Towards complex activity recognition: GPS-free localization and map generation on smartphones

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Introduction

- Nearly 100MM smartphones sold worldwide in 1Q11 (Gartner 2011)
- New smartphones have robust sensor arrays (e.g., accelerometer, gyroscope, magnetometer, ambient light sensor, microphone)
- Smartphones tend to be on or around their users throughout the day
- **Question:** Can smartphones be used to recognize the activities of their owners?

Definitions

- ACTIVITY RECOGNITION - identifying what a user is doing physically
- BASIC ACTIVITIES - activities that can be identified with reasonable accuracy from sensor data streams (e.g., running, walking, sitting)
- COMPLEX ACTIVITIES - activities that require contextual information to be identified; often built from basic activities and contextual inferences (e.g., washing the dishes, reading a specific book, working out at the gym)
- LOCALIZATION - determining the position of a user with respect to a known landmark or waypoint
- MAP GENERATION - using the movement of a user to produce a basic floorplan with walkable paths

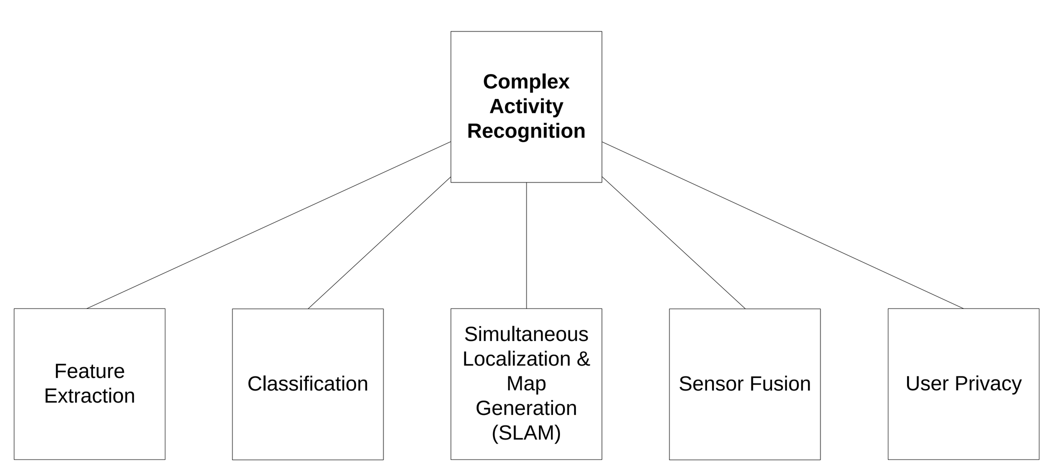
Challenges

While basic activity recognition has been successful, complex activity recognition remains a significant challenge due to the nature of human behavior.

- Variety of human activities (Kim 2010)
  - Concurrent activities - talking with friends while watching TV
  - Interleaved activities - washing dishes when phone rings
  - Interpretational issues - standing next to open refrigerator door
- Technological challenges (Wang 2010)
  - Real-time analysis
  - Communication costs
  - Computational costs

Components of Complex Activity Recognition

Drawing on multiple subsystems, complex activity recognition can be decomposed into five major components.



We focus on the problem of simultaneous localization and map generation (SLAM).

Hardware

Our implementation focuses on the Apple iPhone 4, with the following sensors used for inertial navigation:

- Tri-Axis MEMS Accelerometer
- Tri-Axis MEMS Gyroscope
- MEMS Magnetometer

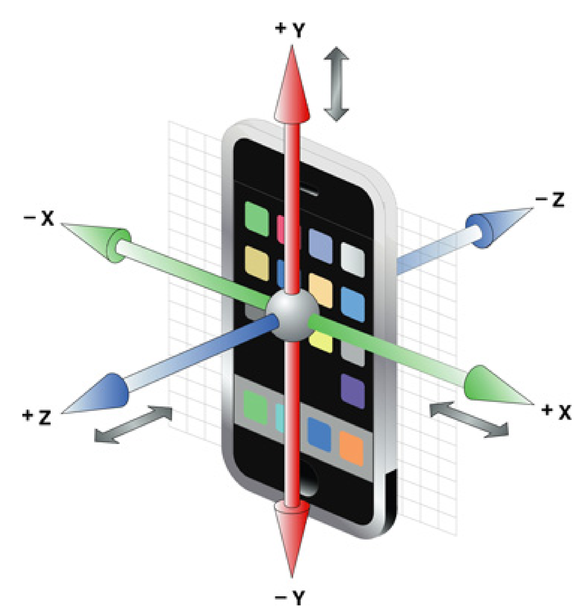


Figure: Acceleration Axes

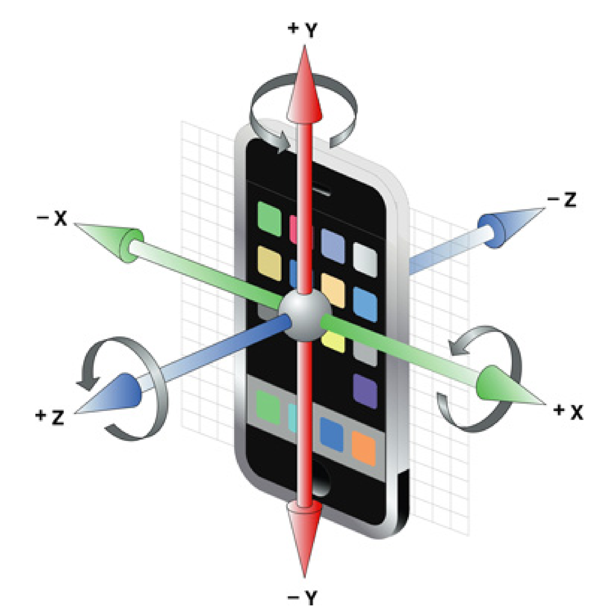


Figure: Gyroscope Axes

Positioning Algorithm

Drawing on techniques from the field of inertial navigation, our positioning algorithm has the following structure.

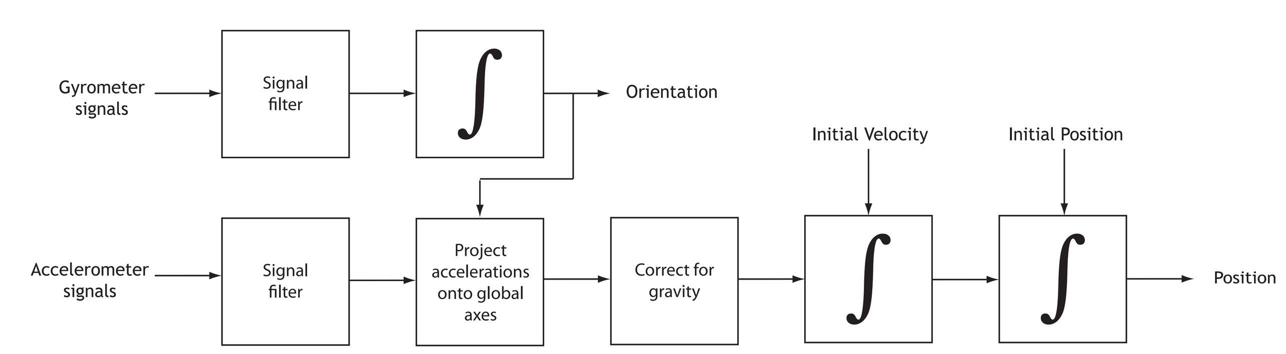
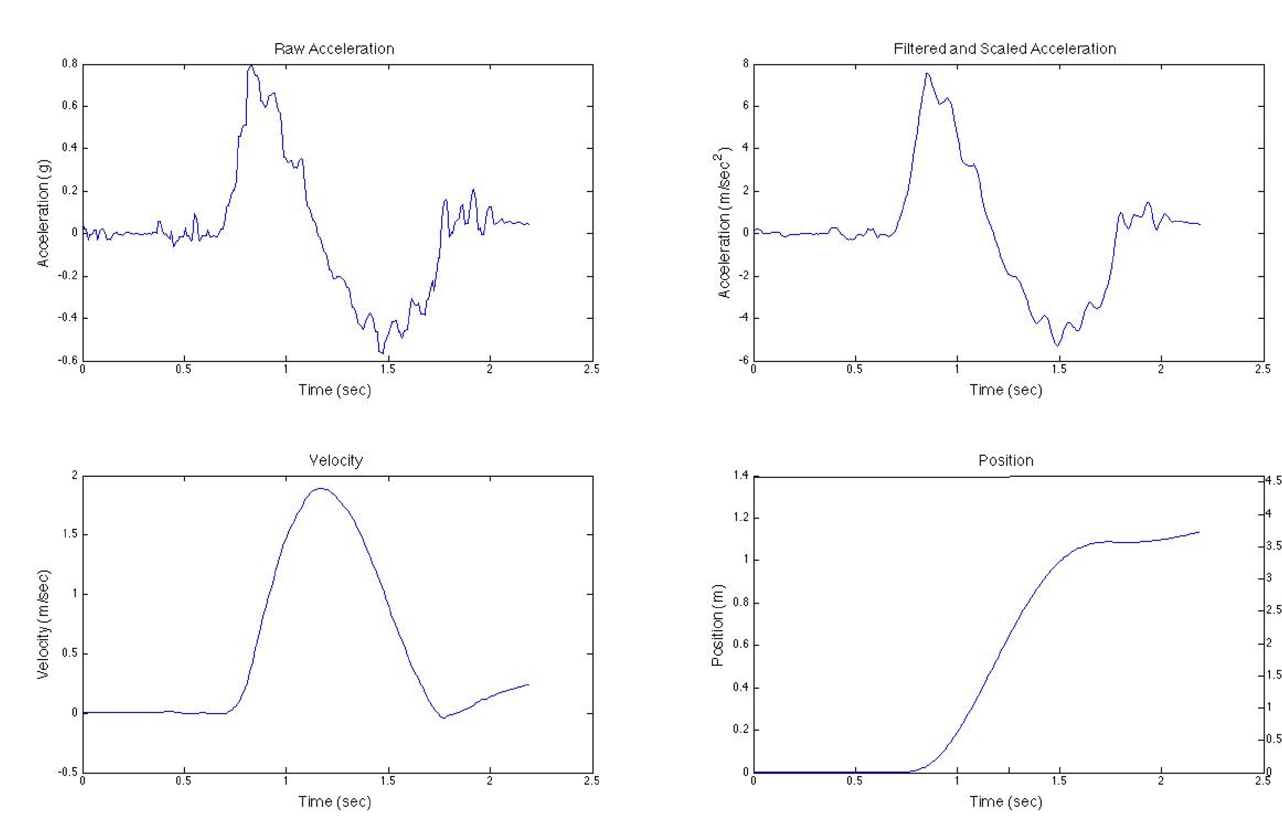


Figure: Strapdown inertial navigation positioning algorithm. Adapted from Woodman.

Below are sample graphs for each of the major integration steps for a displacement of approximately four feet.



Simultaneous Localization and Mapping (SLAM)

Borrowing from the field of robotics, our software considers a situation involving:

- One agent (the user)
- An unknown level of prior knowledge of a given environment

Goal: Localize the user and generate (or modify) a map of the environment.

Currently, our application for iPhone provides basic inertial positioning services through a `SLAMManager` singleton object. After subscribing to it, developers receive acceleration, velocity, and position updates at a desired frequency interval.

Challenges

- Bound errors in inertial navigation
  - Possible use of "zero velocity updates," which have been shown effective in shoe-mounted pedestrian systems
- Position user with sufficient accuracy
  - System will need to have a sense of its own accuracy
- Minimize computational costs in algorithm
  - Currently using BLAS (Basic Linear Algebra Subprograms) optimized for iOS

Current Progress

- Implemented basic inertial positioning algorithm, accurate over short distances
- Developed skeleton structure of a SLAM framework for iOS
- Started estimating error coefficients for Kalman filtering, which will help with system state estimation

Conclusion

We have described the problem of complex activity recognition, whereby a smartphone is able to determine the activities of its owner. Choosing an important subproblem of complex activity recognition, we presented initial findings toward simultaneous localization and mapping (SLAM).

Future Work

- Implement full Kalman filter in the `SLAM Manager`
- Bring inertial navigation techniques to problem of map generation
- Incorporate other forms of localization (like WiFi signals)

References

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