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Wi-Fi Based Inertial RSS and Fingerprinting using Multiagent Technology

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Abstract**—** First, the costly offline process of RSS map construction in conventional fingerprint-based localization is removed by the use of inertial sensors. To collect RSS fingerprints automatically and proposed system conducts inertial sensor-based self-localization and estimates. Second, we successfully constructed the collective fingerprint map by a credibility-based user collaboration scheme. The proposed system is based on a passive user inertial method, which collects and uploads fingerprints automatically in daily life using MAS. We show how to handle multiple floors and stairways, how to handle symmetry in the environment, and how to initialize the localization algorithm using Wi-Fi signal strength to reduce initial complexity.

Keywords**—Inertial sensors, location fingerprinting, Multiagent Technology (MAT), Wi-Fi-based fingerprinting, Received Signal Strength (RSS).**

I. INTRODUCTION

LOCATING mobile objects is an essential function needed by location-aware applications in pervasive computing environments [1], [2]. The Global positioning system (GPS) [3] has commonly been used in outdoor environments and been widely adopted in modern mobile devices such as smartphones. In indoor environments, however, no outstanding solution has been found due to practical issues which are related to complicated infrastructure requirements. Conventional mechanisms for indoor node localization are based on various types of infrastructure support, which include received signal strength (RSS) fingerprints [4], ultrawideband (UWB) [5], ultrasound [6], radiofrequency identification (RFID) [7], inertial measurement units (IMUs) [8], etc. Among the diverse approaches for indoor node localization, the RSS-based fingerprinting system is considered practical since the system can easily be deployed using the current wireless(i.e.,IEEE802.11 Wi-Fi infrastructure).

Several issues should be considered for the practical use of the RSS fingerprint-based localization. In particular, constructing a high-quality RSS fingerprint map is an essential part of the system since localization accuracy highly depends on fingerprint quality. The RSS map-building process typically requires an extensive and thorough site surveying, usually done manually with specific hardware and software tools. Much effort has recently been given to reducing the cost and complexity of fingerprint map building.

SYSTEM OVERVIEW

The proposed system consists of mobile users and the fingerprint server. The mobile users automatically collect the RSS fingerprints for Wi-Fi APs in the vicinity while localizing their position based on their smartphones. The fingerprint server constructs a collective RSS map by integrating individual fingerprints received from the mobile users; then it supplies the map to newly entered users for localization or even back to the mobile users to further enhance the localization accuracy. Fig. 1 illustrates the overall structure of the proposed system. The localization of the mobile object is achieved in three steps: local collection of the RSS fingerprints, construction of the global RSS fingerprint map, and the localization process.

We first propose an Itinerary Energy Minimum for First-source-selection (IEMF) algorithm, which extends LCF by considering the estimated communication cost.

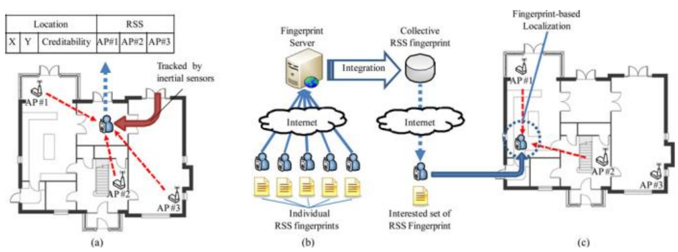


Fig:1 System overview. (a) RSS fingerprint collection. (b) Collective RSS fingerprint construction. (c) Fingerprinting-based localization.

PROPOSED MULTI-AGENT ITINERARY PLANNING ALGORITHMS

A. Estimated Communication Cost of a Candidate Itinerary

We first show how to estimate the communication cost of a given itinerary $t / S[1] / S[2] / \ ,,, \ / S[n] / t$, which means that an agent starts from sink *t* and returns back to *t* after visiting n source nodes, as shown in Fig. 1. Generally, the communication energy consumption for a packet transmission at a given node consists of the receiving energy, the control energy, and the transmitting energy. Let e_{ctrl} be the energy spent on control messages exchanged for a successful data transmission (e.g., acknowledgement). Let m_{rx} and m_{tx} be the energy consumption for receiving and transmitting a data bit, respectively.

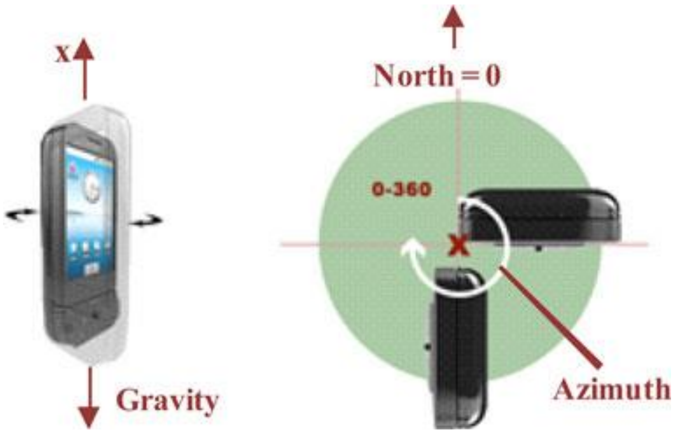


Fig: 2. **Overall process to determine the direction of movement axis. We first find the relative horizontal plane to the ground and determine the movement axis by the initial direction of movement.**

Let c_{tx} denote the fixed energy cost for each transmission, which is independent of the packet length. Without loss of generality, we assume that m_{tx}, m_{rx}, c_{tx}, and e_{ctrl} are the same for every node. Let l_{rx} and l_{tx} be the sizes of a received and a transmitted packet, respectively. When a node receives a packet with size of l_{rx}, after local processing, the size of a transmitted packet by this node (l_{tx}) is different. The communication energy consumption at a node (i.e., an intermediate node or a source node) can be expressed as

$$e(l_{\mathrm{rx}}, l_{\mathrm{tx}}) = m_{\mathrm{rx}} \cdot l_{\mathrm{rx}} + (m_{\mathrm{tx}} \cdot l_{\mathrm{tx}} + c_{\mathrm{tx}}) + e_{\mathrm{ctrl}}.$$

Multiple hops may exist between two adjacent source nodes, e.g., $S[k-1]$ and $S[k]$. Let $d(S[k-1], S[k])$ denote the distance between the two source nodes. In a dense WSN, we can estimate the hop count between $S[k-1]$ and $S[k]$ as $H^{k}_{k-1} = \_d(S[k-1], S[k])/R\_$, where R represents the maximum transmission range. When the agent traverses intermediate sensor nodes (not the source nodes), the agent size remains the same.

SINGLE-AGENT ITINERARY PLANNING PROBLEM

A. Data Aggregation Model

The degree of correlation between sensory data from two sensor nodes is closely related to the distance between them, as well as a particular application scenario. Typically, closely located sensors are very likely to generate data with high redundancy. In densely populated WSNs, data aggregation becomes a very important function for energy conservation, which reduces the redundancy in sensor data and, thus, decreases the volume of data to be transmitted. Many traditional data aggregation schemes exploit a specific network structure (e.g., a cluster based network [2] or forming a data aggregation tree structure [9]). In MA-based WSNs, an MA visits the source nodes one after the other. At each source node, the MA collects sensory data and then performs data aggregation and removes any existing redundancy, depending on the data aggregation function. There is no need for a specific topology structure. However, the data aggregation and energy performance are highly dependent on the order in which the source nodes are visited, i.e., the itinerary. Consider an MA dispatched by the sink node to collect data from n source nodes. Let l_{proc} be the size of the MA processing code, S_{head} be the size of the agent packet header, and l^{0}_{ma} be the agent size when it is first dispatched by the, sink node. Then, we have $l^{0}_{ma} = l_{proc} + S_{head}$. Let $r \in [0, 1)$ be the reduction ratio in sensory data by agent-assisted local processing and l_{data} be the size of raw data at a source node. The reduced data payload collected by the agent at each source, which is denoted by l_{rd}, is $l_{rd} = (1 - r) \cdot l_{data}$. Let l^{k}_{ma} be the agent size when it leaves the kth source ($1 \leq k \leq n$). Since there is no data aggregation at the first source, we have $l^{1}_{ma} = l^{0}_{ma} + l_{rd}$.When the agent visits the second source node, it begins to perform data aggregation to reduce the redundancy between the data collected at the current source and the data it has carried.

Let $\rho \in [0, 1]$ denote the data aggregation ratio, which is a measure of the compression performance. The MA size, after it leaves the second source node, is $l^{2}_{ma} = l^{0}_{ma} + l_{rd} + (1 - \rho)l_{rd}$, and so forth. For the sake of simplicity, we assume that r, ρ, and l_{data} are identical for every source.1 After visiting the kth source node.

ABILITY AND STRUCTURE OF lOSES

The lOSES is the development and breakthrough of managing experiment methodology and the computer simulation Technology. This system may apply in the operating decisions of enterprises, the government management decision, the rmy directing decision, colleges and universities education training domains and so on.

1) The formulation of each kind of solution. Using this system's plan subsystem, the user may input the questions to be solved, the parameters of the question, and anticipated targets in the man-machine contact surface. The system searches the similar question on the database and the Internet, and fmds optimal solutions according to the parameter and

the goal and gives less than three simulation results. If not found or the user feels unsatisfied, it may carry on the machine plan. The system constructs solutions on the basis of question category, parameter, goal and existing logics, and the user may use system compiler to edit logics. Theuser may make the revision to the plan.

2) Appraisal of each kind of solution. Using this system's appraisal subsystem, the user may draw up the plan; input the implementation environment parameter, the anticipated target in the man-machine contact surface. The system carries on the classification and the standardization to the plan (transforms system approval data format), carries on the logical reasoning simulation according to the appraisal logic under the environment parameter which the user provides and carries on the comparison with the user's goal, and it gives the measuring results. The user may edit the appraisal logics, request the system to search the similar plan on the database and the Internet and carries on the logic reasoning to compare and to give the comparison conclusion, the user makes the plan revision according to the conclusion.

3) Choices of each kind of solution.

Using this system's policy-making subsystem, the user may input the multi-wrap solution in the man-machine contact surface (to be directly carried on by the 3D modeling, the 2D modeling or text description) and the targets which the plan needs to display. The system carries on the simulation on the basis of the solution, the environment parameter proposed by the user, and carries on the quantitative analysis to the targets which are cared by the user, gives the divided target experiment conclusion and the total performance experiment conclusion to be chosenby the user. 4) Strategy gambling of each kind of solution. Using this system's gambling subsystem, the user may carry in-line resistance or the man-machine resistance (by on-line resistance primarily). The user draws up the good solution using the man-machine contact surface according to the step input, the system carries on the simulation to the strategy according to certain logic rules and all resources, then will feedback the adjudicated statement to the user, the various users make the plan of next step according to the situation and then implement. When the gamble achieves the finishing condition, the system feedback all quarter's simulation results of victory and defeat, profit and loss. This method is suitable for military struggle gambling and the enterprise management gambling, may examines organization's strategy feasibility and the probability of victory anddefeat.

Accuracy of Collective Fingerprints

We evaluated the quality of collective fingerprint, which is constructed with multiple instances of LFs. First, we analyzed the coverage and the accuracy of the collective fingerprint according to the number of LFs.

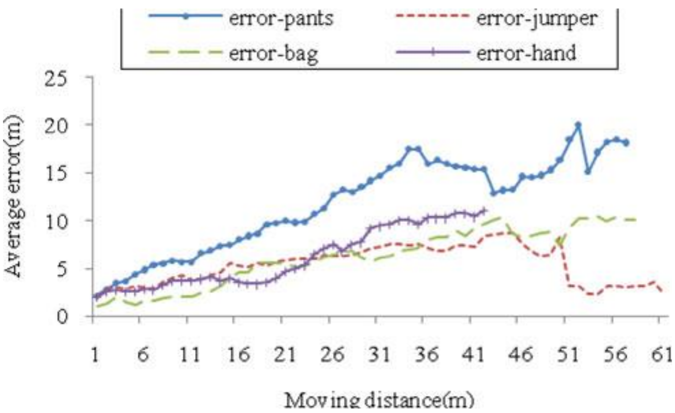
DISTANCE ORDERS OF OTHER SOURCE NODES TO TEST SOURCES

Test Node	1	2	3	4
A	C	B	E	D
B	D	C	A	E
C	D	B	E	A
D	E	A	B	C
E	C	D	B	A

The coverage is the ratio of the fingerprinted grids to total grids (i.e., 80 grids) of the target area. The accuracy is the mean location error in all fingerprinted grids. the coverage and the accuracy increase in proportion to the number of collected LFs. As collected LFs. reach 40, the proposed system attains coverage of 82.5% and a location error of 5.42 m. With this experiment, we validate that the proposed system can indeed construct more accurate and larger radio map as more LFs are collected.

EXPERIMENTAL RESULTS

This section discusses the experiment results that were conducted to evaluate the proposed system.Wewill first describe the platform design and experimental environments. Preliminary experiments are then explained to obtain various parameters used in a real scenario. The performance of the proposed system is compared with the ground-truth RSS fingerprint, which is constructed by a conventional site-survey method.



A. Experimental Setup

To evaluate the proposed system in real nvironments, we implemented the system on the HTC Hero [11], which is an Android smartphone equipped with both an accelerometer and a magnetometer. The experiments were conducted in an engineering building at Yonsei University. The site is 60 × 66 m and has three entrances. The number of APs detected

inside the building is between 5 and 25, depending on the location of the user. To construct diverse types of LF in the experiments, we surveyed 40 participants' paths to work, as well as their phone position at each entrance, as shown in We then collected 40 LFs based on the result of the survey.

Localization Performance with Inertial Sensors

The current location of a mobile user is estimated by inertial sensor-based localization. The localization performance is significantly influenced by the quality of local RSS fingerprints and consequently on the quality of global RSS fingerprints. To estimate the accuracy of inertial sensor-based localization, we analyzed the average location error of all the paths. We compared the performance of two methods, described in Section III-A,for finding heading.

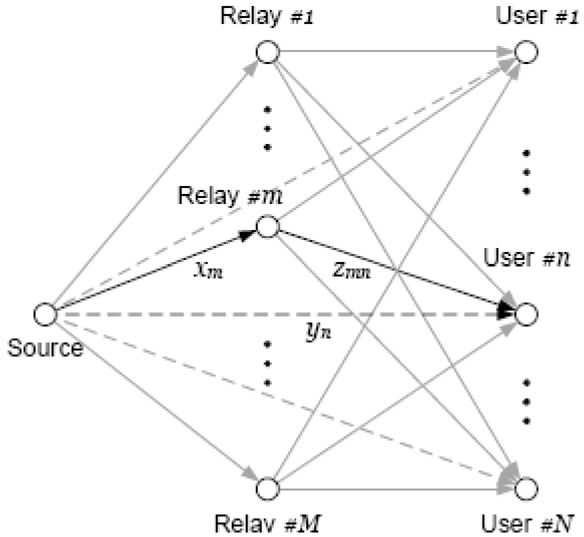
ALGORITHM I. PSEUDO CODE FOR COLLECTIVE FINGERPRINT UPDATE

```
Procedure Update( LF ) //Update CF with newly uploaded LF

for all tuple T_LF (x_LF,y_LF,c_LF,S_LF) in LF
  Overlapped = false
  for all tuple T_CF (x_CF,y_CF,c_CF,S_CF) in CF
    //check overlapped grid
    if (x_LF,y_LF) = (x_CF,y_CF)
      Overlapped = true
      if c_LF > c_CF
        T_GF = T_LF
    //check for alias tuple
    else if Diff (S_LF , S_CF ) < ε_same
      if c_LF > c_CF
        T_CF = null
      else
        T_LF = null
   //copy T_LF to T_CF when no overlapping
    if Overlapped = false
      T_CF = T_LF
```

Alias Filtering with RSS Difference

Such that both A and B stay at the position (*x*, *y*) and measure RSS, but their tuples *TA* and *TB* are stored at different positions because of the location error of inertial sensors-based localization. larger control effort are required. In[7], both its neighbors' states and its neighbors'



neighbors' states. By introducing more information in the second hop, the consensus convergence speed is improved. However, the trade-off for introducing the second hop information is that extra communication and the proposed consensus algorithm is composed of current states doutdated states stored in memory under an undirected communication graph. The algorithm converges faster than the standard consensus algorithm if the outdated states are chosen properly. In [3], from the Laplacian eigenvalue standpoint, the author has focused on maximizing the second smallest eigenvalue of a state dependent graph Laplacian to improve the convergence speed of the network systems.

EFFECT OF RSS SPACING

	# of AP scans per a grid	Location error	Grid hit rate
1 m	0.7	3.1 m	20.1%
2 m	1.4	2.6 m	34.3%
3 m	2.0	3.0 m	50.3%
4 m	2.6	3.5 m	58.1%
5 m	3.4	4.4 m	62.8%

The control input of each agent consists of In discrete-time models, each agent updates its state by computing a weighted average of its own value with values received from their eighbors at each time step. The convergence properties of the consensus algorithms have been further studied under different assumptions on the topology connectivity and information exchange in [1], [2], [4],

RELATED WORK

For the past few years, active research has been conducted on localization methods based on the RSS fingerprints. RADAR [4] was the first WiFi-based localization system which utilized RSS from APs in the vicinity. Ekahau [9] commercialized the concept with enhanced localization accuracy. These systems, however, require an RSS map-building process via laborious offline training for a specific site of interest. Place Lab [9] and Skyhook [14] tried to reduce the cost for offline training by collecting theWiFi signals automatically while moving with a GPS-equipped vehicle. These systems are primarily targeted for outdoor environments and are certainly not applicable to indoor applications. Redpin [10] handled the offline training by incorporating a collaborative approach where users collect fingerprints while using the devices. The system mandates activeparticipation of users to collect fingerprints because users must manually register new fingerprints frequently to enhance the location accuracy. Nattapong and Prashant [10] reduced the number of fingerprints by clustering theRSS signalswith similar measurement values. Also, several studies were conducted to improve the positioning accuracy of the RSS fingerprint-based mechanism.Bayesian modeling [11] and statistical learning [11] belong to this category. Meanwhile, many IMU-based localization systems have been developed, especially in the robotics area, to track the locations of mobile robots. Applying the technique to human tracking poses a new challenge since human behavior, compared to robots, is dynamic. Moreover, a subtle motion of human movement should be carefully considered to obtain reasonable tracking accuracy. Godha and Lachapelle [2] proposed a pedestrian navigation system that achieves accuracy of 2 m both indoors and outdoors by integrating GPS and IMU. Lasse and Tim proposed a Monte-Carlo-based localization system which uses an accelerometer for step counting and a magnetometer to track

Conclusions

In this paper we have developed a multi agent system that uses an inertial sensor networks, automatically storing the fingerprinting and a measure the signal range. The costly offline process of RSS map construction in conventional fingerprint-based system is removed by the use of inertial Sensors. The MAT system conducts inertial sensor-based self-localization and collect RSS fingerprints automatically the localization. Second, we successfully constructed the collective fingerprint map by a credibility-based user collaboration scheme. The proposed system is based on a passive user participation model, which collects range of signal and uploads fingerprints. For the future work, we plan to improve the proposed system in several aspects. The inertial sensor-based MAS will be enhanced to improve the quality of local fingerprints. Finally, we plan to implement a MAS system by detecting the precise entrance position of the range, which was assumed to be known in the current work.

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