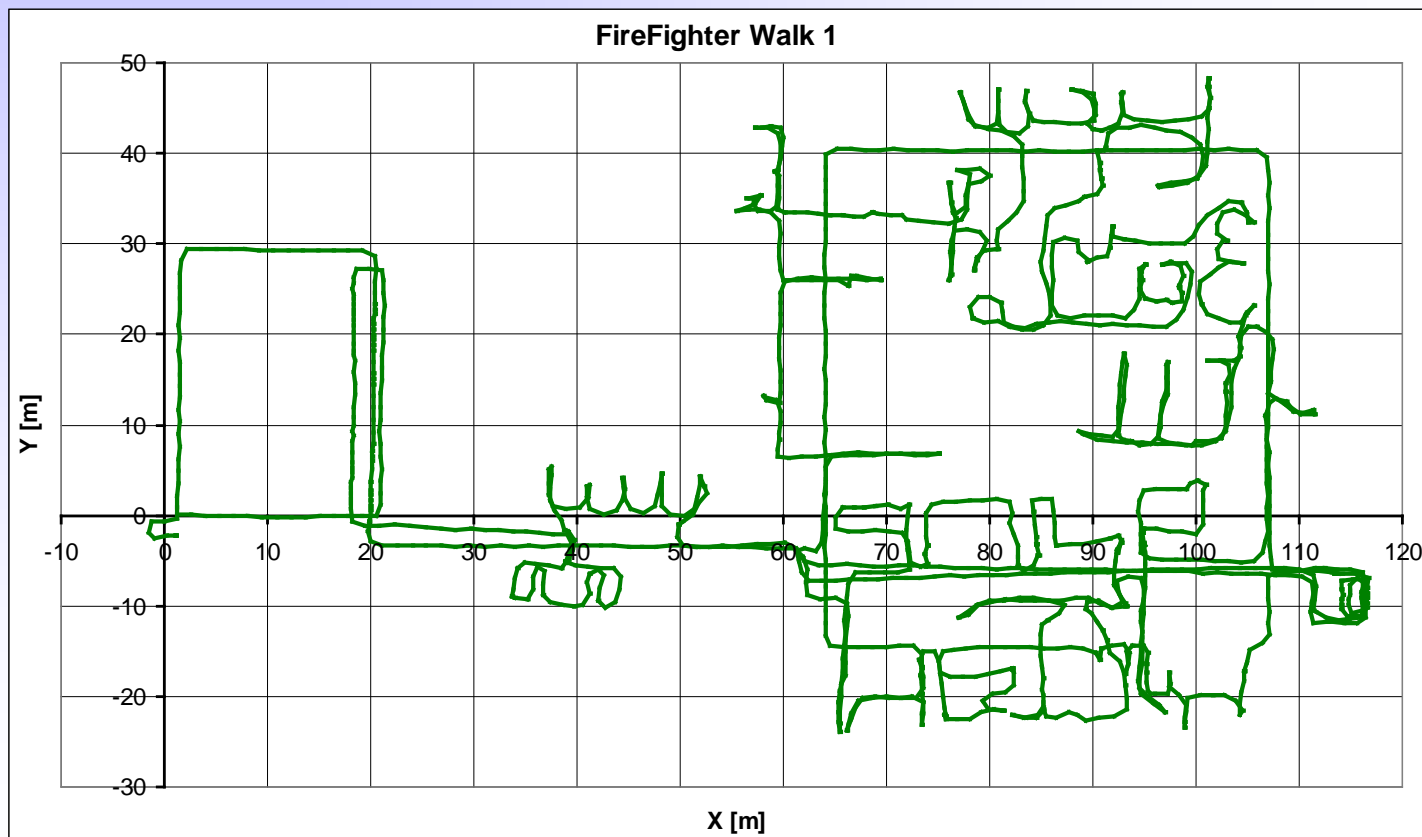


Walk duration: 42 min, Distance: 2,528 m,
Heading error: 2.1°

Final position error: 10 m (0.4% of distance traveled)

Challenging Walks

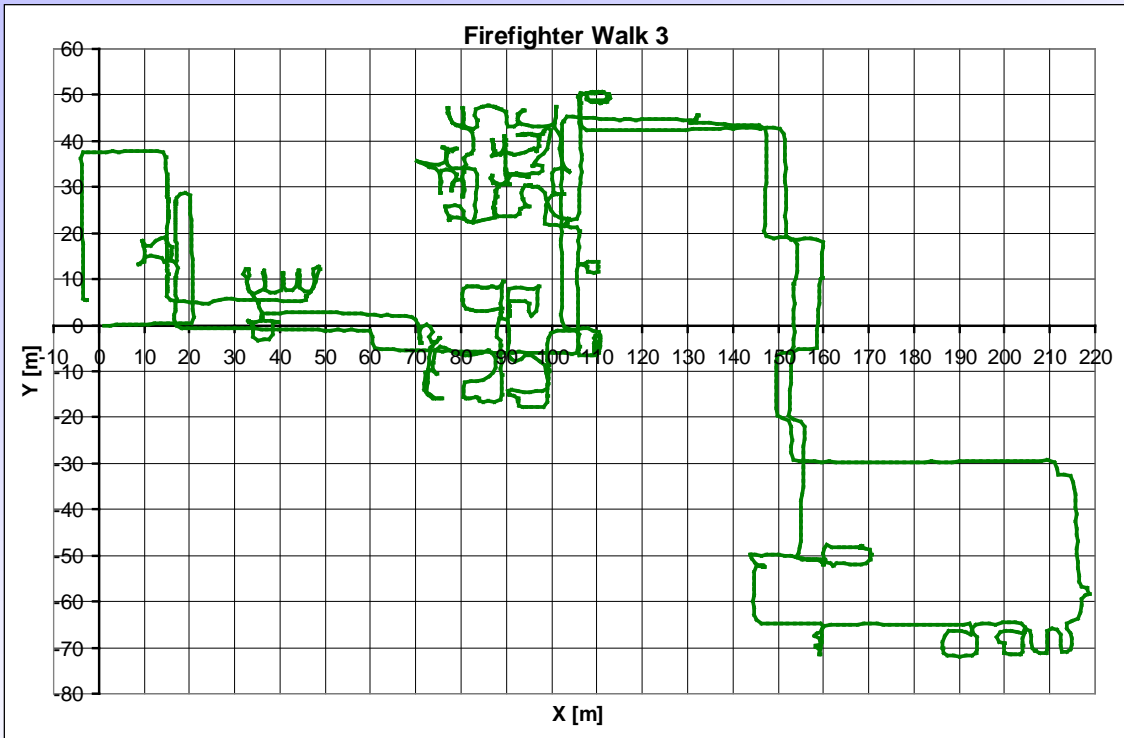
- ◆ Subject emulated actions of a firefighter searching for victims in a large factory.
- ◆ Subject walked around to look behind every machine on the factory floor
- ◆ Subject spent ~70% of the time not walking along straight corridors



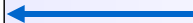
Walk duration: 31 min, Distance: 1,685 m.

Average heading error: 3.1° . Final position error: 2.5 m (0.15% of distance traveled)

Additional “Firefighter” Walks



Walk duration: 33 min.
 Distance: 1,812 m.
 Average heading error: 2.6°
 Final position error: 6.2 m
 (0.34% of distance traveled)



Walk duration: 30 min.
 Distance: 1,657 m.
 Average heading error: 2.3°
 Final position error: 9.9 m
 (0.6% of distance traveled)

