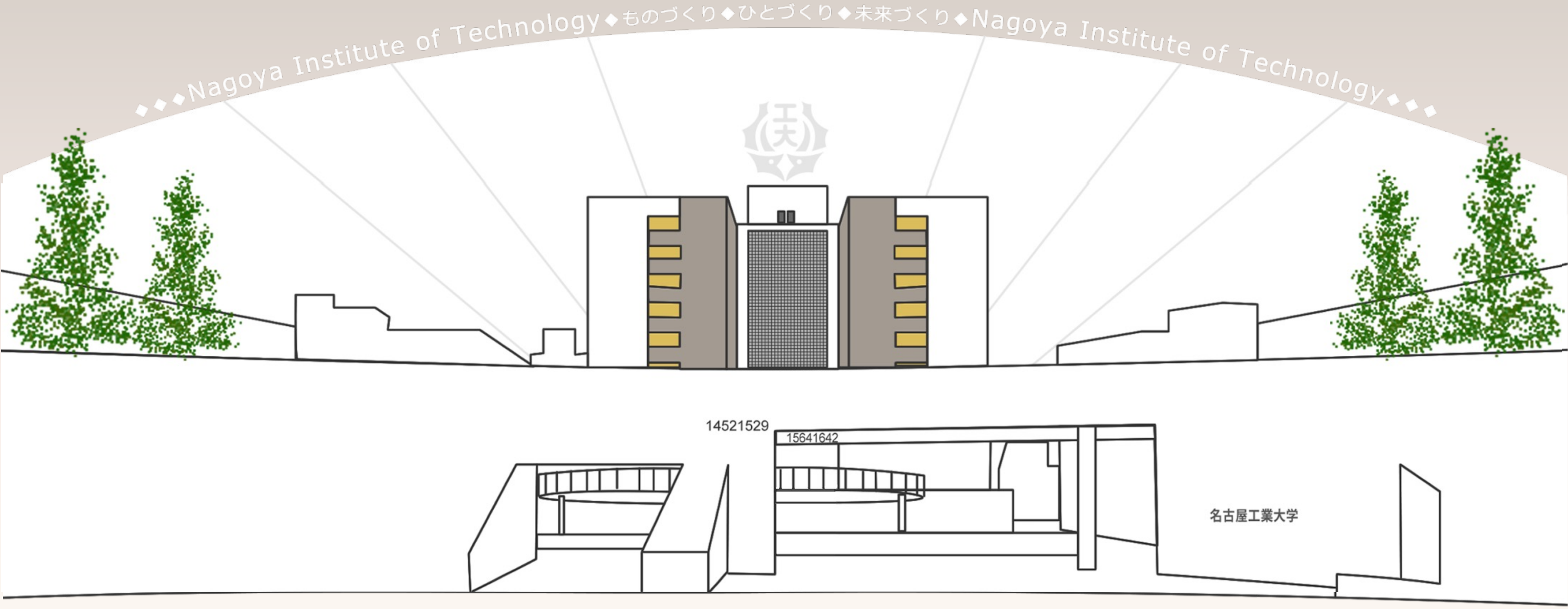
Indoor/Outdoor Route Estimation Method Based on Global Map Matching Using BLE Beacons and GPS

Shinsuke Kajioka*, Takanori Saito, Daisuke Yamamoto

Nagoya Institute of Technology (Japan)

*kajioka@nitech.ac.jp



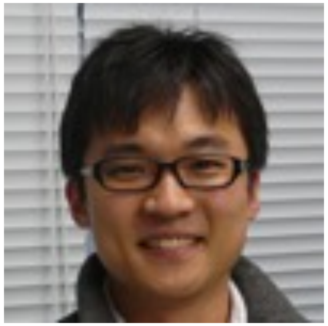
国立大学法人 名古屋工業大学

名古屋工業大学

GEOProcessing 2023 IARIA

About the Presenter

Shinsuke KAJIOKA received the master's degree in information science and technology from the Osaka University, Japan, in 2008 and the Ph.D. degree in information science and technology from the Osaka University, Japan, in 2011. He was an assistant professor at the Osaka School of International Public Policy, Osaka University from 2011 until 2012. He is currently an assistant professor at the department of computer science with holding the additional post of Information Technology Center and Cybersecurity Center at Nagoya Institute of Technology, Japan.



Background

- Devices such as smartphones and beacons with Bluetooth low energy (BLE) functionality are increasingly popular.
  - BLE-based services, particularly location-estimation services using BLE beacons, are gaining popularity.
  - BLE beacons are reliable during power outages and disasters due to low installation costs, stand-alone operation, low power consumption, and long battery life.
  - The Nagoya Institute of Technology has installed 1,600 BLE beacons in all classrooms and hallways on campus for smartphone-based class attendance system.

Existing Research

- Global map-matching method for beacon-based location estimation[2]
  - Method uses beacons to estimate users' routes and stays.
  - Utilizes two networks: a route network for representing movement path and a beacon network for representing beacon locations.
  - System integrates and filters beacon signals from smartphones to estimate routes and stays.
- Existing BLE beacon-based location estimation methods are limited to indoor locations.

[2] D. Yamamoto et.al., Global Map Matching using BLE Beacons for Indoor Route and Stay Estimation, Proc. 26th ACM SIGSPATIAL 2018, pp. 309-318, 2018.

Problems

- Most research on BLE beacon-based location estimation focuses on indoor use
  - Limited research on integrating BLE beacons with GPS, which is used outdoors
  - BLE beacon-based studies use radio reception strength as input data for position estimation
  - GPS-based studies use latitude and longitude as input data for route estimation on road networks

→ Combination of GPS and BLE beacons is challenging due to differences in data formats, methods, and estimation targets.

Purpose

- Proposal of a method that combines BLE beacon and GPS data for estimating overall optimal path of human movement across indoor and outdoor areas
  - Enables highly accurate estimation of indoor and outdoor routes, and flexibility in adding "semi-outdoor" routes
  - Method focuses on direct route estimation with high accuracy, without estimating location first
- Specialization on route estimation may contribute to the development of geographic information systems, including positioning information.

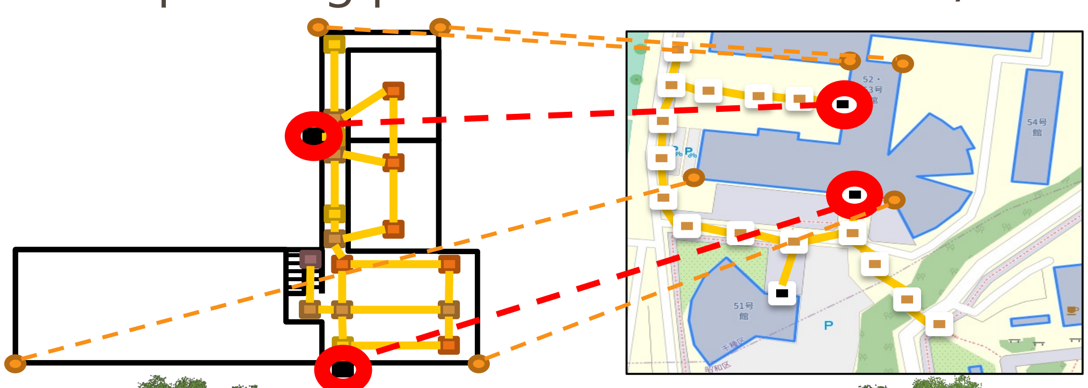
Approach

- Challenge 1: Existing methods are limited to indoor-only path/beacon networks.
- Approach 1: Define a new network that spans indoor and outdoor areas and develop a GIS tool that allows easy editing of this network.

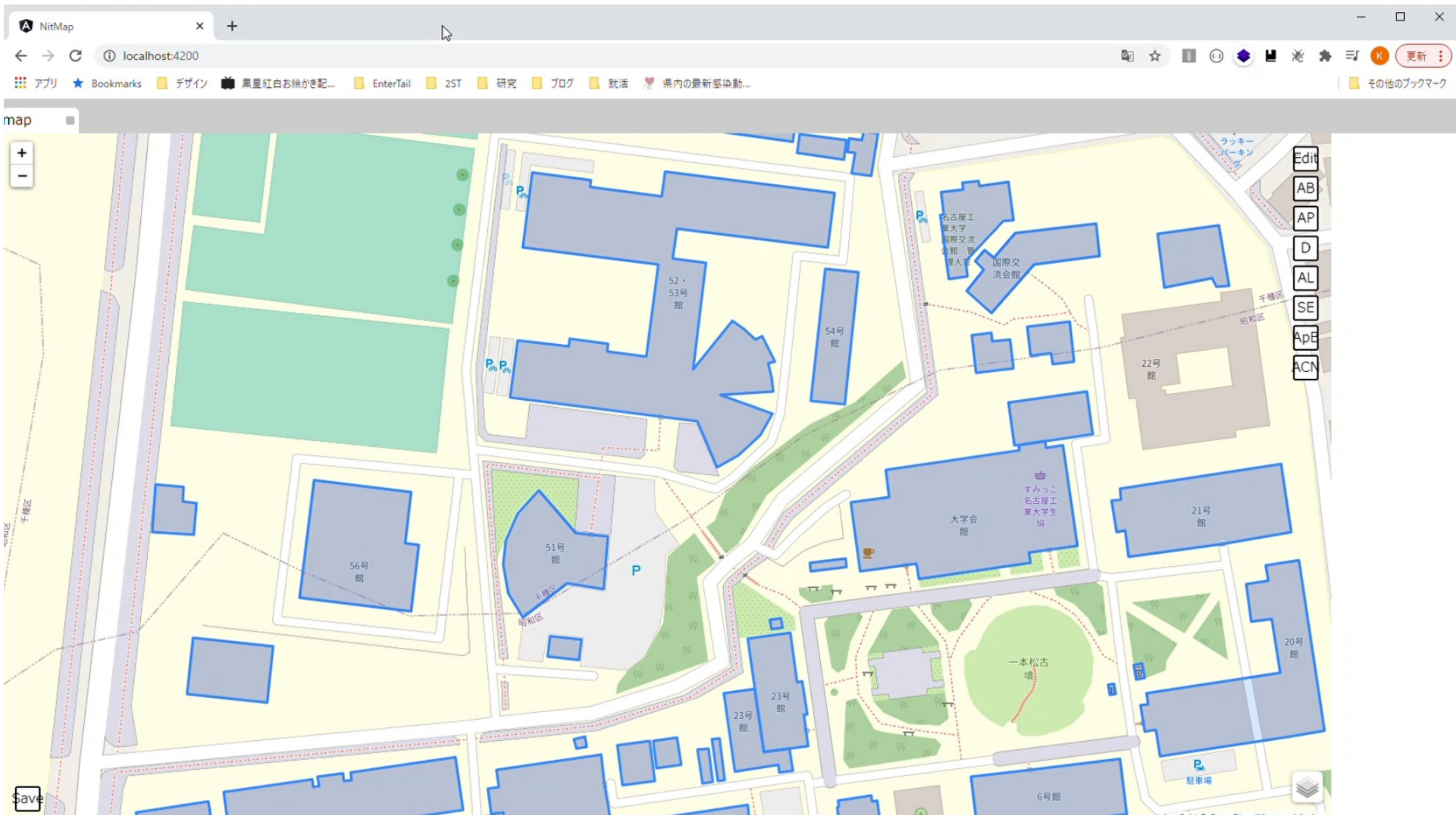
- Challenge 2: There are no BLE beacons installed outdoors.
- Approach 2: Propose an algorithm that utilizes not only BLE beacons but also GPS for path estimation, enabling indoor and outdoor path estimation.

Constructing a network that spans indoor and outdoor areas.

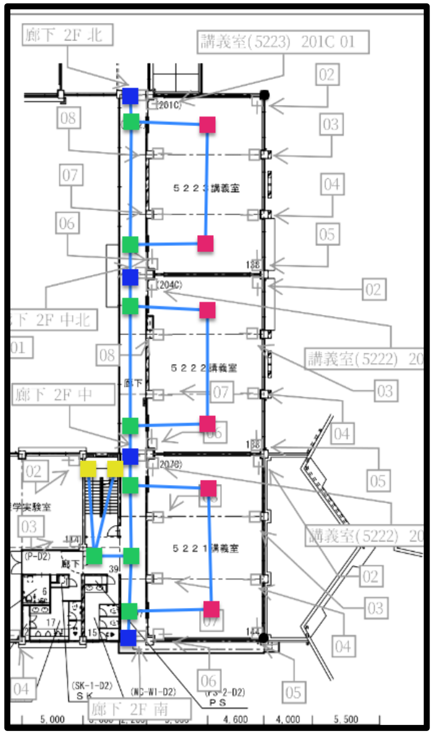
- Indoor network
  - Creating a network on an indoor floor plan
  - Converting local coordinates to latitude and longitude coordinates using corresponding points.
- Outdoor network
  - Creating a network on an outdoor map
  - Connecting the outdoor network with the indoor network through entrance/exit nodes.



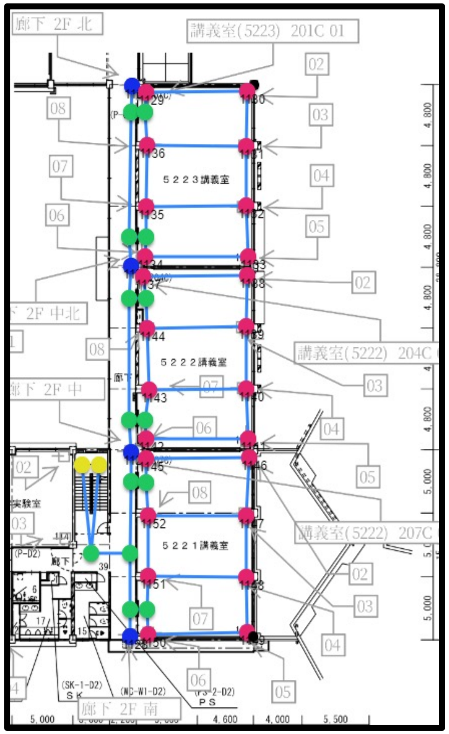
Creating a Network – Demo Video



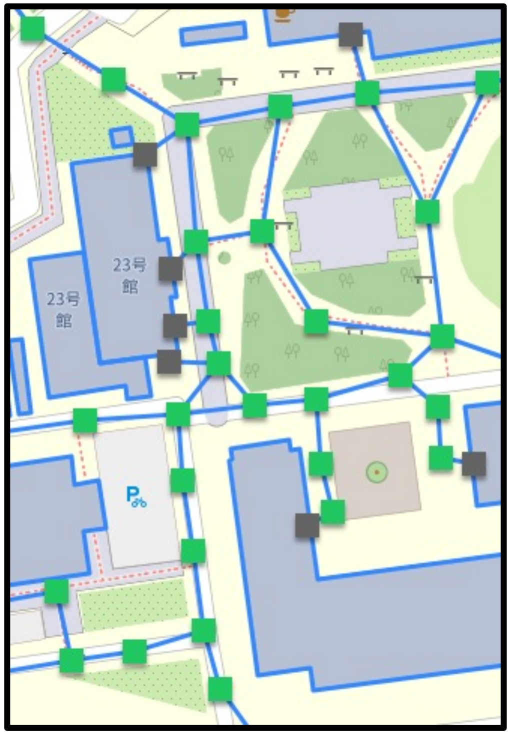
Example of Constructed Network



Example of Indoor Path Network



Example of Indoor Beacon Network



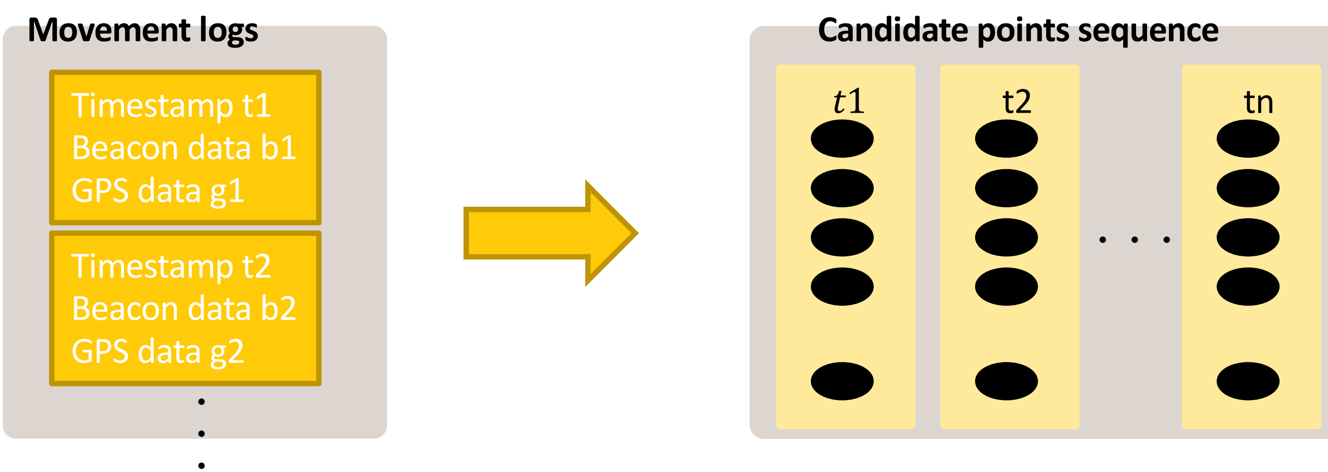
Example of Outdoor Path Network

Process of Path Estimation:

- Generate candidate points at each timestamp from the movement logs.
- Calculate scores between candidate points at each timestamp.
- Use the Viterbi algorithm to determine the candidate point sequence with the highest score.
- Convert the candidate point sequence into a path on the path network.

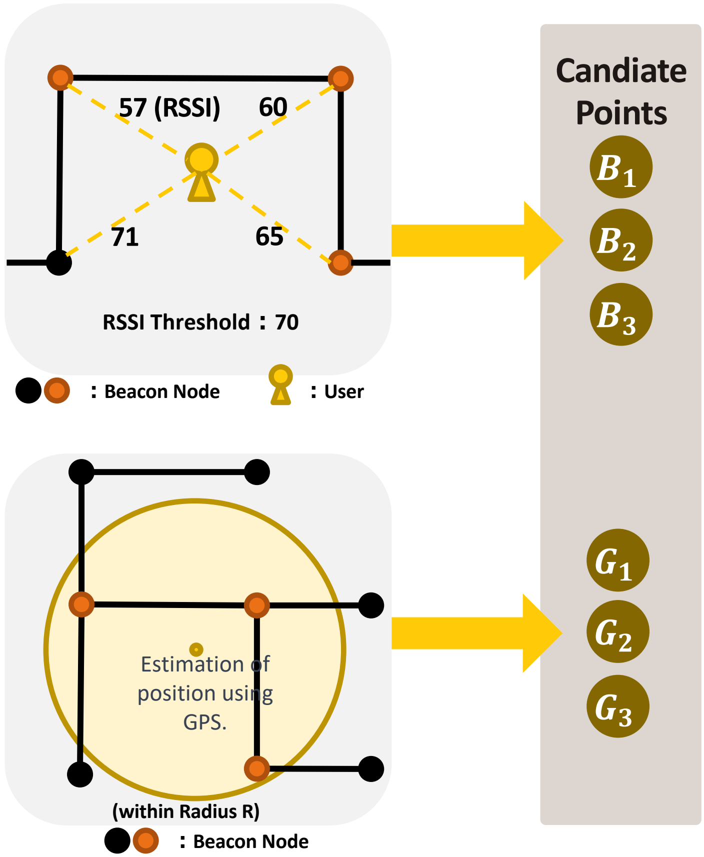
1. Generate candidate points at each timestamp from the movement logs.

- Generate candidate points from the movement logs.
- Candidate points are generated from beacon data and GPS data included in the messages at each timestamp in the movement logs.



2. Calculate scores between candidate points at each timestamp.

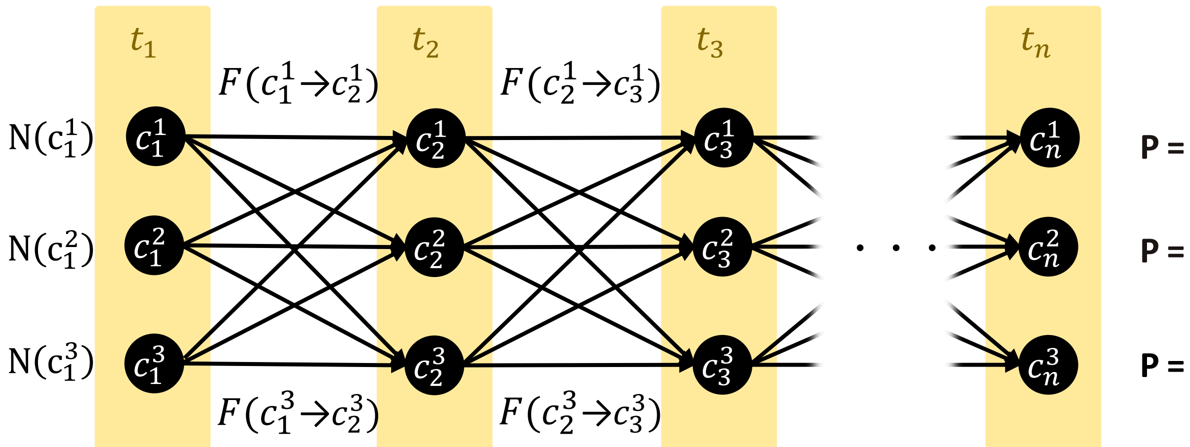
- Candidate points based on beacons:
  - Candidate points are generated from beacon data. A node with a matching major value is considered a candidate point when its received signal strength indicator (RSSI) is above a threshold.
- Candidate points based on GPS:
  - Candidate points are generated from GPS data. Nodes within a circle centered at the estimated GPS position are considered candidate points when their estimated accuracy is above a threshold.



3. Determine the candidate point sequence with the highest score.

Calculate scores N and F for all candidate points, evaluate the scores for all candidate point pairs, and determine the candidate point sequence with the maximum score P.

- $\mathrm{P} = argmax(c_1, c_2, \cdots, c_n)\left\{\mathbf{N}\left(\boldsymbol{c}_{\mathbf{1}}^{j}\right) + \sum_{i=2}^{n} \boldsymbol{F}(\boldsymbol{c}_{\mathbf{i-1}}^{t} \rightarrow \boldsymbol{c}_{i}^{s})\right\}$



Score between c_{i-1}^{t} , c_i^s

- $F\left(c_{i-1}^{t} \rightarrow c_i^s\right) = N\left(c_i^s\right) * F_t\left(c_{i-1}^{t} \rightarrow c_i^s\right)$

$0 < N\left(n_i^j\right) \leqq 1$
$0 < F_t\left(c_{i-1}^{t} \rightarrow c_i^s\right) \leqq 1$

Score c_i^j : $N\left(c_i^j\right)$

Evaluating proximity between candidate points and the user

Scoring using beacons

$$N\left(c_i^j\right) = \frac{1}{10^{\frac{1}{20}(\mathrm{RSSI}_{\max} - RSSI)}}$$

Scoring using GPS

$$N\left(c_i^j\right) = \frac{1}{\mathrm{d}}$$

Score : $F_t(c_{i-1}^{t} \rightarrow c_i^s)$

Evaluating naturalness of walking speed.

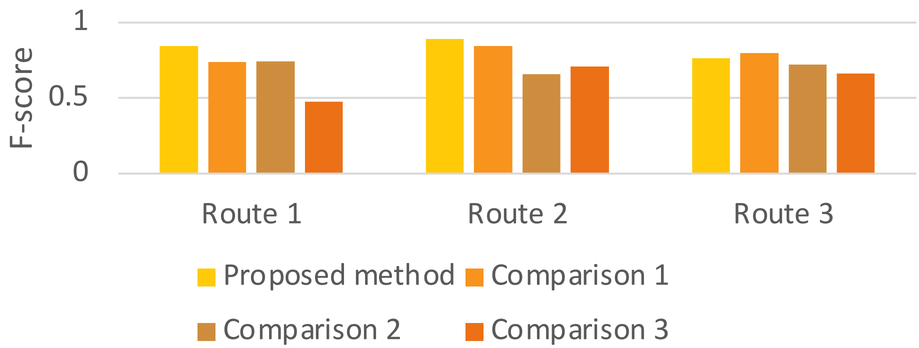
$$F_t\left(c_{i-1}^{t} \rightarrow c_i^s\right) = \begin{cases} 1 \ (v \leqq v_a) \\ \dfrac{v_a \times t \times L}{dist} \ (v > v_a) \end{cases}$$

Experiment

- Experiment Objective
  - To compare and verify the route estimation results of the proposed method with the results of the comparison methods.
- Experiment Subjects
  - Proposed method
  - Comparison method 1 (Beacon-based candidate point priority)
  - Comparison method 2 (BST matching)
  - Comparison method 3 (GPS data-based candidate point generation)
- Experiment Method
  - Collecting 18 sets of movement logs for 3 routes, each repeated 6 times.
  - Calculating F-value from the precision and recall of the link composition between the route estimation results of each method and the actual walked routes and comparing the average values.

Experimental Result

- The proposed method achieved the highest F-score in all routes except for Route 3.
- Route 3, which involves frequent indoor/outdoor transitions, experienced a decrease in accuracy for the proposed method due to unstable GPS estimation accuracy.



Results of t-test comparing with the proposed method

	Route 1	Route 2	Route 3
Comparison method 1	0.0073	0.0192	0.0514
Comparison method 2	0.0070	0.0002	0.0031
Comparison method 3	0.0002	0.0005	0.0124

Conclusion

- We proposed an algorithm for estimating indoor/outdoor human movement routes using logs from beacons and GPS.
- The method extends the BST matching approach from previous research to realize route estimation using candidate points generated from beacon data and GPS data.
- Future work:
  - Improving the scoring of candidate points
  - Exploring network structure
  - Conducting comparative experiments in different experimental environments with varying beacon deployment conditions.