LAST MILE NAVIGATION USING SMARTPHONES

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NAVIGATION

THE ACT OF FINDING THE WAY TO GET TO A PLACE
Yuanchao Shu • Paris, France • September 10, 2015

https://studioartofficial.wordpress.com/2014/08/19/vintage-tuesday-6/
HISTORY OF NAVIGATION

HISTORY OF SPECIAL INSTRUMENTS

**English**
Sextant and chronometer

**Arabs**
Magnetic compass and Kamal

**Portuguese and Spanish**
Mariner's astrolabe and compass
Circumnavigation and mapping

**American**
Satellite navigation system

**Asian**
Monsoon winds

**Polynesian**
Motion of stars, waves
MODERN NAVIGATION SYSTEMS
WORKING PRINCIPLE

Positioning
Mapping
Path Planning
MODERN NAVIGATION SYSTEMS
STATE-OF-THE-ART

• Positioning
  – Outdoor: satellite-based, meter-level positioning accuracy.
  – Indoor: WiFi, geomagnetism, IMU, Bluetooth, FM [Youssef’05, Yoon’13, Xiong’13].

• Mapping
  – We need a map.
    • Satellite mapping, war-driving, floorplan mapping etc.

• Path Planning
  – Extensively studied in robotics and mathematics.

Does this suffice?
LACK OF MAP INFORMATION
BOTTLENECK OF NAVIGATION SYSTEMS

Coverage
Global, rural, indoor

Resolution
Trails, parking lots

Fidelity
Provisional paths

Positioning + + Path Planning = Navigation
LACK OF MAP INFORMATION

BOTTLENECK OF NAVIGATION SYSTEMS

Coverage
Global, rural, indoor

Fidelity
Provisional paths

Resolution
Trails, parking lots

Maps ?

Positioning
Path Planning
Navigation
LAST MILE NAVIGATION PROBLEM

Navigates one to the vicinity of destination tens of miles away, but fails to find a feasible path from there to final destination
• Plug-and-play
• Lightweight
• Smartphone-based
• Last mile navigation

FollowMe
**BASIC IDEA OF FOLLOWME**

- Exploits “scents/crumbs” left behind by the previous travelers.
**BASIC IDEA**

**OF FOLLOWME**

(leader’s) Trace-collection phase

(follower’s) Navigation phase
USE CASES
OF FOLLOWME
DESIGN
Trace Collection & Real-time Navigation
ARCHITECTURE OF FOLLOWME

Trace Collection Module

Reference Trace

Preprocessing
Magnetometer
Step Detector
Accelerometer
Turn Detector
Gyroscope
Level Detector
Barometer
TECHNICAL DESIGN
REFERENCE TRACE CONSTRUCTION

Sensory data
- Geo-magnetic
- Accelerometer
- Gyroscope
- Barometer

Detection results
- Steps
- Turns
- Level changes

Timestamps

Level changes
- Turns
- Steps

Reference trace

Time
ARCHITECTURE OF FOLLOWME

Navigation Module

- Walking Progress Estimator
- Deviation Detector
- Nav. Instructions

Reference Trace

Trace Collection Module

- Preprocessing
- Step Detector
- Turn Detector
- Level Detector
- Magnetometer
- Accelerometer
- Gyroscope
- Barometer

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ARCHITECTURE
OF FOLLOWME

Walking Progress Estimator → Deviation Detector → Nav. Instructions

Navigation Module

Reference Trace

Preprocessing
Step Detector
Magnetometer
Accelerometer

Trace Collection Module

Turn Detector
Level Detector
Gyroscope
Barometer
A NAVIGATION EXAMPLE
TECHNICAL DESIGN
WALKING PROGRESS ESTIMATION

- Step-constrained trace synchronization algorithm
  - Filter out high-freq. mag. and utilize differential info. to handle device and usage diversity
  - Sync. based on legacy dynamic time warping (DTW)

Given \( S_a = S_a[i], i = 1, \ldots, L_a \) and \( S_b = S_b[i], i = 1, \ldots, L_b \),

**DTW aims to find a monotonic mapping function \( f : I[1, L_a] \to I[1, L_b] \) between \( S_a \) and \( S_b \) such that**

\[
\text{minimize: } \sum_{i=1}^{L_a} (S_a[i] - S_b[f(i)])^2
\]

where \( I[1, L_a] \) is the integers from 1 to \( L_a \).
TECHNICAL DESIGN
WALKING PROGRESS ESTIMATION

• Step-constrained trace synchronization algorithm
  – Filter out high-freq. mag. and utilize differential info. to handle device and usage diversity
  – Sync. based on legacy dynamic time warping (DTW)
    • Full knowledge of traces
    • Quadratic computational complexity
  – Online DTW with linear computation overhead

\[ D[i][j] = \min(D[i-1][j-1], D[i-1][j], D[i][j-1]) + \text{dist}(i, j) \]
TECHNICAL DESIGN
WALKING PROGRESS ESTIMATION

• Step-constrained trace synchronization algorithm
  – Filter out high-freq. mag. and utilize differential info. to handle device and usage diversity
  – Sync. based on legacy dynamic time warping (DTW)
    • Full knowledge of traces
    • Quadratic computational complexity
  – Online DTW with linear computation overhead
    • Step-constrained search space
      \[
      \text{If } < m_i > \in < s_j > \rightarrow < \hat{m}_i > \in < \hat{s}_j >, \text{ and } < m_{i+1} > \in < s_k > \\
      \rightarrow < \hat{m}_i > \in < \hat{s}_j >, \text{ then } |(\hat{s}_j - \hat{s}_i) - (s_k - s_j)| > c
      \]
    • Dynamically changing search band
• Step-constrained trace synchronization algorithm
  - Filter out high-freq. mag. and utilize differential info. to handle device and usage diversity
  - Sync. based on legacy dynamic time warping (DTW)
    • Full knowledge of traces
    • Quadratic computational complexity
  - Online DTW with linear computation overhead
    • Step-constrained search space
      \[ \text{If } < m_i, s_j > \rightarrow < \hat{m}_i, \hat{s}_j >, \text{ and } < m_{i+1}, s_k > \]
      \[ \rightarrow < \hat{m}_i', \hat{s}_j', >, \text{ then } |(\hat{s}_j' - \hat{s}_j) - (s_k - s_j)| > c \]
  • Dynamically changing search band
IMPLEMENTATION AND EVALUATION

• Implementation
  – Android 4.4.2, Samsung Galaxy S5
  – Two threads
    • Data collection: 50Hz
    • Signal processing
      – DTW buffer size: 12s (c = 600)

• Evaluation
  – Four-story campus building
  – 5 participants
  – 10 different reference traces
EVALUATION
NAVIGATION ACCURACY

CDF of spatial error in navigation

Spatial error (m)

FollowMe
Geomagnetism, with PF
WiFi, with PF
**EVALUATION**
**NAVIGATION ACCURACY**

Lead time of navigation instructions at different checkpoints

- **Checkpoint A**
- **Checkpoint B**
- **Checkpoint C**
- **Checkpoint D**

- User A
- User B
- User C
- User D
RELATED WORK

**Robotics**
Special hardware-based nav.
[Cho’10, Bonin’08]
Complicated humans’ locomotion;
Limited energy buffer of smartphones.

**Geo-magnetic**
Anomalies-based local. and nav.
[Glazner’10, Gozik’11, Chung’11, Grand’12],
Ubiquitous and stable;
Localization-based navigation (map?);
Tedious fingerprint collection.

**Smartphone**
Nav. with or w/o infrastructure
[Li’12, Chintalapudi,’10, Rai’12, Xiong’13,
Yang’12, Chen’12]
Accumulative error and usage-dependent;
Non-universal (e.g., GPS, WiFi);
High bootstrap effort of fingerprinting.

**Leader-follower**
Trace-based nav.
[Constandache’10, Riehle’12, Zheng’14]
Customized devices (e.g., robots);
Infrastructure-dependent (e.g., WiFi, beacons);
Constraints imposed on users.
CONCLUDING REMARKS

INFRASTRUCTURE FREE
Cloud-based or Ad-hoc
No need of floor plans (maps)
WiFi/Bluetooth-independent

HIGH EFFICIENCY
Low-power sensors
Low computation
Energy efficient

MINI. USER INVOLVEMENT
Plug-and-play
Fast and easy bootstrapping
No action required during NAV
More info. and updates

FollowMe
THANK YOU

Q&A