TAMPERE UNIVERSITY OF TECHNOLOGY

A Survey of People Movement Analytics Studies in the Context of Smart Cities

Elena-Simona Lohan*, Tomi Kauppinen, and Sree Bash Chandra Debnath

*elena-simona.lohan@tut.fi

Presenter from Tampere University of Technology, Finland
Other participant units: Aalto School of Science and University of Trento

Outline

- Introduction& Motivation
- Smart city and users' movement analytics
- Mobility models
- Semantic analysis
- Open-access repositories for user traces
- European and international projects
- Open challenges
- Conclusions

Introduction

- The location information and movement-related data is becoming easier and easier to collect from the user mobile devices: cellular&Wifi localization solutions already available + GNSS solutions
- Significant research and commercial efforts dedicated to analyze the user location and movement data in the last decade
- The goal of this paper is to give a compact and
- comprehensive overview of the challenges and solutions related to collecting, storing, analyzing, visualizing, using or distributing people's movement data

Motivation – Why mobility data?

Examples of application areas

- Ehealth
  - Changes in a person's mobility patterns can be related with physical and emotional well-being and can signal incipient Neurodegenerative diseases
  - Mobility patterns and frequency of falls can be used as risk detectors of an incipient neuro-degenerative disease
- Urban planning
  - Regulating traffic in the Hot-spots of a city
  - Shared urban transport (e.g., shared cards, shared bikes, …)
- Network operators
  - Location-based billing
  - Mobility management
- etc

Questions for research

- Which are the potential uses of user movement data in the context of the smart cities & IoT?
- Which mobility models and probability distribution functions to use?
- Which are the challenges related to collecting, storing, analyzing, distributing and using in any way the movement data at both individual level or from
- large volumes?
- Which solutions exist to these challenges in European and international projects?
- Which are the main public repositories of such movement data at the present moment?

Our paper gives a survey of the work addressing these challenges!

Smart city & people movements

- **Smart city vision**: interconnected wireless links between all wireless devices (at close proximity from each other) + access to Internet through backhaul network
- 11 main movement analytics categories: Health-related, Social networking, Transportation, Smart Homes, Smart shopping, Tracking, Resource optimization, Safety, Smart urban planning, Greener environment, and Infotainment/Gamification

Mobility models (1/4)

- "**Human trajectories show a high degree of temporal and spatial regularity**" (Barabasi lab)
- Main parameters:
  - User step distribution
  - User angle changes
  - User speeds
  - User acceleration
  - Pause and flight times

Mobility models (2/4)

TABLE I. STATISTICAL DISTRIBUTIONS OF USER MOBILITY PARAMETERS FOUND IN THE LITERATURE

Model Type	Model name	Distributions
Synthetic	Brownian motion[11]	Gaussian distribution of user speeds; Uniform distribution of azimuth angles
Synthetic	Random waypoint model[11]	Uniform distribution of user speeds; Uniform distribution of azimuth angles
Synthetic	Levy walk [12], [14]	Constant user speeds
Synthetic	Mobility models for terminal [11], [25] mobility in cellular systems	Either Uniform distribution or boundary crossing distribution of azimuth angles (scenario dependent)
Synthetic	Slaw model [26]	Truncated Power Law (TPL) distribution of flight times and pause times
Traced-based	Barabasi et al. [14], [24]	Truncated power law distribution of user steps
Traced-based	Kim et al. [27]	Lognormal distribution of user speed; non-uniform distribution of angles, reflecting the direction of roads and walkways
Traced-based	Lee et al. [12], [13]	Mostly uniform distribution for azimuth angles, but some cases with stronger biases at −90 and +90 degrees; Truncated Pareto distribution for flight lengths; Gaussian distribution for mean square displacements

Mobility models (3/4) - examples

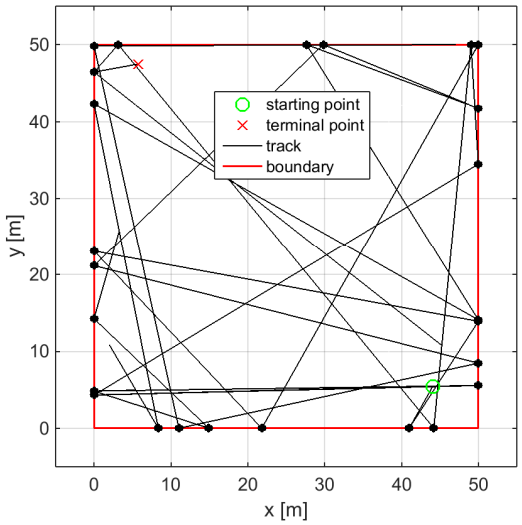


Illustration of a 2D synthetic indoor trajectory according to the random direction mobility model

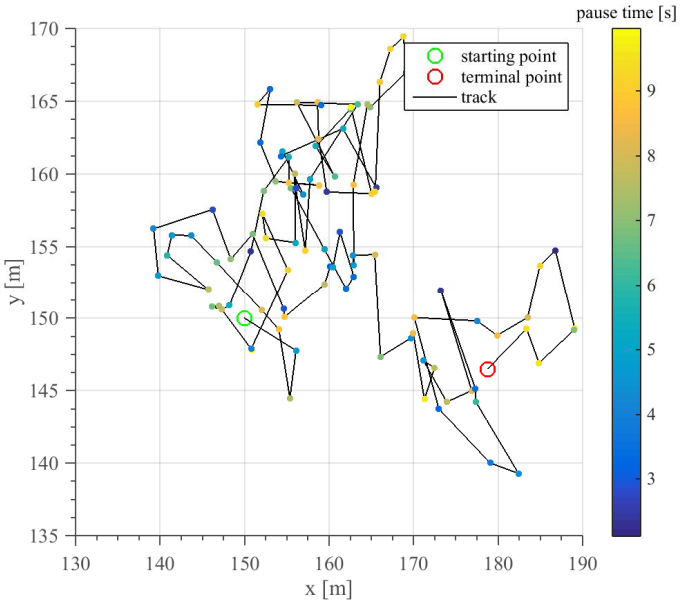
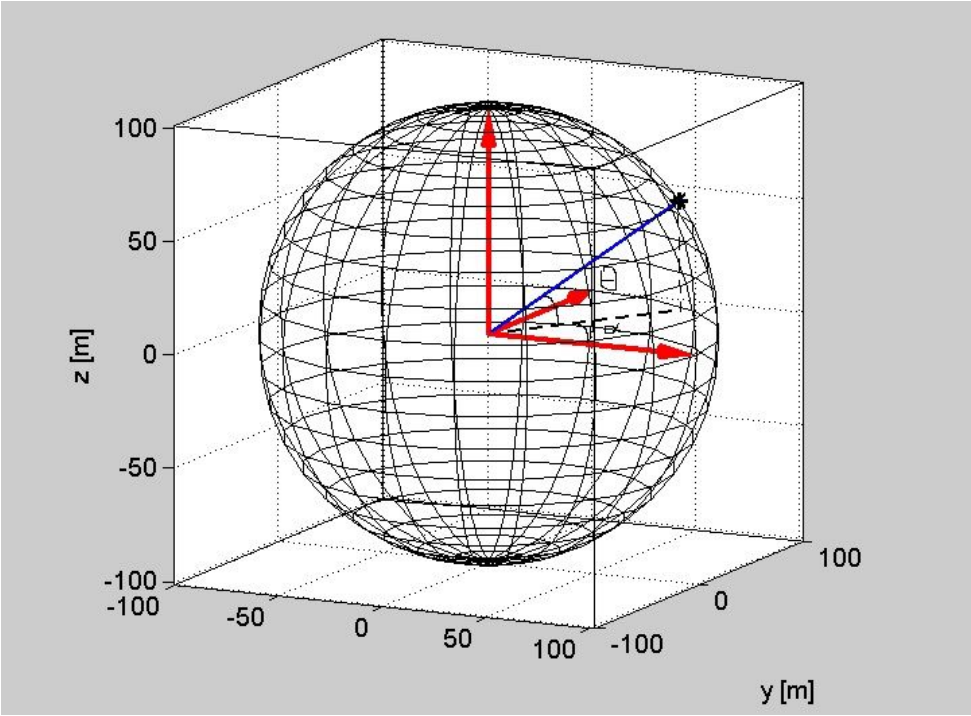


Illustration of a 2D synthetic indoor trajectory according to the random waypoint mobility model

Open-source simulator available at our group page www.cs.tut.fi/tlt/pos

Mobility models (4/4) – 2D vs 3D



- Height estimation is typically the most difficult, both in indoor and outdoor scenarios
- Azimuth angles also need to be modeled in 3D case

Semantic analysis

Semantic analysis = deductive reasoning and conceptual representations of trajectory patterns

Three semantic categories:

- convergence/divergence patterns, e.g., most frequented places
- flock patterns, e.g., group of friends or families
- trajectory patterns, e.g., individual pedestrian or vehicular trajectories

Open-access repositories for user traces (1/2)

- Many available, but not unified or inter-linked
- If a researcher wants to use such data, there are various distribution terms, some which require user consent for the data => large-scale analysis hindered by the distribution terms
- Not a unified format of data, as there are no current standards for mobility data collection
- A summary of the main repositories is in the next slide

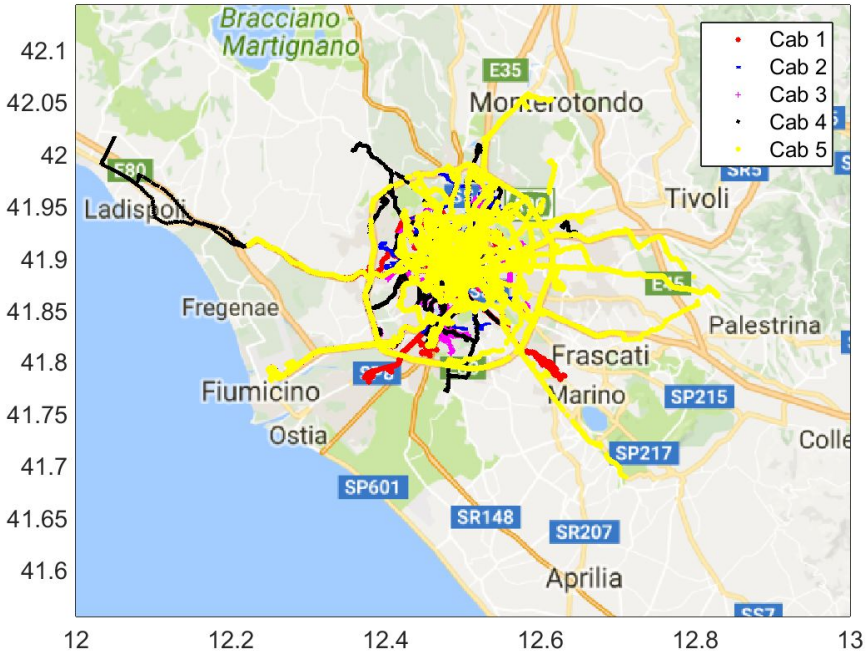
Open-access repositories for user traces (2/2)

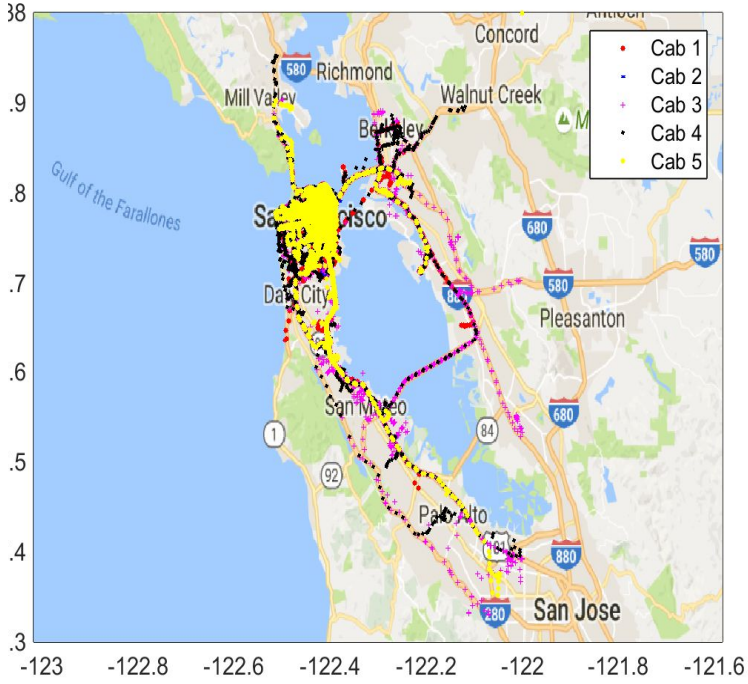
TABLE III. OPEN-ACCESS REPOSITORIES WITH MOVEMENT-RELATED USER DATA

Repository	Data types	Data formats
CRAWDAD [18]	user traces, e.g. from taxi drivers and geo-tagged stationary positions	Various (e.g., XML, TXT, MAT, etc)
OSM [17]	user traces and geo-tagged stationary positions	XML, PBF
WikiLoc [16]	user traces, under various activities (walking, trekking, biking, running, ...)	GPX
CityPulse [43]	geo-tagged stationary positions	CSV
ODI, Trento node [47]	geo-tagged stationary positions	GeoJSON
Malaga City hall [46]	user traces and geo-tagged stationary positions	GeoJSON , CSV
TLC [49]	geo-tagged stationary positions	CSV
Dan Work [50]	vehicle traces	CSV, MAT

Example of user traces

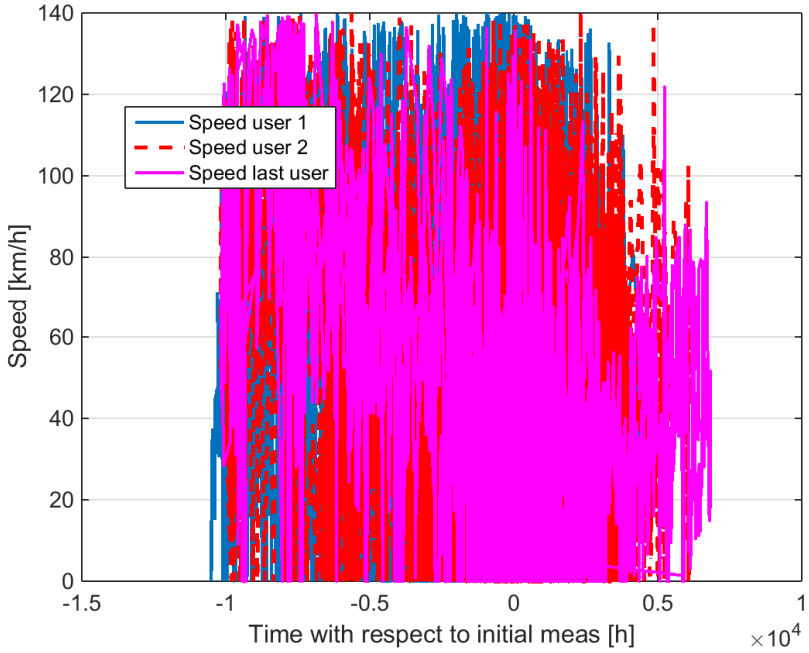
- Taxi drivers in Rome (left) and taxi drivers in San Francisco (right), based on CRAWDAD repository



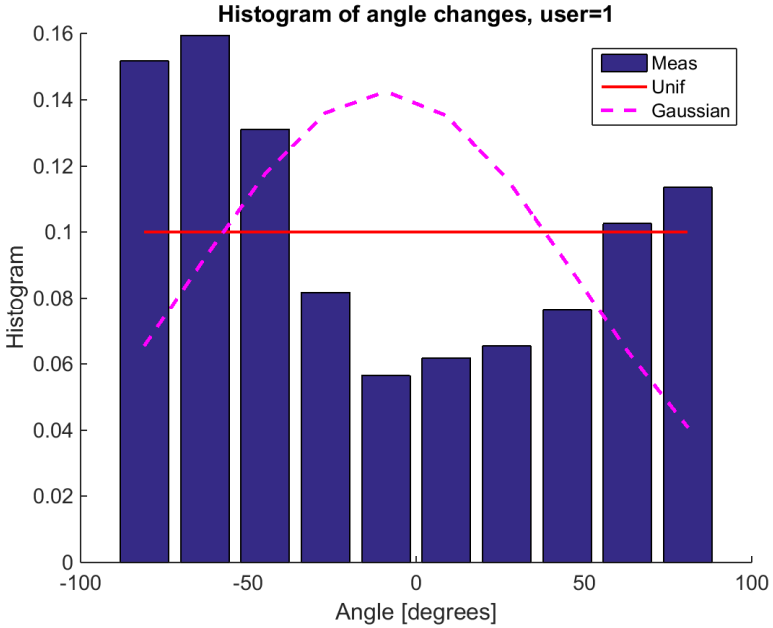


Example of user trace analysis

- Taxi driver in Rome, based on CRAWDAD repository



Speeds



Angle changes

European projects

EU FP6 GeoPKDD http://www.geopkdd.eu (2005 – 2008)	Spatio-temporal knowledge discovery and data mining methods for moving objects and their trajectories
EU FP7 URBANMOB http://cordis.europa.eu/result/rcn/166344_en.html (2013 – 2014)	Utilising the data produced by Oulus Urban Pervasive Infrastructure and other sources for modelling and exploiting urban flows and networks; work based on wireless traces
EU FP7 Urban Sensing http://urban-sensing.eu (2012 – 2015)	Data collected from social media for analyzing patterns of use and citizens' perceptions related or concerning city spaces;
EU FP7 EUNOIA http://eunoia-project.eu (2012 – 2013) EU FP7 CitySense (2013 – 2016)	Investigates how new data available in the context of smart cities can be exploited to understand mobility and location patterns in cities; compares mobility and location patterns in different European cities provided innovative smart city applications and offers a number of semantically annotated datasets in open access [43]
EU Open-Cube www.opencube-project.eu (2013 – 2015) EU FP7 MULTI-POS www.multi-pos.eu (2012 – 2016)	Developing software tools that facilitate publishing of high-quality Linked Statistical Data and reusing distributed Linked Statistical Data in data analytics and visualisations; focusing on economic and social indicators in cities Initial Training Network in the field of multi-technology positioning; reduced-scope analysis of indoor mobility models in the context of signals of opportunity
EU H2020 ETN GEO-C http://www.geo-c.eu (2015 – 2018)	Training Network of PhD researchers focusing on how people can understand the processes driving smart cities and their services, and how they can gain a sense of control rather than being controlled by the services provided by a smart city
EU H2020 EOpen4Citizens http://open4citizens.eu (2016 – 2018)	Project focusing on how to empower the citizens to make meaningful use of open data

International projects

Future Urban Mobility Singapore National Research Foundation http://ares.lids.mit.edu/fm/index.html (2010 – 2015)	Developing a new paradigm for the planning, design and operation of future urban mobility systems, aiming at both passengers and freight, in order to enhance sustainability and societal well-being on a global scale
US NSF 0335244 ORBIT http://www.orbit-lab.org/ (2003 – 2008)	Building an open access research testbed for next-generation wireless networks, and covering also location-based mobile network services
US NSF 0643322 Exploring dynamics of pedestrians http://www.nsf.gov/awardsearch (2007 – 2012)	Producing new techniques for extracting features, processes, and phenomena from movement data-sets generated by agent-based models
US NSF 1441177 Human Geography Motifs http://nsf.gov/awardsearch (2014 – 2016)	Examining how shifting motifs in the everyday rhythms and tempo of people form interdependently, with mobile transport and communications infrastructure
US NSF 1421325 Published network mobility traces http://nsf.gov/awardsearch (2014 – 2017)	Developing and evaluating techniques for manipulating and then publishing mobility traces formally proven and with high accuracy
US NSF 1320694 MobiBench http://nsf.gov/awardsearch (2013 – 2017)	Producing benchmarks in the form of evaluation scenarios and test-suites for mobile networking protocols and services for user and vehicular mobility

Open challenges

- Existence of many standards and formats
- Indoor user traces: limited availability
- 3D analysis: height is difficult to estimate
- Ontology approaches: still missing
- Indoor maps: poor availability or protected by NDA
- Open-access platforms: very few
- Privacy issues

Conclusions

- Finding the right tools for the collection, analysis&semantic processing of user movement data is an important step towards developing better Location Based Services
- Unified overviews of the different aspects of the movement analytics in the context of smart cities hard to find -> our paper addressed this gap
- We summarized the main mobility models, the main open-access repositories and the main EU and international projects related to user mobility data
- We pointed out towards the existing research challenges and how solving them can serve to various applications in the smart cities