Light-weight Indoor Localization

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Motivation and Background

- Location information is the heart of mobile computing.
  - Location based service
  - Context-aware service
  - Location related security issue
  - Mobile robotics

Motivation and Background

- Basic components of a practical localization system
  - A reference coordinate system (e.g. the map)
  - A localization component that can compute the coordinates of the object being tracked with respect to the reference system.
  - For relative localization systems, whether the reference coordinate system is necessary depends on the number of relevant space dimensions. Actually, everything is relative!

Motivation and Background

- Outdoor Localization – quite successful
  - With the help from satellite remote sensing and geography the ultimate global reference system can be easily constructed.
  - Angle-of-Arrival (AoA) based methods with the help of satellites
    - Global Positioning System (GPS)
    - 北斗
  - Use dead reckoning as assistance
    - When no signal from satellites available

Motivation and Background

- Indoor Localization – far from practice
  - Indoor reference systems are not easy to get and there is no such third-party general approach as geographical remote sensing.
  - The localization component is well studied and it can be useful (the accuracy can be very high) without considering some practical issues!

Related Works

Existing approaches generally can be put into three categories

- Propagation-based methods
  - Use different wireless signal propagation models to compute the distance between the transmitter and the receiver. Use physical characteristics.
  - All existing models are environment-dependent. Poor matches between environmental settings and models will cause significant error. (one possible research direction is to find a best way to classify different types of surroundings, then dynamically detect and select most suitable models)
  - Some calibration effort is needed at the setup to compute the best parameters for those models under the coverage area.
  - Locations of some anchor points should be provided.

Related Works

Existing approaches generally can be put into three categories

- ML-based methods
  - The goal is to find a good learning function to perform the mapping from the signal space to the physical location space.
  - Due to the uncertainty and non-linearity of the wireless signal distribution, traditional mapping from the signal space of RSS to location is very difficult to perform. (One possible research direction is to find other location-related signal spaces and corresponding learning functions for localization)
  - The accuracy can be impressively high with very large and detailed training sets.
  - The performance of the system greatly depends on the data sets. Considering the property of high uncertainty both in geographical and temporal dimensions, unpractical calibration effort is needed.
  - A reference system with known mapping between signal space and location space should be provided.

Related Works

Existing approaches generally can be put into three categories

- Combined methods
  - ML-based methods totally depend on data! From large enough and representative data sets, they trying to figure out the hidden structures and extract purely mathematical models.
  - Propagation-based methods use some well-known signal propagation models derived from experimental and theoretical physics. They are essentially some intuitive physics-related structures of the data space.
  - Combined methods trying to balance between the dependence on data and completeness of structures.

Related Works

With high-level descriptions for understanding the general indoor localization problem and main directions for solving it, there are still implementation-related issues for system developers to take into account.

- System architectures and hardware requirements – There are also security and privacy issues that need to be carefully considered
  - Customized receivers
  - Customized transmitters
  - Additive plug-in without intrusion
- Retrievable data resources
  - RSS – commonly available
  - CSI – currently only available with specific wireless NICs
  - Angle-of-Arrival (AOA) – multi-antenna systems
  - Time-of-Arrival (TOA) – high resolution systems, acoustic systems, etc.
  - Images, straight profiles of locations – cameras, visible light communication
  - …

My Proposal

- System Architecture
  - Use wireless signals from 802.11 WLAN as the main tool to profiling locations
    - Easily accessible technology
    - Available almost everywhere in indoor settings where LBS is required.
  - Concentrate all the computation in mobile devices
    - Receiver-side localization can protect the privacy of users.
    - Smart phones and other mobile terminals have very impressive computational capability now and they are equipped with multiple accesses to data resources.
    - The mobility of users can be leveraged in localization.
    - Information from different users can be coordinated.
- High-level Methodology
  - Simultaneous localization and map construction (SLAM)
    - No prerequisite location information of access points or other anchor points.
    - Traning-while-using: When users are using the systems, they are simultaneously contributing to it.
    - I consider it as a good way to balance between data-driven models and physical models.
    - It is well studied in the area of mobile robotics.

SLAM Basics

- Why SLAM is possible?
  - Map is naturally consisted of static 'landmarks' in the two dimensional space.
  - When the object is moving around, its equipped sensors are observing the surroundings from different dimensions (distances, bearings, temperature, altitude, images, etc.).
  - The sensed data contains the relative positional information between landmarks and the object. Since we can easily obtain the moving trajectories of the sensing object, the spatial relation between different landmarks can be constructed.

SLAM Basics

- SLAM for robotics
  - Mobile robots are all equipped with high-end sensors for ranging. (infrared based distance measuring, etc.)
  - Mobile robots are instructed by commands from controllers and thus the moving trajectories are easy to obtain.
  - The major problem is how to deal with accumulated error in perceiving moving trajectories and observations of landmarks.

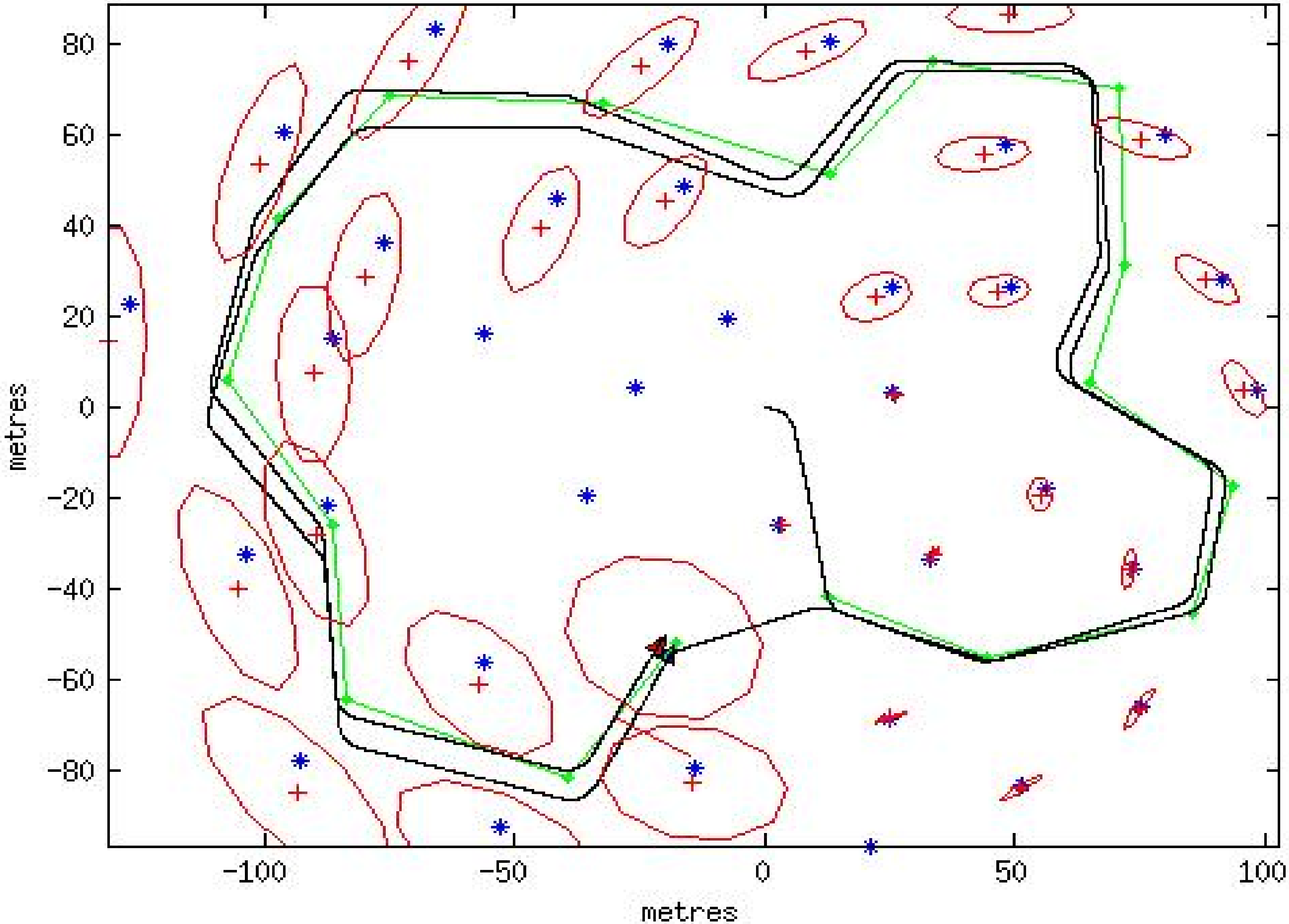
SLAM Basics

- Structures of the SLAM problem
  - With measurement data, SLAM is a problem of probabilistic estimation.
  - The mathematical model mainly consists of two part – the observation model and the kinematics model.
  - The observation model will describe the error distribution of relative measurements. (distance, angle, etc.)
  - The kinematics model will describe the error distribution of moving trajectories.

SLAM Basics

- Solutions of the SLAM problem
  - Bayesian estimation.
  - For linear models and Gaussian error distributions – Kalman Filtering.
  - For nonlinear models and Gaussian error distributions – Extended Kalman Filtering (basically, it use some methods to linearize the models).
  - For nonlinear models and non-Gaussian error distributions – Rao-Blackwellized Filter (with the help of particle filtering or Monte Carlo sampling).

SLAM Basics



SLAM for us

- System model
  - Landmarks – APs for WLAN. (also think about if we could extract content information from those APs)
  - Movement controllers – wearable sensors and smart devices.
  - The computation is performed by smart devices.
  - For multi-user coordination, there may be a centralized server to collect results from different users and then dispatch the synthesized results. Some users can also play the roles of servers.

SLAM for us

- Challenges and system design issues
  - The Kinematics model
    - Data from motion sensors on smart-phones is not easy for us to use. Some restrictions are needed to depict the locomotion accurately. (can we leverage the information provided by wireless signals? For example, RSS from some APs may decrease significantly due to shadowing at corners.)
  - The observation model
    - This is the most difficult part due to the complexity of indoor environments. Traditional signal propagation models may become invalid and the error distribution is hard to predict.
    - What kind of sensing information should be used to build the observation model? (RSS, AoA, etc.)
  - How to combine ML and propagation based models to extract the above models?

SLAM for us

- Current design decisions
  - Use Angle-of-Arrival as the observation.
    - Only receiver-side requirements
    - Smart devices are commonly equipped with multi-antenna systems.
    - Different from other propagation models, the accuracy of angle estimation will be relatively high under LOS conditions and there is no requirement for tuning parameters.
    - Assume that CSI is retrievable.
  - Moving distances can be obtained by counting steps and we assume the attitude of smart devices is fixed so that the turning angles can also be successfully estimated.

Observation Model

- Detect LOS and NLOS situations
  - Implement and test some schemes from existing papers.
- Build and test the LOS observation model.
  - Mainly figure out the error distributions
- Test the AoA performance under NLOS situations.
  - Typical indoor scenarios?
  - Correlated factors? (distance, heights, etc.)