In stations of complex three-dimensional structure such as Tokyo, Shinjuku, and Shibuya stations, customers often get lost because the route from their current position to the destination is difficult to understand. Outside, it is possible to navigate customers using smartphones. However, it is impossible to do the same thing in stations because GPS cannot be used indoors.

We thus inquired about equipment required at the station in order to provide accurate navigation to our customers. As a result of this study, we found the best possible choice for an indoor positioning system in the station. Additionally, we distinguished the accuracy of the positioning system. Moreover, we extracted the key issues for installation in a station.

**Keywords:** Indoor positioning, Navigation, Wi-Fi, Bluetooth, Smartphone

**1 Introduction**

In stations of complex three-dimensional structure such as Tokyo, Shinjuku, and Shibuya stations, customers often get lost because the route from their current position to the destination is difficult to understand. Outside, it is possible to navigate customers using smartphones. However, it is impossible to do the same thing in stations because GPS cannot be used indoors.

In this research, we carried out experiments in which we simulated positioning of passengers in a station to identify what infrastructure railway stations need to have in the future. Specifically, we sorted out and evaluated the environment of indoor positioning using the Smart Station Lab in the Research and Development Center of JR East Group.

**2 Selection of Positioning Technology**

2.1 Preliminary Examination of Indoor Positioning Technology

There are many positioning technologies using smartphones and other mobile terminals for diverse positioning purposes in narrow to broad ranges as shown in Fig. 1. Among those, positioning technology using the Global Positioning System (GPS) has enabled positioning with accuracy of approx. 10 m or of a few meters when combining with interferometric positioning that also uses phase information of radio waves. In recent years, development has been underway on more advanced GPS technology using quasi-zenith satellites that can reduce the effect of wave refraction within the ionosphere and the troposphere, with an aim of achieving accuracy of tens of centimeters. However, we excluded GPS technology from consideration in this research because indoor positioning is difficult with that.

With indoor positioning technology, a positioning method using information of base stations of telecommunications carriers has already been put into practical use, but it is not suitable for a service that needs exact positioning due to it having errors of up to several kilometers. At the same time, there is much demand for an indoor positioning service, and expectations are high for it to offer station services using indoor positioning such as navigation services combined with a station map and other services provided according to the user location such as at ticket gates and shops. The major elemental technologies now under examination for achieving those services are the following.

1. Wi-Fi
2. Two-dimensional barcodes (tag)
3. Bluetooth
4. Visible light communications
5. Indoor MESSaging System (IMES)
6. Pedestrian Dead Reckoning (PDR) using sensors of smartphones

In order to achieve an indoor positioning system using the above-mentioned elemental technologies other than PDR by utilizing the sensors of smartphones, the operator of that system has to bear the costs for building such infrastructure. Due to that and the fact that some elemental technologies cannot be applied to specific models of smartphones, selection of the elemental technology has great impact on the level of use by customers. The following will cover the features of individual indoor positioning technologies.

2.2 Comparison

Past surveys showed much demand for indoor positioning technologies, and various technologies have been studied. However, those studies revealed that each of the technologies still has its own problems and that there is no specific technology

---

*Frontier Service Development Laboratory, Research and Development Center of JR East Group*
established as a de facto standard as GPS technology is for outdoor positioning.

For the basic evaluation at the Smart Station Lab in this research, we examined the applicability in that Lab of the six elemental technologies. Each technology was evaluated in total according to eight items shown in the left row of Table 1. As a result, we selected Wi-Fi positioning technology and Bluetooth positioning technology as technologies that can be applied to indoor environments at relatively low equipment cost.

<table>
<thead>
<tr>
<th>Item</th>
<th>Mobile positioning</th>
<th>Positioning in still state</th>
<th>Compliance with Japanese laws</th>
<th>Attachment to station ceiling</th>
<th>Need of power</th>
<th>Device cost</th>
<th>Setup cost</th>
<th>Terminal dependence</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>WiFi</td>
<td>Very good</td>
<td>Very good</td>
<td>Very good</td>
<td>OK</td>
<td>Necessary</td>
<td>High</td>
<td>High</td>
<td>Dependent</td>
<td>Very good</td>
</tr>
<tr>
<td>2D barcode (tag)</td>
<td>Poor</td>
<td>Very good</td>
<td>Very good</td>
<td>OK (“*)</td>
<td>Unnecessary</td>
<td>High</td>
<td>High</td>
<td>Dependent</td>
<td>Poor</td>
</tr>
<tr>
<td>Bluetooth</td>
<td>Very good</td>
<td>Good</td>
<td>Very good</td>
<td>OK</td>
<td>Necessary</td>
<td>High</td>
<td>High</td>
<td>Dependent</td>
<td>Good</td>
</tr>
<tr>
<td>Visible light communications</td>
<td>Very good</td>
<td>Very good</td>
<td>Very good</td>
<td>OK</td>
<td>Necessary</td>
<td>High</td>
<td>High</td>
<td>Dependent</td>
<td>Good</td>
</tr>
<tr>
<td>IMES</td>
<td>Good</td>
<td>Good</td>
<td>Very good</td>
<td>OK</td>
<td>Necessary</td>
<td>High</td>
<td>High</td>
<td>Dependent</td>
<td>Good</td>
</tr>
<tr>
<td>PDR</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
<td>OK</td>
<td>Necessary</td>
<td>High</td>
<td>High</td>
<td>Dependent</td>
<td>Poor</td>
</tr>
<tr>
<td>Setup cost</td>
<td>Good</td>
<td>Poor</td>
<td>Poor</td>
<td>Low</td>
<td>Dependent</td>
<td>Dependent</td>
<td>Dependent</td>
<td>Dependent</td>
<td>Poor</td>
</tr>
<tr>
<td>Applicability</td>
<td>Very good</td>
<td>Poor</td>
<td>Very good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Poor</td>
<td>Poor</td>
</tr>
</tbody>
</table>

*1: PDR technology assumes positions according to change in relative position, so it cannot detect absolute position.

*2: 2D barcode (tag) needs to be placed facing the reader, so it is not suitable for attachment to the ceiling.

### 3.2 Spot Positioning

For spot positioning, we set up multiple beacons with an aim of positioning with high accuracy persons approaching and entering specific station facilities. The method and place for setting beacons up was not limited. The six purposes of the positioning tests were as follows (Fig. 3 and 4).

1. **Scenario 1: Detection of persons entering staircase**
   - The purpose was to detect whether or not passengers are in the staircase area (Fig. 3). We further studied whether more detailed detection within the staircase area is possible.

2. **Scenario 2: Detection of persons passing through ticket gate**
   - The purpose was to detect whether or not passengers have passed through the ticket gate yet (Fig. 3). Distinguishing between individual gates with two or more ticket gates is excluded from the scope of this research because it is difficult to do with spot positioning only.

3. **Scenario 3: Detection of persons approaching guide sign (i)**
   - The purpose of this test scenario was to detect persons approaching the guide sign on the third floor (concours floor) of the Smart Station Lab (Fig. 3).

4. **Scenario 3: Detection of persons approaching guide sign (ii)**
   - The purpose of this test scenario was to detect persons approaching the guide sign on the first floor (platform floor) of the Smart Station Lab (Fig. 4). This scenario was carried out with Wi-Fi positioning technology only.

5. **Scenario 5: Detecting persons waiting for train**
   - The purpose was to detect whether or not people are lining up for a train in front of the platform doors on the first floor (platform floor) of the Smart Station Lab (Fig. 4). This scenario was carried out with Wi-Fi positioning technology only.

6. **Scenario 6: Detecting persons in train car**
   - The purpose of positioning persons in the train car was to detect persons in the test car (Fig. 4). This scenario was carried out with Bluetooth positioning technology only.

---

**3 Building an Indoor Positioning Environment**

For the positioning technologies using Wi-Fi and Bluetooth that were examined in advance, we made an environment within the Smart Station Lab of the Research and Development Center of JR East Group where indoor positioning could be done. The purpose of the environment was to evaluate two types of technology: mesh positioning that enables comprehensive positioning in a broad area and spot positioning that enables local positioning at high accuracy.

### 3.1 Mesh Positioning

For mesh positioning, we set up beacons to cover the total area of the Smart Station Lab (third floor = concours floor) shown enclosed with a dotted line in Fig. 2. The beacon locations were limited to the 4 m-high ceiling or the walls so as to not interfere with the flow of passengers in the station.

**Fig. 2 Area Covered with Mesh Positioning**
(area enclosed with dotted line)
We created applications to display positioning results in the environments designed as described in the chapter above. The developed applications are listed in Table 2.

Table 2 List of Display Applications

<table>
<thead>
<tr>
<th>Name</th>
<th>Mobile platform</th>
<th>Positioning tech.</th>
<th>Display</th>
</tr>
</thead>
<tbody>
<tr>
<td>App A</td>
<td>Android</td>
<td>Wi-Fi</td>
<td>Own position</td>
</tr>
<tr>
<td>App B</td>
<td></td>
<td></td>
<td>Other’s position</td>
</tr>
<tr>
<td>App C</td>
<td>iOS</td>
<td>Bluetooth</td>
<td>Own position</td>
</tr>
<tr>
<td>App D</td>
<td></td>
<td></td>
<td>Other’s position</td>
</tr>
</tbody>
</table>

4.1 Own-position Display Application (App A)
We developed App A to display one’s one position in a Wi-Fi positioning environment. It finds one’s own position based on the strength of signals from the Wi-Fi beacons set up as mentioned in the previous chapter.

4.2 Others’ Position Display Application (App B)
We developed App B to display the positions of others in a Wi-Fi positioning environment. It finds one’s own position based on the strength of signals from the Wi-Fi beacons set up as mentioned in the previous chapter, and it shares that position information with other tablets in a preset environment. It sends information on one’s own position and others’ positions from individual tablet terminals to the server to display those on the map.

4.3 Own-position Display Application (App C)
We developed App C to display one’s one position in a Bluetooth positioning environment. When it receives the ID of a Bluetooth beacon set up as mentioned in the previous chapter, it transforms the ID into the latitude/longitude identified with that ID and displays a mark (pin) at one’s one position on the map of the Smart Station Lab. This app works with terminals of iOS only because the software development kit of the Bluetooth beacon is offered in an iOS version only (Fig. 7).

4.4 Others’ Position Display Application (App D)
App D is different from other three apps in that persons are given a beacon to operate in an environment where no Bluetooth positioning devices are set up. When it receives the IDs of the Bluetooth beacons of individual persons, it displays on the screen the IDs for beacons with a radio wave intensity greater than the threshold.
5 Verification Results

With an aim of achieving positioning of customers in stations, we obtained fundamental data on such positioning in a simulated environment. The results can be explained as follows.

5.1 Mesh Positioning
5.1.1 With Still Persons
When positioning persons who are still, both Bluetooth beacons and Wi-Fi beacons showed similar tendencies. With Bluetooth beacons, we made detailed analysis of the relationship between the distance to the place of positioning and the signal strength, finding a tendency for the signal strength to decrease as the distance increased. We also observed a tendency for the signal strength from beacons on a wall to be lower by approx. 5 dB than that of beacons set up on other places (movable ceiling). The fluctuation of the signal strength was significantly large, but no relationship with distance or placement was seen.

We also found out that the positioning correction algorithm applied to the scenarios using Wi-Fi beacons could reduce positioning error to less than 6 m.

5.1.2 With Walking Persons
When positioning persons who are walking, Wi-Fi beacons could detect the persons as being on the route they were walking for the most part, while Bluetooth beacons detected the persons as diverging greatly from the actual route they were walking. Bluetooth beacons, however, could detect persons walking around the concourse.

5.2 Spot Positioning
5.2.1 Detecting Persons Entering Staircase
Both Bluetooth and Wi-Fi beacons could detect persons entering the staircase. However, persons at the middle of the stairs (on and around the landing) could be detected by Wi-Fi beacons only.

5.2.2 Detecting Persons Passing Through Ticket Gate
Both Bluetooth and Wi-Fi beacons could detect persons passing through the ticket gate. However, persons within the ticket gate could be detected by Wi-Fi beacons only.

5.2.3 Detecting Persons Approaching the Guide Sign
Bluetooth beacons could detect persons approaching the guide sign with accuracy of around 1 m and by Wi-Fi beacons with accuracy of around 50 cm.

5.2.4 Detecting Persons in Cabin and Persons Lining up for Train
It was difficult to detect based on signal strength whether the persons were inside or outside the car when using Bluetooth beacons. While limited to inside the car, we observed a tendency for the signal strength to decrease as the distance from the Bluetooth beacons increased. When detecting passengers who lined up for the train, only the passenger who was first in line could be detected by average signal strength. The second and subsequent passengers in the line could not be distinguished because the rate of the decrease of the signal strength was not constant.

6 Conclusion

We were able to select the most appropriate candidates for positioning technologies to locate the positions of persons in a station with an aim of improving customer service. We also were able to clarify the accuracy of Wi-Fi and Bluetooth positioning technologies in different conditions and find future issues and possible solutions mainly on introduction to stations. However, the advantages and disadvantages of the positioning technologies could not be clearly determined yet in this research.

We will go forward with research on services utilizing the results of this research with an aim of achieving easy-to-understand stations.