Motivations

WiFi fingerprint based indoor localization: one of the most promising solutions to ubiquitous location service. A key enabler to make it fully practical, however, remains unsolved: radio map updating.

- Ubiquity: Low deployment cost
- Crowdsourcing-based radio map automatic construction
- Sustainability: Long-term stability?

Automatically updating radio maps

Quality: High accuracy

Measurements of RSS Variations

Significant RSS variations:
- Small within a short term of several days, yet disperse to a considerable scale over a long term.
- Caused by environmental dynamics including transient interference, such as moving objects, door opening and closing, and prolonged dynamics like light, temperature, and humidity change.

As a consequence, a static radio map may gradually deteriorate or even break down, especially over long-term deployment, leading to grossly inaccurate location estimation.

Key Insights

The static power of mobile devices:

- Employ mobile devices as movable reference points to collect fresh fingerprints, which, if accurately localized, can be used to adapt the in-service radio map.

- Reference data (Fresh RSSs at its location)
- Continuous user trajectory (radio & sensor)

Basic rationale:

Certain underlying relationship of nearby RSSs may exist and remain relatively stable over time since neighboring locations reflect similar dynamic changes in the surrounding environments, even though the RSSs for every individual location greatly change.

Approach

AcMu: Automatic and Continuous radio Map Updating service for wireless indoor localization, with no additional hardware or extra user intervention.

Data Collection by Inertial Sensing

Pin Data: a bucket of “spot data” attached with a short tail of “trajectory data”. If static, collect sufficient RSSs; if moving, monitor a trajectory by the widely used dead-reckoning, which consists of step counting, orientation reckoning, and stride length estimation.

Reference Point Estimation by Trajectory Matching

A trajectory can be treated as a rigid structure, which holds the relative geometry information. Hence, the trajectory matching task can be treated as to superimpose a rigid structure in the location space, which can be done by a series of translation and rotation.

- Detecting feasible region from initial WiFi location estimation.
- Locking feasible orientation from trajectory direction.
- Joint location estimation to search for a set of candidate locations that satisfy the geometry constraints while minimize the fingerprint difference.

Radio Map Updating via Regression Analysis

Given newly collected fingerprints from a set of reference points \( \mathbf{R}_t = \{ r_{ij} \}_{i=1}^n \) at time \( t \), consider the \( j \)th AP at location \( l_i \), we aim to learn a functional relationship \( \mathcal{H}_{ij} \) from the radio map at time point \( t_0 \) as

\[
 f_j(t_0) = \mathcal{H}_{ij}(r_{ij}(t_0, r_{ij}(t_1), \ldots, r_{ij}(t_n)))
\]

where each \( f_{ij} \) denotes an RSS value at location \( l_i \). We learn the function by Partial Least Square (PLS) Regression, which is particularly suitable for our case where serious multicollinearity exists among observation variables. Then each \( f_{ij}(t_0) \) is updated to \( f_{ij}(t) \) according to the learned \( \mathcal{H}_{ij} \) with newly arrived RSSs from \( R_t \).

Experiments

Methods: RADAR-based KNN, Horus-based KNN, Trajectory-based

We prototype AcMu in a typical building for 20 days across a continuously running period of 6 months.

AcMu consistently yields accurate prediction, with average RSS residuals of less than 4dB after 3 and 6 days and around 4dB on the 9th day while 5.5dB for 6 months later.

AcMu provides up to 30% improvements on average localization accuracy by using the updated radio map even after a 6-month running, for both deterministic scheme like RADAR (left) and probabilistic scheme like Horus (right).

AcMu gains remarkable accuracy improvement of more than 2x with trajectory-based localization, compared to the static radio map (1.4m to 3m), over a long-term of 6 months.