Spatio-temporal Gaussian Process Based Radio Map Reconstruction

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1. INTRODUCTION

Over the past decade, the increasing use of Wifi technology has been implemented in real-world location based applications, especially in localizing clients holding mobile devices in indoor environments.
Unfortunately, the common outdoor positioning methods like GPS and WiFi hotspot-based wardriving efforts do not work reliable in indoor environments . So, an accurate alternative wireless positioning for indoors is needed. Fortunately, there have been many solutions proposed to locate indoor mobile clients due to widespread deployment of WiFi.

There are several method of Wi-Fi localization. Wi-Fi triangulation’ s goal is to map RSSI as a function of distance. This method requires a steep linear characterization curve in order to be properly implemented. Functions describing these curves are then used with live RSSI values as
input to generate an (x,y) location prediction.

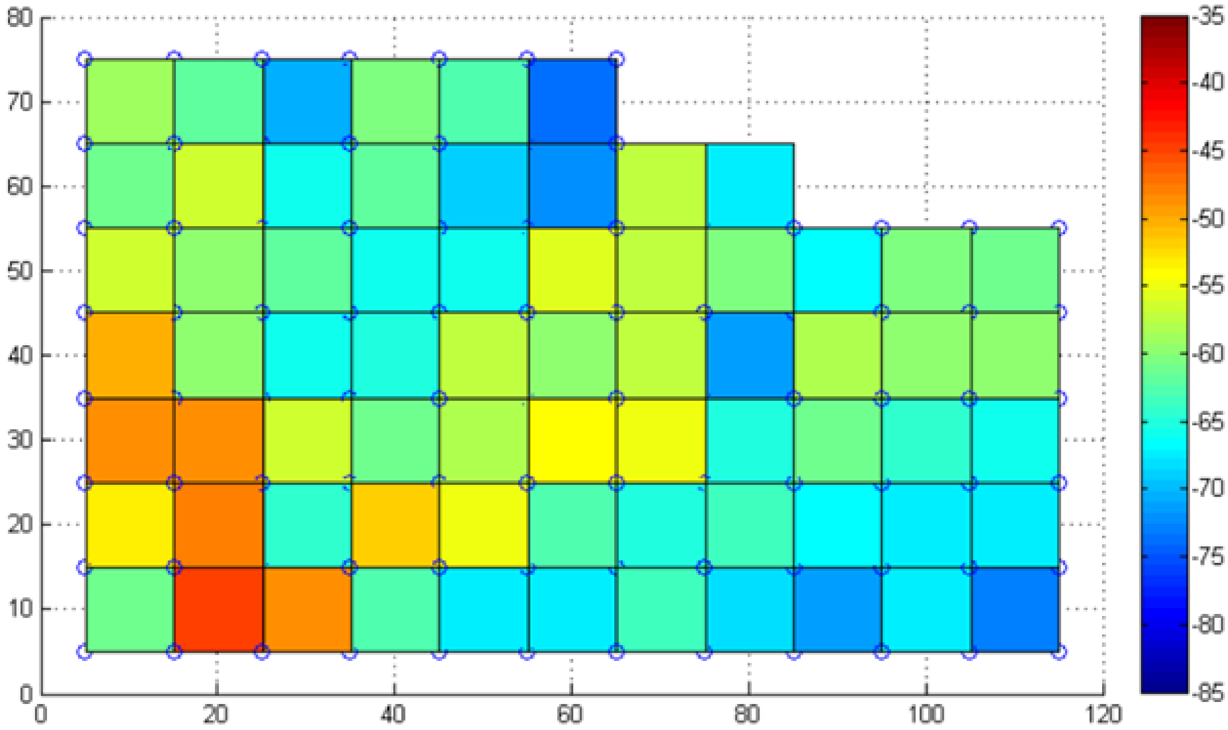
Most adopted solutions for indoor localization use fingerprinting of ambient environment signatures. According to
recent published literature , fingerprint methods outperform other methods and techniques (time-based, anglebased, and power-based techniques) in indoor positioning scenarios. At the same time, a more successful technique requires a substantial ‘pre-deployment’ effort by way of creating a radio map. Over the last decade, many algorithms have been proposed to model WiFi radio maps and use this to predict a mobile client’ s location from Received Signal

Strength Indicators (RSSI) values obtained from multiple
access points (APs).

1.1 Fingerprinting

Fingerprint wireless localization techniques is performed on two phases: offline phase and online phase. During the offline phase, the signal strength received from the access points at selected locations are stored in a database, resulting in a radio map. During the online phase, the system use the signal strength samples of mobile clients from the access points to search radio map to estimate the client’ s location. In general, radio map based techniques can be categorize into two groups: probabilistic techniques and deterministic techniques. In my work, I develops a new probabilistic techniques based localization system that increases the accuracy of indoor positioning.

In this way, we can understand that the bridge connect the two phase is the radio map. Here is a visualization example of radio map.



This is the radio map of one of the routers. We divide the whole space in to several blocks, as the picture shown. The color of each blocks indicates the RSS of the access point.

1.2 Challenges

The first problem is when we want to localize in a large environment,like large factory or supermarket, we may pay a large effort to construct the radio map of the environment.

Another challange with fingerprints is that they are vulnerable to several dynamic factors in candidate
locations.

The first kind of factors are *inherent factors*, such
as different candidate locations and changes of wireless channels over time when the client is standing at a fixed location.

Another kind of factors are *external factors*, such as WiFi
hardware variance problem: the WiFi device (training device) used to contrust radio

maps during the offline phase
differ from the WiFi devices (positioning device) used during
the online phase, or difference between positioning devices.
To handle such factors it is imperative to first understand
the impact of these factors. The experiments described later
indicate how these factors influence the accuracy of localization. Further, we also consider these factors into our indoor localization system model.

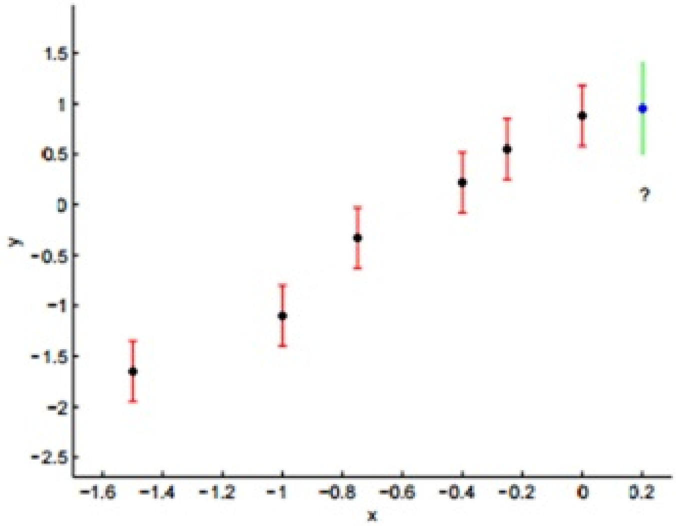
2 Aim

- Use part of the data to reconstruct the whole radio map
- Use these data to predict the radio map
- Construct the transfer function model between different device

3 Gaussian Process

3.1 Motivation

When we are given a training set $D=\{(x_i,y_i)|i=1,\dots,n\}$, we want to da regression on this data set, which means when we are given a new input, regression must give the output y for this input. For the Linear data set we can use linear regression to predict it. However, for common data set, linear regression will not work quite well, in this way we need Gaussian Process.



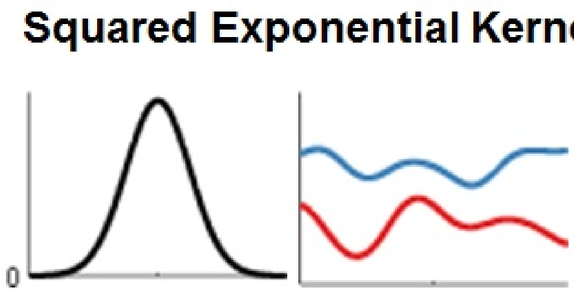
3.2 Definition

We assume $y = \{y_1, y_2, \ldots, y_n\}$obey multivariate Gaussian distribution.That is:$\mathbf{y}$ ~ $\mathcal{N}(0, K)$.Here, K is:

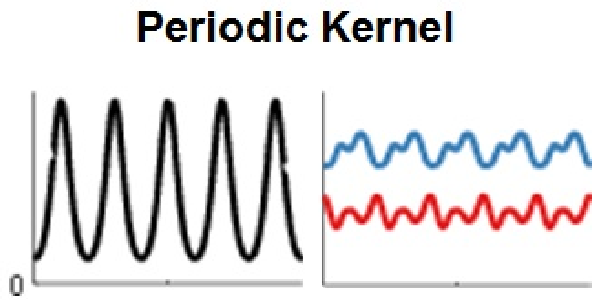
$$K = \begin{bmatrix} k(x_1, x_1) & k(x_1, x_2) & \cdots & k(x_1, x_n) \\ k(x_2, x_1) & k(x_2, x_2) & \cdots & k(x_2, x_n) \\ \vdots & \vdots & \ddots & \vdots \\ k(x_n, x_1) & k(x_n, x_2) & \cdots & k(x_n, x_n) \end{bmatrix}$$

Since we assume that the mean of the distrubition is zero. We only should force on the convariance function, which also called kernel function is the Guassian Process.

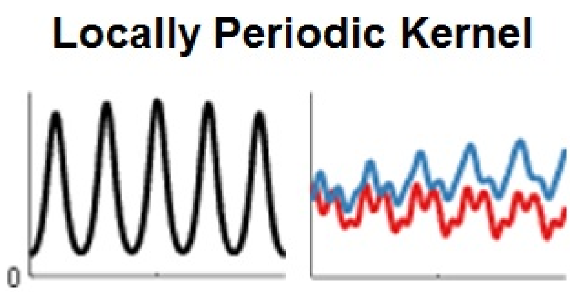
There are many kinds of kernel function, like Squared Exponential Kernel, Periodic Kernel, and so on.



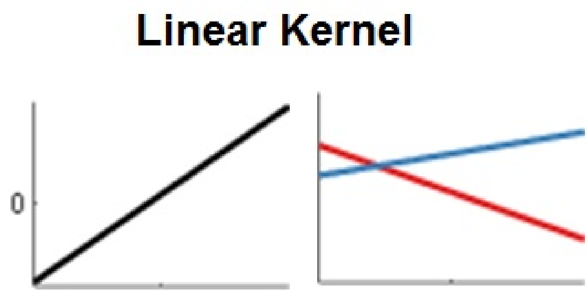
$$k_{\mathrm{SE}}(x, x') = \sigma^2 \exp\left(-\frac{(x-x')^2}{2\ell^2}\right)$$



$$k_{\mathrm{Per}}(x, x') = \sigma^2 \exp\left(-\frac{2\sin^2(\pi|x-x'|/p)}{\ell^2}\right)$$



$$k_{\mathrm{LocalPer}}(x, x') = k_{\mathrm{Per}}(x, x')k_{\mathrm{SE}}(x, x')$$



$$k_{\mathrm{Lin}}(x, x') = \sigma_b^2 + \sigma_v^2(x-c)(x'-c)$$

We should choose the proper kernel when we do regression.

3.3 Regression

When there is a new input *x*,

$$\begin{bmatrix} \mathbf{y} \\ y_* \end{bmatrix} \sim \mathcal{N}\left(\mathbf{0}, \begin{bmatrix} K & K_*^{\mathrm{T}} \\ K_* & K_{**} \end{bmatrix}\right)$$

where,

$$K = \begin{bmatrix} k(x_1,x_1) & k(x_1,x_2) & \cdots & k(x_1,x_n) \\ k(x_2,x_1) & k(x_2,x_2) & \cdots & k(x_2,x_n) \\ \vdots & \vdots & \ddots & \vdots \\ k(x_n,x_1) & k(x_n,x_2) & \cdots & k(x_n,x_n) \end{bmatrix}$$

$$K_* = \begin{bmatrix} k(x_*,x_1) & k(x_*,x_2) & \cdots & k(x_*,x_n) \end{bmatrix}$$

$$K_{**} = k(x_*,x_*).$$

The aim of this regression is get the *y** for the input. Using the Bayesian Regression,we can get

$$y * |\mathbf{y} \sim \mathcal{N}(K * K^{-1}, K * * - K * K^{-1} K_*^T)$$

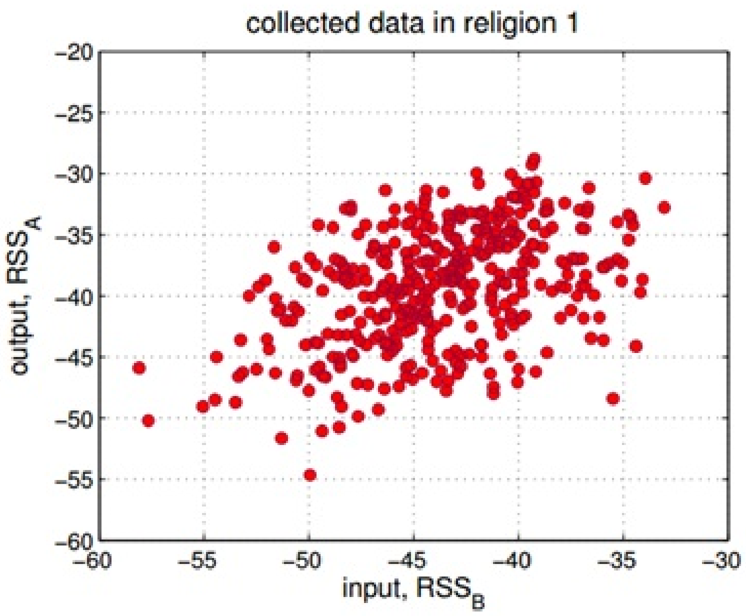
The mean of *y** then is $\overline{y_*} = K_* K^{-1} \mathbf{y}$

The variance is $var(y_*) = K_{**} - K_* K^{-1} K_*^T$

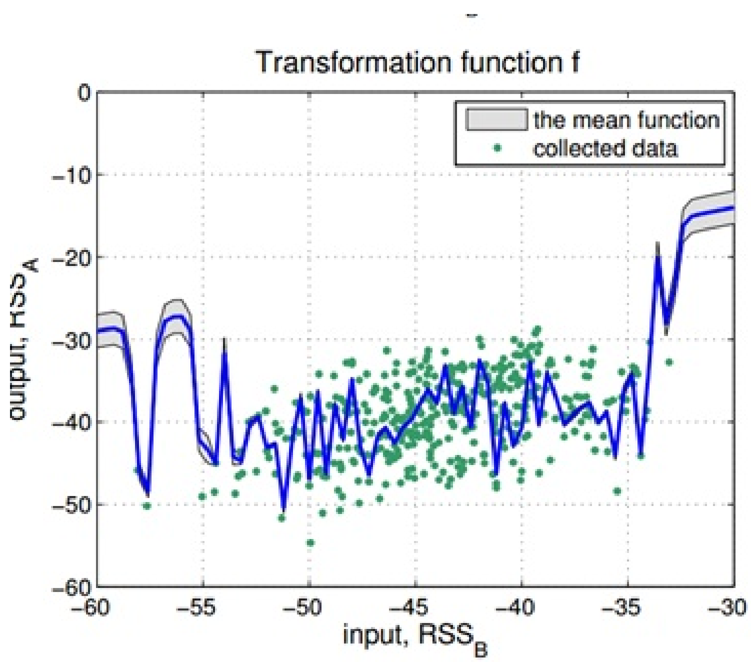
4 Radio Map Reconstruction Model

4.1 Transfer Function

We want to find the transfer fuction between different device.We use different devices get RSSI data from a big classroom with four Wi-Fi APs



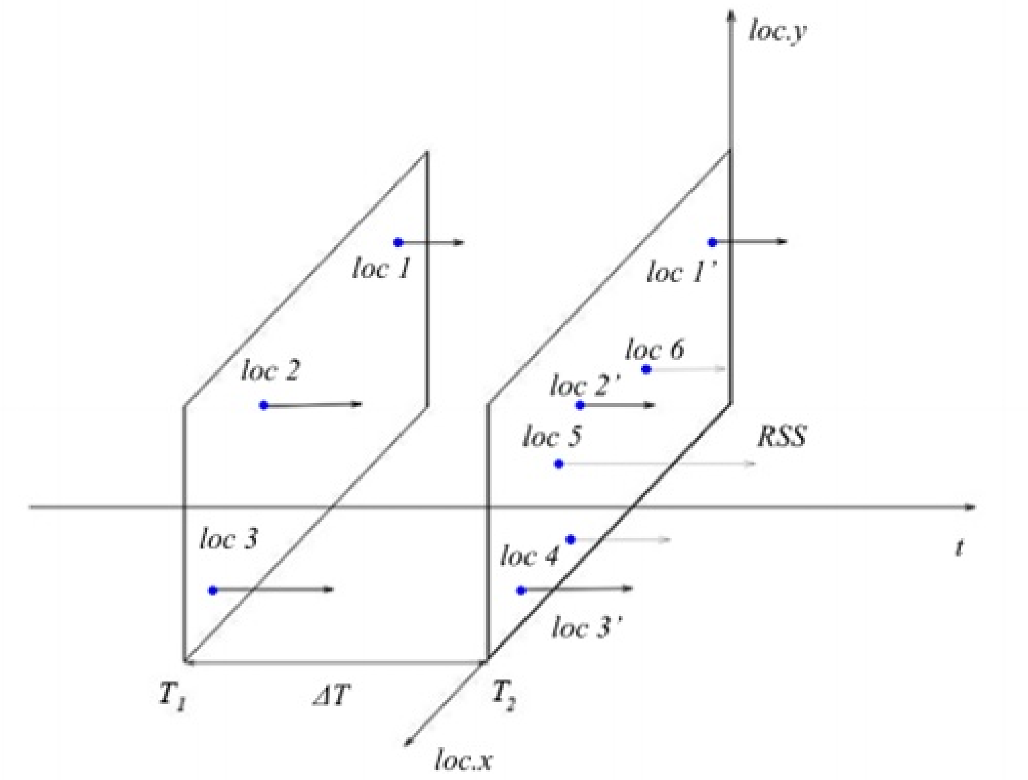
We suppose device A is the standard device.In this given location, device A and another device B all get the RSS fromthe same AP. We suppose that the RSSA is the standardvalue, and RSSB should be mapped to RSSA collected bydevice A.
Then we use Gaussian Process to do the regression, illustrated by the following figure.



In this way, for a new input RSS value collected by device B we can map it to the standard device A.

4.2 Spatio-temporal model

The other model we need to construct is using limited data of a given space at a given time to predict the value of the space we do not collect the RSS and the RSS value in the future.
The following figure can illustrate how the model works.



We first get the value from *loc1,loc2,loc3* and *loc1',loc2',loc3'*, then use Guassian Process to get the value of *loc4 ,loc5, loc6* at T_2.

5 Future Work

Fisrt, we should combine the Spatio-temporal model and transfer model into a signal Gaussian Process mode. Then we should use the new data collected by Hawei Company to evaluate our model.