Wi-Fi based Continuous Monitoring of Tourists' Travel Behavior: Results of Two Large-Scale Field Experiments in Japan

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Background and objective

Tourism would be one of the important sectors for economic and regional developments throughout the world and the tourism travel demand has been rapidly growing mainly from emerging market countries (World Travel & Tourism Council, 2017). In the case of Japan, there has been rapidly increasing trend of inbound and outbound of tourism travel trend for the last decade (Japan Tourism Agency, 2015) and it is predicted that this growth trend would continue for the next decade. In contrast with such fast increase in tourist travel demand, however, dealing with visitor congestion at many popular tourist spots would be would be one of the most urgent issues in tourism management in many countries. Several famous sightseeing sites in suffer from temporally and spatially concentrated tourist demand for their lack of capacities for attraction sites or facilities.

In order to establish more appropriate tourism strategies, the data on tourists' traveler behavior (e.g. tourist site destination choices, trip-chain making and tour choices, and dwelling time at each spot) would be quite informative. Traditional paper-based questionnaire survey has been widely utilized for tourists' travel data collection but it has drawbacks in terms of inaccuracy and inefficiency, particularly when analyzing tourism demand for *wide-area tourism* in which tourists would travel across several distant sightseeing spots in multiple days. GPS-based survey methods, which has been popular for collecting urban travel data, may have potentials for obtaining more accurate and detailed information on tourists' traveler behavior but the method has become difficult for large spatial scale analysis because of its high costs.

For cost efficiency reasons, this paper explores the feasibility of a passive travel survey data collection mainly for tourists. The recent spread of information, communication and technology (ICT) services into society offers increasing opportunities to use pervasive ICT devices (e.g., smartphones) to collect detailed location and time-of-day information of travelers, without conducting any full-scale travel surveys. At present, many people (including tourists from emerging market countries) carry their smartphones with them and these devices generally contain the functionality for access to wireless fidelity (Wi-Fi). Most importantly, each of these Wi-Fi devices has its own unique media access control (MAC) address and it would thus be possible to detect the traces of their Wi-Fi access records both temporally and spatially. This Wi-Fi based continuous monitoring of tourists with sensors installed at each sightseeing spot may exhibit innovative potentials for travel data collection if we are able to trace each MAC address.

There have been several applications of Wi-Fi based approach for human monitoring or travel survey. These applications include: journey travel time estimation (Abedi et al., 2015), waiting time estimation of bus passenger (Kusakabe et al. 2017), tracking of pedestrian

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trajectories (Vu et al., 2010; Musa and Eriksson, 2012), estimating origin and destination for city bus passenger (Dunlap et al., 2016) and for paratransit passenger (Fukuda, et al., 2017). Danalet et al. (2014) and Danalet et al. (2016) recently analyzed destination detection and choice modeling. These studies, however, mainly targeted pedestrians moving within relatively small spaces (a university campus) and there are a few articles in the literature that focus on tourists travel choices in the relatively-large areas across a variety of distant sightseeing spots. Furthermore, tourists' traveler behavior significantly changes across different seasons so that continuous long-term monitoring would be needed for fully revealing the whole picture of tourists' traveler behavior. Such aspects would serve to complicate the use of Wi-Fi-based monitoring for behavioral data collection of tourists.

With the above-mentioned background and motivation, this study seeks applicability of Wi-Fi based continuous monitoring technology for collecting tourists' travel behavior through the data analysis from two large-scale field experiments in Japan. Monitoring equipment has been located into some popular spots and transport nodes in two popular sightseeing districts. After appropriately cleansing the full records at each site to obtain the dataset of *probably* tourists, we explore (i) day-to-day/within-day variation of tourists' concentration across different places; (ii) staying duration of tourists at each site; and (iii) spatio-temporal patterns of tourist movements.

Wi-Fi based tourist monitoring and data collection

As in the case with Kusakabe et al. (2017) and Fukuda et al. (2017), we use a specialized monitoring device that is convenient for flexible data collection called a "WifiScanner" (Figure 1), which was originally developed by the Regional Futures Research Center (RFRC) and which can automatically capture a search request (called "probe request (PR)") that is emitted continuously from each mobile device. The device is small in size (approximately 2 cm×5 cm×10 cm), so data collection is possible regardless of the device location. While the search range of the Wi-Fi adapter module is affected by various conditions (e.g., the presence of buildings, ambient temperature, and the degree of human crowding), it may be possible to reach distances of 300 to 400 meter under ideal conditions.

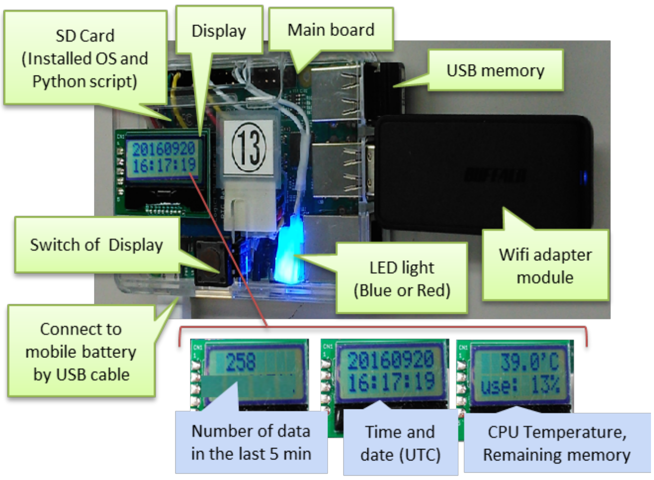
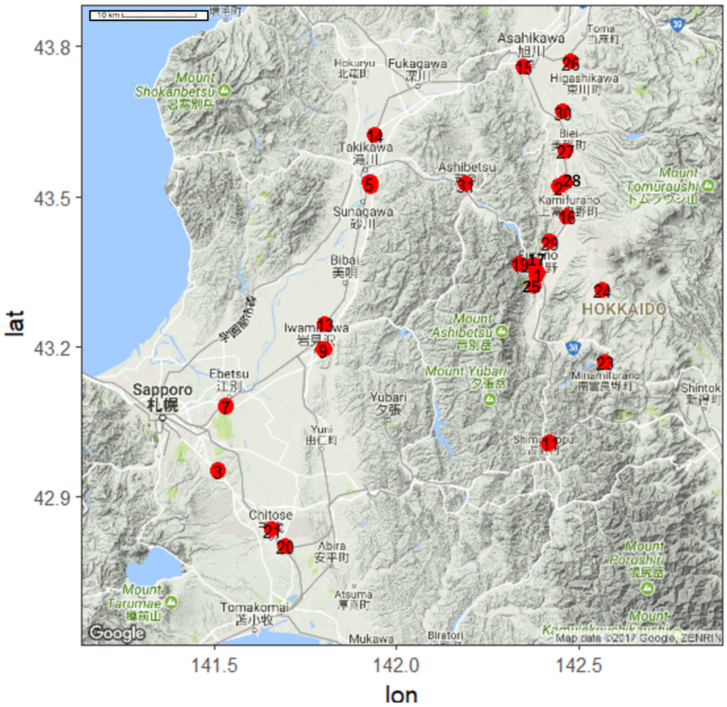


Figure 1. Photograph of WifiScanner device

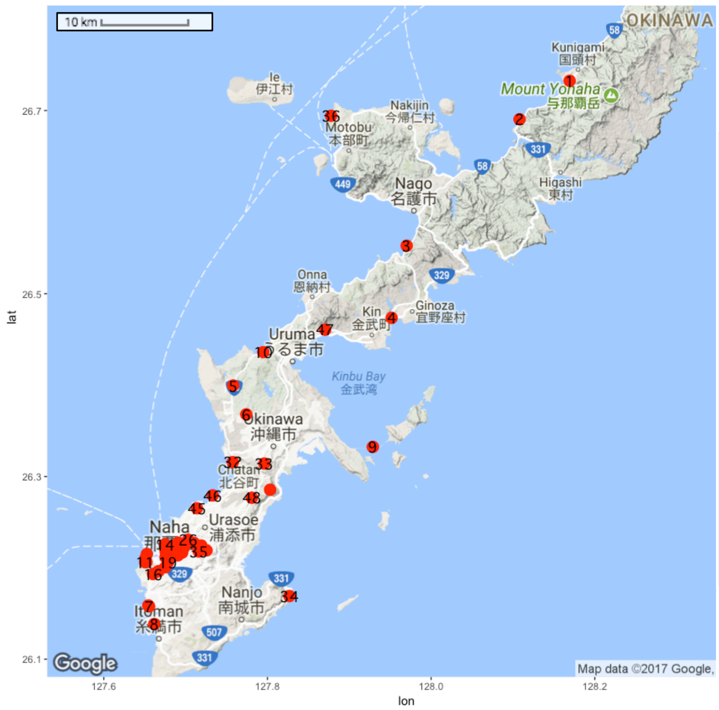
Wi-Fi PRs can be captured on each of 14 channels in the 2.4 GHz band (IEEE, 2012). In passive scanning, a client device such as a mobile device listens on each channel for beacons that are sent periodically by the WifiScanner and the contents of the PR include the sender's unique device identifier (one-way hashed MAC address for privacy considerations) and the received signal strength indicator. The interval in which the address can be recorded by the scanner is fully dependent on the specifications of each mobile device. The recorded data would be transmitted to the server every 5 minutes via internet.

During the summer season of 2016 and 2017, we carried out two large-scale monitoring experiments in two districts: (1) Central Hokkaido [Period: June 21, 2017 – July 23, 2017] and (2) Main Island of Okinawa [Period: August 24 – 27, 2016 and August 6, 2017 – September 18, 2017] (Figure 2). In each site, one or more WifiScanners were placed over a period of more than one month to capture the PRs from possible tourists. The full data record in Central Hokkaido, for example, includes more than 30,400,000 PRs from 31 sites. After appropriately being cleansed (i.e. removing redundant and/or irrelevant PRs), it is further reduced to 1,204,476 unique identifiers most of which are possibly expected to be from tourists.



No.	Site name	No.	Site name
1	Furano naturax hotel	17	Campana Rokkadei
2	Lavender owner's garden	18	Furano cheese factory
3	Wattu inbound Parking Area	19	Highland furano
4	Wattu outbound Parking Area	20	Rent-a-car shop New Chitose Airport
5	Sunagawa outbound Parking Area	21	Roadside-station Chitose
6	Sunagawa inbound Parking Area	22	Sunagawa highway oasis
7	Nopporo outbound Parking Area	23	Roadside-station Minamifurano
8	Nopporo inbound Parking Area	24	Goro's stone house
9	Iwamizawa outbound Parking Area	25	Furano marche
10	Iwamizawa inbound Parking Area	26	Asahiyama Zoo
11	Simukappu outbound Parking Area	27	Roadside-station Biei Oka-no-kura
12	Simukappu inbound Parking Area	28	Shikisai-no-oka
13	Roadside-station Mikasa	29	Choei lavendor firm
14	Roadside-station Takikawa	30	Rent-a-car shop Asahikawa Airport
15	Roadside-station Asahikawa	31	Roadside-station Star plaza asibetsu
16	Flower Land Kamifurano		

[a] Central Hokkaido (31 sites)



No.	Site name	No.	Site name
1	Roadside-station Kunigami	26	Monorail-Furushima
2	Roadside-station Ogimi	27	Monorail-Municipal hospital
3	Roadside-station Kyoda	28	Monorail-Gibo
4	Roadside-station Ginoza	29	Monorail-Syuri
5	Roadside-station Kinabansho	30	Rent-a-car shop Toyosaki
6	Roadside-station Kadena	31	Rent-a-car shop Tomarin
7	Roadside-station Toyosaki	32	Cyatan tourism information center
8	Roadside-station Itoman	33	AEON mall Okinawa Rycom
9	Roadside-station Ayahashi	34	Sefa Utaki
10	Roadside-station Onna	35	Syuri castle
11	Naha airport-Domestic Terminal	36	Churaumi quarium
12	Naha airport-Intl. Terminal	37	International street
13	Naha airport-LCC Terminal	38	Peace street
14	Cruise ship Terminal	39	Makishi public market
15	Monorail-Naha airport	40	Tsuboya pottery museum
16	Monorail-Akamine	41	Naha bus terminal
17	Monorail-Oroku	42	Kuninda terrace
18	Monorail-Ounoyama park	43	Ukishima street
19	Monorail-Tsubokawa	44	Okinawa general bureau
20	Monorail-Asahibashi	45	Pizza house
21	Monorail-Kentyomae	46	Okinawa convention center
22	Monorail-Miebashi	47	Igei Parking Area outbound
23	Monorail-Makishi	48	Nakagusuku Parking Area outbound
24	Monorail-Asato	49	Nakagusuku castle
25	Monorail-Omoromachi		

[b] Main Island of Okinawa (49 sites)

Figure 2. Location maps of WifiScanner installations in two experiments

Figure 3 illustrates day-to-day patterns of counting unique identifiers of PR in some popular sightseeing spots in Hokkaido. The large number of count implies that there would be a lot of visitors to that site. Also, it can be seen that there would be weekday-weekend variations. For example, Asahiyama Zoo (No. 26) is one of the always popular sites and the number of counts is constantly large implying that there would be considerate number of visitors throughout the whole experiment period. On the other hand, Flower Land Kamifurano (No. 16) would collets more identifiers around July 10 around when there was a full bloom of lavender in that park which would be quite attractive for tourists.

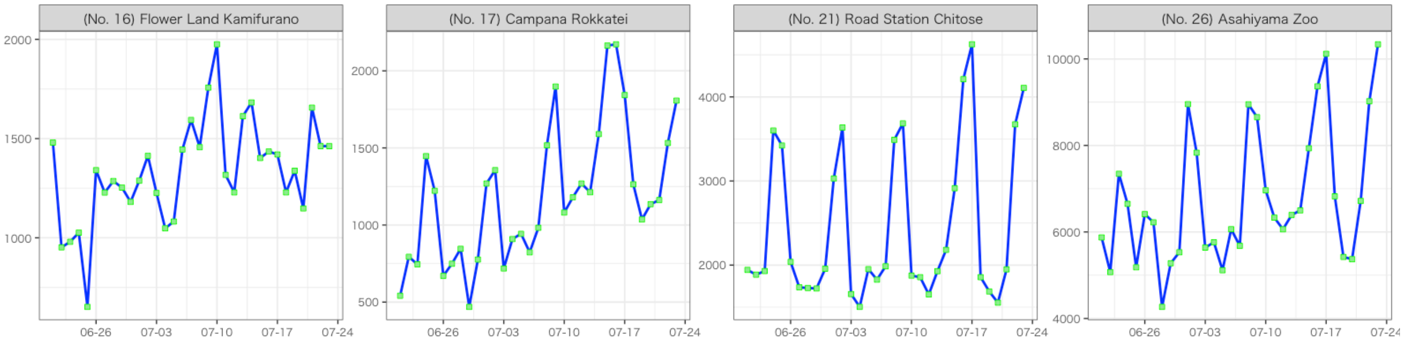


Figure 3. Daily trends of unique identifier count in some popular sightseeing spots in Hokkaido (The location number corresponds to the number shown in Figure 2 [a])

To check the reproductively of tourist demand, we have compared actual tourist count and probe request count from a WifiScanner installed at Okinawa Churaumi Aquarium (No. 36 in Figure 2 [b]). The results are shown in Figure 4 and it is indicated that the ratio of tourist number and PR count number would be stable over all of the comparison period (the mean value of the ratio: 1.35 and the variance: 0.08).

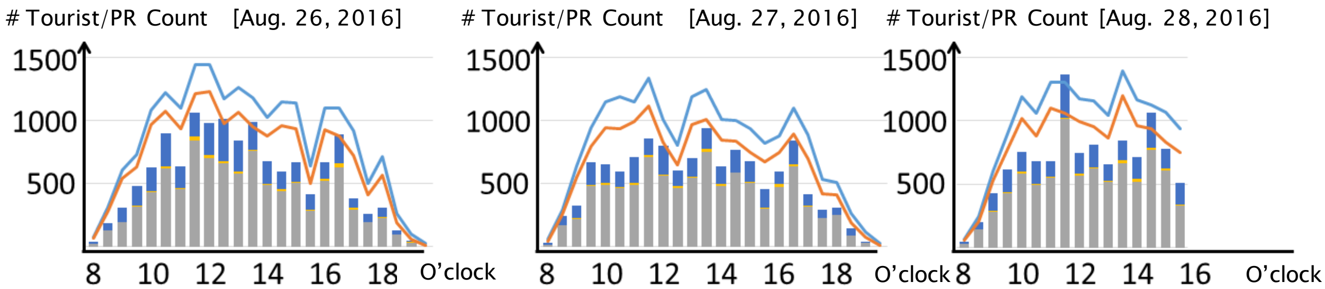


Figure 4. Comparison of actual tourist count and probe request count (Okinawa Churaumi Aquarium, Grey bar: # Adults, Blue bar: # Children, Blue line: # Unique identifiers for every 30 minutes, Orange line: # Unique identifiers for all the period)

By jointly analyzing PR records obtained from different sites but with the same unique identifiers, it is possible to infer tourists' movements from one site to another just like origin-destination tables. Table 1 show the calculation results tourists' flow matrix computed in Main Island of Okinawa with the sites being aggregated into six regions. For example, the number of unique identifiers formerly recorded in North Region and then recorded subsequently recorded in Motobu Peninshula is 192 which is approximately 0.04% of the total count. It is obvious that the movement from/to/within Naha City (the capital of Okinawa Prefecture) is fairly dominant.

Table 1. Tourists' flow (quasi origin-destination) matrix in Main Island of Okinawa

Precede \ Succeed	North Region	Motobu Peninshula	Central Region	Naha City	West Region	South Region	Trip Generation
North Region	236 (0.05%)	192 (0.04%)	61 (0.01%)	168 (0.04%)	11 (0.00%)	4 (0.00%)	672 (0.14%)
Motobu Peninshula	140 (0.03%)	6,799 (1.46%)	3,227 (0.70%)	8,903 (1.92%)	310 (0.07%)	263 (0.06%)	19,642 (4.23%)
Central Region	90 (0.02%)	4,411 (0.95%)	2,381 (0.51%)	8,283 (1.78%)	303 (0.07%)	388 (0.08%)	15,856 (3.42%)
Naha City	84 (0.02%)	7,972 (1.72%)	10,688 (2.30%)	371,359 (79.98%)	3,854 (0.83%)	12,130 (2.61%)	406,087 (87.46%)
West Region	19 (0.00%)	1,228 (0.26%)	1,189 (0.26%)	1,792 (0.39%)	132 (0.03%)	166 (0.04%)	4,526 (0.97%)
South Region	10 (0.00%)	338 (0.07%)	759 (0.16%)	13,577 (2.92%)	346 (0.07%)	2,473 (0.53%)	17,503 (3.77%)
Trip Attraction	579 (0.12%)	20,940 (4.51%)	18,305 (3.94%)	404,082 (87.03%)	4,956 (1.07%)	15,424 (3.32%)	464,286 (100.00%)

Modeling tour patterns

While some data analysis, we have worked on the model development for predicting tour patterns with machine learning techniques and discrete choice approaches. Firstly, individuals "typical" tours are subtracted and classified into the moderate number of patterns by utilizing the technique of nonnegative matrix factorization (e.g. Lee and Seung, 1999). Then, the joint choice model of tour patterns (i.e. the combination of sites visited and the staying duration for each site) is formulated and estimated in disaggregate modeling manner. These results would be fully described in the full paper.

Acknowledgements

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