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Improving Indoor Positioning via Machine Learning

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Keywords: Bluetooth Low Energy, Indoor Positioning, RSSI, Machine Learning, Support Vector Machine.

Abstract: The problem of real time location system is of current interest. Cities are growing up and buildings become more complex and large. In this paper we will describe the indoor positioning issue on the example of user tracking, while using the Bluetooth Low Energy technology and received signal strength indicator(RSSI). We experimented and compared our simple hand-crafted rules with the following machine learning algorithms: Naive Bayes and Support Vector Machine. The goal was to identify actual position of active label among three possible statuses and achieve maximum accuracy. Finally, we achieved accuracy of 0.95.

1 INTRODUCTION

The problem of positioning in indoor space is relevant and include many complex substasks. The main problem that will be discussed in this paper is the user tracking in a defined environment. We are interested in the detection of signal source's position among three distinguished parts of the building entrance: outside of the building, in vestibule and inside of the building. Our goal is to estimate and compare machine learning algorithms and our hand-crafted rules in position detection.

Main items of our indoor positioning system are as follows: • base station - device that listen for active label advertising and send its rssi to the desktop server software; • active label - Beacon that act as BLE advertiser; • server software calulate the active label position and save data to database

We are using Bluetooth Low Energy(BLE) compatible devices, Beacons, as active labels because of their sufficiently small size, low battery consumption, lower cost. Beacon is based on Bluetooth low energy proximity sensing by transmitting a universally unique identifier picked up by a compatible app or operating system. Position calculation based on the RSSI values. Since beacon transmit radio waves, RSSI value oscillate influenced by absorption, interference and diffraction effects. In this case, there should be implemented special filter to make RSSI amplitude lower.

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2 RELATED WORKS

In the work (Mussina and Aubakirov, 2018), we have estimated the RSSI filtering algorithms, such as: median, mode, single direction outlier removal, shifting and feedback filtering.

- Mode method counts occurrences of each RSSI value and finds RSSI with maximum occurrences.
- Median method sorts all RSSI values at first, then it chooses RSSI in the middle of the list.
- SDOR presented in work (Chai et al., 2016) uses ten recent RSSI values to calculate threshold. Their mean $(rssi_{mean})$ and standard deviation $(rssi_{std})$ of these ten RSSI are calculated. Any RSSI that is below $(rssi_{mean} - 2 * rssi_{std})$ is removed from the stored RSSI. Then the average value of the remaining RSSI, $rssi_p$, is the preprocessed RSSI and used in next calculations.
- Feedback filtering based on idea that RSSI of round n-1 affect RSSI of round n, see formula (1). The average value of all calculated RSSI is corresponding to smoothed RSSI value. See example in figure 1.
- Shifting filtering based on the same idea as a feedback filtering except the definition of a round. In shifting filtering, round is a period of 3 seconds. During round system gets number of RSSI, and if it is first round it calculates the average value of all received RSSI, else it use formula (1), where $RSSI_n$ is received RSSI and $RSSI_{n-1}$ is smoothed average value of previous round. The average value of all calculated RSSI is corresponding to

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smoothed RSSI value of round n. See example in figure 2.

$$RSSI = \alpha * RSSI_n + (1 - \alpha) * RSSI_{n-1} \quad (1)$$

, where α is a coefficient and equal to 0.75.

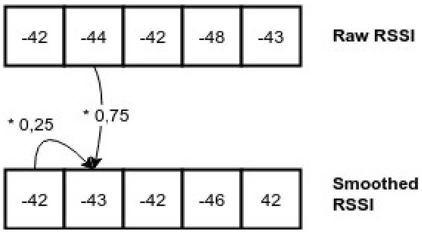

Figure 1: Feedback filtering example.

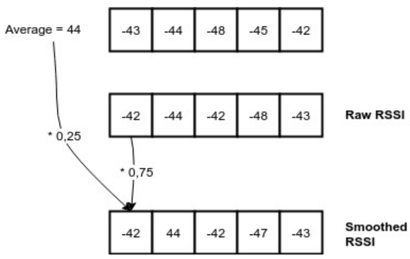

Figure 2: Shifting filtering example.

Comparison of RSSI filtering algorithms shows feedback and shifting as the best filter among presented. In further calculations we used feedback filtering.

The machine and deep learning have been used in localization problem solving during last years. The work (Ibrahim et al., 2018) described the deep learning approach on the example of Convolutional Neural Networks. The main difference of (Ibrahim et al., 2018) research among other is in a usage of RSS time-series to reduce the noise. Authors used public dataset (Torres-Sospedra et al., 2014) focused on WLAN fingerprint-based indoor localization technique. It consists of 529 features that can describe in what building, floor and position user with smart phone is located. Authors achieved accuracy of 100% in prediction of building and floor. For estimation of coordinates prediction the mean error was used. Task and experiment of current article is specific and we need to collect our own dataset for training and testing the models. We also rely on the idea that series of RSSI among time should produce better results.

Convolutional Neural Networks also implemeneted in (Iqbal et al., 2017). The purpose of real time location system in (Iqbal et al., 2017) was to monitor clinical workflow and track patients. Authors combined CNN with Artificial Neural Network (ANN) and got better accuracy than with single CNNs.

Together with Neural Networks, work (Qathrady and Helmy, 2017) examine the machine learning techniques such as Linear Regression, Decision Trees and Random Forests. Authors made deep research on transmission power value, TX power, which improved classification accuracy.

The choice of machine learning algorithms was based on the work (Ahmadi and Bouallegue, 2017), which shows a survey on machine learning techniques for localization using RSSI. The conclusion of the article presented perfomance evaluation of Naive Bayes, Decision Tree, Support Vector Machines, Artificial Neural Network and k Nearest Neighbors techniques. The Naive Bayes approach showed lower localization error with Decision Tree and Support Vector Machines. We suppose that solution of the localization problem should be simple. Therefore, handcrafted rules will be compared with Naive Bayes and Support Vector Machines techniques.

Finally we will try to compare localization accuracy between our system and some systems presented in mentioned above papers.

3 METHODS

The main task was to identify active label position during its path from outside of the building to inside and vice versa. We have many active labels that go between two base stations placed at the edges of the vestibule, figure 3. In our experiments we avoid smartphones, since work (Mussina and Aubakirov, 2018) shows smartphone make RTLS dependent on its signal receiving capability.

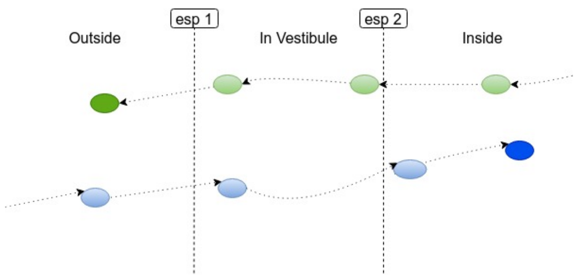

Figure 3: Experiment visualization.

Main statuses for active labels are INSIDE, IN_VESTIBULE and OUTSIDE. Secondary statuses are LOST_INSIDE, LOST_OUTSIDE and LOST_UNKNOWN. Secondary statuses are determined by simple rules, based on received signal or previous status:

- If base station one, esp1 from figure 3, received signal and base station two, esp2 from figure 3, did not receive signal, then active label is lost somewhere outside of the building.

- If base station one did not receive signal and base station two received signal, then active label is lost somewhere inside.
- If no base station received signal, then determine by previous status.
  - Active label is lost inside, if previous status was INSIDE.
  - Active label is lost outside, if previous status was OUTSIDE.
  - Active label status is LOST_UNKNOWN, if previous status was IN_VESTIBULE.

The main research was directed at the determining status, when both base station received signals from active labels. We tried two approaches: hand-crafted rules and machine learning.

3.1 Dataset

At first, let us introduce some common definitions of classification applicable to our problem, to make further explanations more readable and understandable. Classification is a task of assigning a target value $t_i \in T$ to each vector $\langle d_1, d_2, ..., d_M \rangle \in D$, where D is a domain of features, M is a total number of features and T is a target values array. Features in our case are RSSIs from two base stations and target values are $T = \{INSIDE, IN\_VESTIBULE, OUTSIDE\}$.

Initially domain vector has size $M = 2$, $D = \{RSSI_1, RSSI_2\}$. However, after first test we guessed that machine learning can be improved by increasing RSSI vector size M. Finally, we have experimented with different vector's sizes. For example, if we would like to take into account 3 last RSSIs from both base stations, then $M = 6, D = \{RSSI_{1,1}, RSSI_{1,2}, RSSI_{1,3}, RSSI_{2,1}, RSSI_{2,2}, RSSI_{2,3}\}$

In the subsection 4.2 we will show work of machine learning approach on different RSSI vectors.

3.2 Hand-crafted Rules

In theory, graph with RSSI from both base station and one active label should look like in figure 4. It is obvious that esp1's RSSI will be higher than esp2's RSSI, if Beacon, active label, will be outside. Similarly, esp2's RSSI will be higher than esp1's RSSI, if Beacon will be inside. Determining Beacon's status in vestibule is the most difficult part of the research. In vestibule active label could be closer to esp1 or esp2, our hand-crafted rule based on the direction of pair of RSSIs, as depicted in figure 5. The domain vector looks like $D = \{RSSI_{1,1}, RSSI_{1,2}, RSSI_{2,1}, RSSI_{2,2}\}$. For example, if domain vector look like $D = \{-76, -73, -80, -90\}$, then active label is in vestibule. All rules can work, if base stations are the same and there are no obstacles between Beacon and stations. Conditions for statuses look as follow:

1. INSIDE
   - RSSI from esp1 lower than RSSI from esp2
2. IN_VESTIBULE
   - RSSI from esp1 and esp2 are equal
   - RSSI values from esp1 decrease and RSSI from esp2 increase, figure 5 upper X-axis
   - RSSI values from esp1 increase and RSSI from esp2 decrease, figure 5 lower X-axis
3. OUTSIDE
   - RSSI from esp1 greater than RSSI from esp2

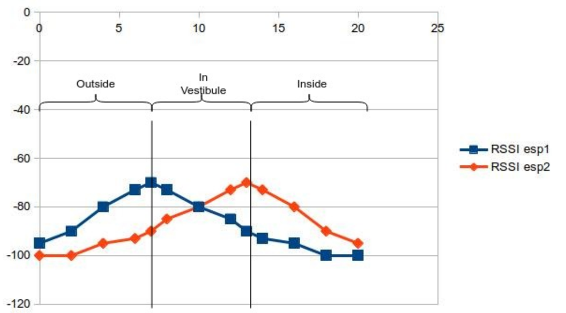

Figure 4: RSSI from both base station in theory.

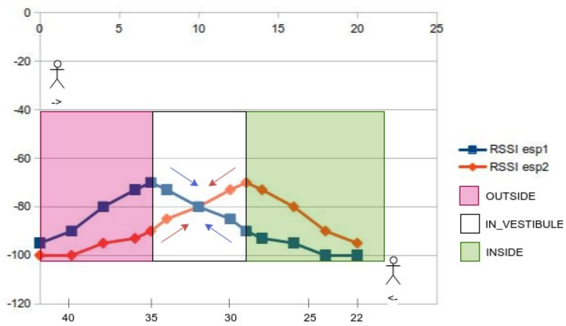

Figure 5: RSSI with directions.

3.3 Machine Learning Algorithms

We chose Naive bayes and SVMs algorithms for our research. For both approaches we used Orange library. The Naive Bayes(NB) is a supervised learning algorithm that can be used with continuous variables. NB technique based on the Bayes' theorem with the feature independence assumption. This independence plays role during calculation of conditional probability, formula 2.

$$P(c|x) = \frac{P(X|c)P(c)}{P(x)} \quad (2)$$

, where $P(c|x)$ - posterior probability of given class value c and feature value x, $P(c)$ - class prior probability, $P(x|c)$ - likelihood, probability of x with given c, $P(x)$ - predictor prior probability.

Support Vector Machine(SVM) classification approach is another supervised algorithm that construct optimal plane, hyperplane, separating smaples by their classes. SVM defines the classification function as in formula 3.

$$f(x) = sign(\langle w,x\rangle + b) \quad (3)$$

, where $\langle , \rangle$ is the scalar product, w is the normal vector to the separating hyperplane, b is an auxiliary parameter.

4 EXPERIMENTS AND DISCUSSION

Experiments consists of two main parts: data collection and data processing.

4.1 Data Collection

At first, we needed to collect dataset with RSSI from two base station and appropriate class, since machine learning algorithms need sufficiently large dataset to obtain model of prediction.

Assumptions:

- The base station performed by ESP-WROOM-32 devices. ESP-WROOM-32 is an Espressif's miniature high-performance, combined Wi-Fi + Bluetooth + BLE module, designed for a wide range of applications. It is made on the basis of the popular dual-core chipset ESP32. Device is small, cheap and easy programmable on C language.
- Size of environment was 18.35m x 3m. Base stations are located at the distance of 2.35 meters at the center, where vestibule supposed to locate. Imagined outside and inside area was of 8m length.
- The active label performed by iTAG product based on the Bluetooth 4.0 version. iTAG is a kind of Bluetooth Low-energy product. It is also cheap and sufficiently small to go with it.
- iTAG devices devided to three group by color: pink, white and green. Each group located at the appropriate class position, see figure 6.
- During 20 minutes, trainee walk with iTAG in different directions within their class position such that iTAGs are not stand still.
- Environment is Non Line of Sight Channel(NLOS). NLOS occurs when there are obstructions between the source and receivers, which can cause large positive biases in the corresponding distance information (Zekavat and Buehrer, 2012). Obstacles such as human body and all activated iTAG devices are presented.

Base station scan for signals from iTAG devices every 100ms among 1 second. After 1 second, base station sends collected signals' information to the software server. The signal's information consists of base station's id, iTAG address and RSSI. Server software accept data, filter RSSI among each received iTAG and save data to database. Also it saves iTAG address to the list of active devices. Another software thread reads each second RSSIs from database for iTAG devices which are in the list of active devices. Thread reads from database the last saved within 5 seconds RSSI from both base stations and save new sample to database. After saving thread removes iTAG from active device list.

Collected dataset shown in table 1.

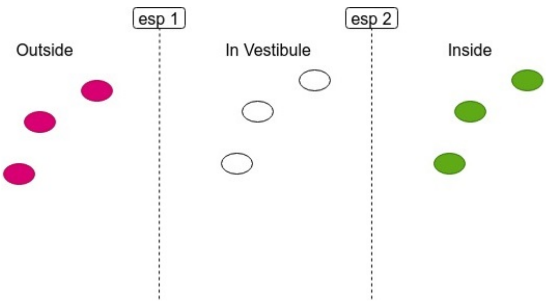

Figure 6: Data collection.

Table 1: Dataset.

	all	train	test
Dataset	9984	7988	1996
INSIDE	3165	2532	633
IN_VESTIBULE	3423	2739	684
OUTSIDE	3396	2717	679

4.2 Data Processing

In subsection 3.1, we desribed classification domain which is constructed as a series of RSSI by time. Producing such domain vectors caused problem of finding the exact size M of the domain vector D. Considering the velocity of human walk, which is 1.38 m/s, we assumed that it is needed to process RSSIs received at each second. During this experiments our iTAG devices were not configured to pass exact number of signals per seconds. Analysis of dataset give us that maximum number of received RSSI values from one device during one second is four, but this number is not usual for our dataset. Usually we got two or three RSSI values per second from each device. For this research we will take into account vector size from 1 to 4, as the absolute minimum and absolute maximum numbers of RSSIs values that could be received per second.

Subsection 3.2 described the view of RSSI from two base station in theory. Results from the test were different as expected. Figures 7 and 8 show RSSI filtered and non-filtered respectively.

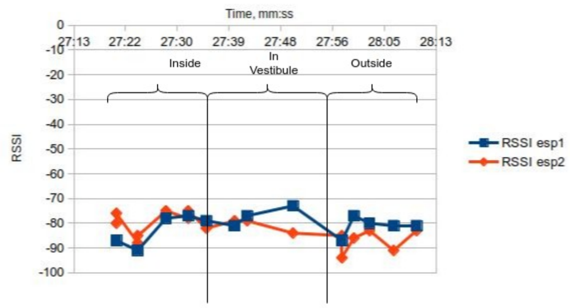

Figure 7: RSSI filtered.

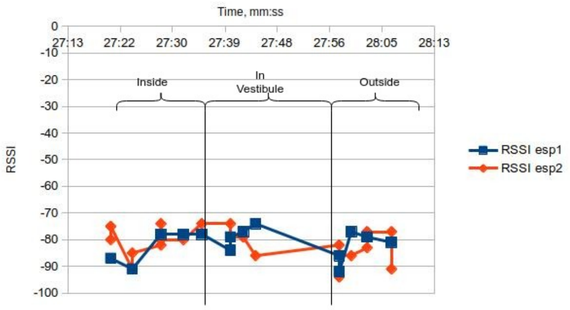

Figure 8: RSSI non-filtered.

Filtered RSSI looks more reliable. In outside part non-filtered RSSI from esp2 sometimes is greater than RSSI from esp1, which is not correct in theory. Contrariwise, filtered RSSI from esp1 in outside part is greater than from esp2, which is theoretically true.

We checked the assumption that machine learning approach could work better on non-filtered RSSI. All approaches were estimated by *accuracy*. Table 2 shows accuracy for non-filtered RSSI.

Table 3 demonstrates the accuracy of examined techniques that worked with filtered RSSI and at the same time depicts the results of works (Iqbal et al., 2017) mentioned as CNN+ANN and (Qathrady and Helmy, 2017) mentioned as TX, for half a meter estimation. Hand-crafted rules showed lowest prediction capability.

Table 2: Accuracy of all examined approaches on non-filtered RSSI.

Technique	*accuracy*
Hand-crafted rules	0.5136
Naive Bayes, vector_size = 1	0.6752
Naive Bayes, vector_size = 2	0.760
Naive Bayes, vector_size = 3	0.821
Naive Bayes, vector_size = 4	0.838
Support Vector Machine, vector_size = 1	0.6734
Support Vector Machine, vector_size = 2	0.768
Support Vector Machine, vector_size = 3	0.834
Support Vector Machine, vector_size = 4	0.855

Table 3: Accuracy of all examined approaches.

Technique	*accuracy*
Hand-crafted rules	0.5836
Naive Bayes, vector_size = 1	0.739
Naive Bayes, vector_size = 2	0.842
Naive Bayes, vector_size = 3	0.883
Naive Bayes, vector_size = 4	0.926
Support Vector Machine, vector_size = 1	0.741
Support Vector Machine, vector_size = 2	0.881
Support Vector Machine, vector_size = 3	0.927
Support Vector Machine, vector_size = 4	0.958
CNN+ANN	0.999
TX, half a meter	0.950

Machine learning algorithms showed better accuracy than hand-crafted rules. Mainly hand-crafted rules can't work with unstable RSSI values, unless values will be fileterd sufficiently enough for rules. Machine learning demonstrates better results on filtered RSSI.

Comparing accuracy from table 2 and table 3 we can conclude that filtereing has improved accuracy for a little bit.

SVM approach on data with RSSI's vector of size 4 presented better result among our approaches. Comparing with (Iqbal et al., 2017) and (Qathrady and Helmy, 2017) it has lower accuracy. The reason could be in training datasets, because (Iqbal et al., 2017) has 5 times more base stations which lead to more data and the (Qathrady and Helmy, 2017) had 1.8 million records of RSSI. Also estimation of TX power approach was held in clear environment with no obstacles. In future works we will consider deep learning approach and try to increase performance by Neural Networks.

5 CONCLUSIONS

We have used only two classification algorithms, Naive Bayes and Support Vector Machine, that is very small number. However, this research shows that machine learning is applicable for localization problem and it is more effective than hand-crafted rules. Also classification approach works better on filtered RSSI and with more RSSI-features in dataset. In future we will look for better filtering algorithm. Our next research goals are experiment with bigger dataset, compare filtration and classification algorithms within this experiment of entry/exit, implement Neural Networks. After tests we got the assumption, that classification may produce better results if we combine machine learning algorithms results with majority rule. The main part in machine learning process is dataset collection, which is very laborious process, that must be clear and accurate. We will experiment with time of scanning and RSSI receiving time matching between two base station. Finally, machine learning and RSSI filtering make user tracking problem sufficiently solvable. We achieved accuracy of 95.8%.

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