Doctoral Dissertation

Gamified participatory sensing for sustainable spatiotemporal tourism information collection

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Abstract

An important role of smart cities is to aggregate and curate urban environment information provided by various sectors to improve citizens' quality of life better. In order to sense the urban environment, it is essential to involve human sensors through participatory sensing to complement and enhance the information obtained from infrastructures established by the government or industry with sensible information obtained through their experience. However, it is an important issue how to encourage people, who are engaged in daily activities with their own objectives, to take sensing behaviours. Gamification has been attracting attention as an incentive mechanism to solve this problem.

In this dissertation, we focused on smart tourism, which is one of the important applications in smart city environments, and in order to realize sustainable spatiotemporal tourism information collection using gamified participatory sensing, we addressed the following two research challenges: (1) design of gamification and tasks that consider the burden on tourists, and (2) design of an appropriate task allocation interface and interaction, and personalization. In challenge (1), we introduced mission, point, and ranking functions as gamification elements. There are two types of missions: check-in mission to post photos and reviews at the designated tourist attraction and area mission to collect sensor data at the designated tourist attraction. We also designed three types of reward methods that differ in setting points obtained when completing missions. We conducted a

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tourism experiment with 33 participants to investigate our gamification designs' effect on the efficiency of tourism information collection and tourism satisfaction. The results show that area missions should be adopted when considering tourism satisfaction and that the variable reward method effectively collects tourism information without decreasing the satisfaction. In challenge (2), we designed two types of interfaces: a map-based interface in which the user selects the spots on the map with markers and a chat-based interface in which the agent character in the application passively selects the spots at the request of the user. For the chat-based interface, we developed four dialogue templates based on the dimensions of elaborateness and directness to elucidate the appropriate dialogue sentence. We conducted a tourism experiment with 118 participants to investigate the interface's effect on information collection efficiency and tourism satisfaction. The results show that the absolute amount of the collected data is about 1.4 times larger in the map-based interface, but the chat-based interface was able to more efficiently collect high-demanded spot information. There was a significant tendency to prioritize the mission over tourism in the chat-based interface. Moreover, there was a significant difference in the index of elaborateness among the agents, and more elaborate sentences were preferred. Finally, we found that there are correlations between some personality traits and contribution to sensing and interface preferences.

Keywords:

smart city, smart tourism, participatory sensing, gamification, user interface, communication styles, user modeling

Contents

List of Figures

List of Tables

1. Introduction

1.1. Background

With the development of information and communication technologies (ICTs) and the spread of Internet of Things (IoT) devices such as smartphones, the ubiquitous computing society, defined as anywhere and anytime access for anyone and anything, is about to be realized. Smart city is a concept that integrates modern technologies, such as advanced information and telecommunications networks and artificial intelligence (AI), into a ubiquitous computing society and applies them to the city [1]. The key role of a smart city is providing the better quality of life to citizens in terms of social, economic, and cultural aspects by aggregating and curating information provided by various sectors and optimizing the quality of services. The construction of a smart city is based on infrastructures such as sensor networks built by government and industry to sense urban dynamics. These infrastructures will be complemented and enhanced by the involvement of "human sensors" through participatory sensing to provide the essentials. Participatory sensing systems encourage individuals carrying smartphones to explore phenomena and events of interest using in-situ data collection and reporting [2]. Application domains for which participatory sensing has been used so far include environment monitoring [3, 4], public health [5], urban safety [6],education [7], transport [8] and tourism [9], that closely related to smart city environment. However, for the general citizens, who live for their own purposes on a daily basis, it is necessary to motivate them to contribute in order to participate in sensing. In general, there are two main types of incentives that can be used in participatory sensing to induce motivation: monetary incentive and non-monetary incentive. Monetary incentive is a straightforward approach of paying the participants for data contribution. Non-monetary incentive provides experiences, such as fun, social contribution, and intrinsic motivation. As a mechanism to induce participants' contributions, gamification, which incorporates game thinking and mechanism into non-game content, has been attracting attention.

The tourism sector is one of the applications that will benefit from the sophistication of smart cities. In the parts of literature of Tu et al. [10] and Guo et al. [11], tourism is actually seen as a service provided by the smart cities and smart tourism is thus conceptualized as a goal for the smart city. Therefore, the realization of smart tourism is a very important domain for the achievement of the smart city itself. Various ICTs have already been applied to the tourism sector, for example, centralized reservation systems for air travel and distribution and web-based services such as the distribution of tourism information through web media. These web-based reservations and information sharing through web media and social media services have been referred to as e-tourism. On the other hand, smart tourism is a concept that creates a new tourism experience through the integration of services that utilize more advanced ICTs. According to Gretzel et al. [12], the three basic components underlying smart tourism are *smart destination*, *smart business ecosystem*, and *smart experience*.

- **Smart Destination**
  The smart destination is defined as "an innovative tourist destination, built on an infrastructure of state-of-the-art technology guaranteeing the sustainable development of tourist areas, accessible to everyone, which facilities the visitor's interaction with and integration into his/her surroundings, increases the quality of the experience at the destination, and improves residents' quality of life" [13]. The key aspect of smart destinations is the integration of ICTs into physical infrastructure.

- **Smart Experience**
  The smart experience component specifically focuses on technology-mediated tourism experiences and their enhancement through personalization, context-awareness and real-time monitoring [14]. This means that various information is synchronously aggregated in real time for a more efficient and richer tourism experience. Here, tourists not only consume but also create, annotate or otherwise enhance data that constitutes the basic of experience.

- **Smart Business Ecosystem**
  Smart business refers to a business ecosystem where various stakeholders are dynamically interconnected and business processes are digitized and agile in order to create and support the exchange of touristic resources and the co-creation of the tourism experience. A distinct aspect of this smart business component is that it includes public-private collaboration to an extent that is unusual and results from governments becoming more open and technology-focused as providers of infrastructure and data. In addition, smart tourism recognizes that consumers can also create and offer value as well as monitor and therefore take on business or governance roles.

Importantly, across these three components, data are aggregated, interconnected, and processed to create and use rich value and experience in real-time. Based on these considerations, Gretzel et al. [12] defined Smart Tourism as:

> Tourism supported by integrated efforts at a destination to collect and aggregate/harness data derived from physical infrastructure, social connections, government/organizational sources and human bodies/minds in combination with the use of advanced technologies to transform that data into on-site experiences and business value-propositions with a clear focus on efficiency, sustainability and experience enrichment.

Table 1.1 summarizes the difference of e-Tourism and Smart Tourism [12].

In the past, e-Tourism was based on planning and booking tourism in advance through web media and social networking services (SNSs), and after the visit tourists post information on SNSs such as blogs to interact with other tourists. On the other hand, in Smart Tourism, tourists are able to dynamically obtain personalized and holistically optimized tourism experiences during their trip, from aggregated information obtained from various sectors, such as real-time big data (e.g., sensor data in the city and fresh experience episode from other tourists), existing tourism information, and administrative open data. This structure also consists of a smart tourism ecosystem where tourists not only consume it, but also create or enhance data that constitutes the basic of experience [15].

	e-Tourism	Smart Tourism
Sphere	digital	bridging digital & physical
Core technology	websites	sensors & smartphones
Travel phase	pre- & post-travel	during trip
Lifeblood	information	big data
Paradigm	interactivity	technology-mediated co-creation
Structure	value chain / intermediaries	ecosystem
Exchange	B2B, B2C, C2C	public-private-consumer collaboration

Table 1.1.: The differences between e-Tourism & Smart Tourism

1.2. Problem Statement

As mentioned above, to realize smart tourism and thus smart cities, not only tourists and citizens consume contents from the system, but the ecosystem that generates it needs to function properly. Participatory sensing is one way to achieve these problems [2]. Participatory sensing systems encourage individuals carrying smartphones to explore phenomena and events of interest using in-situ data collection and reporting. It is considered as a paradigm for realizing Smart City, and the following two advantages are mentioned: 1) it extends the sensing capabilities that have been deployed in terms of dedicated sensor networks, 2) it makes the citizens feel part of the Smart City in which they all live. Fix My Street* is a good example of participatory sensing being operationalized in the real world, considering the above two advantages. This is a map based website and app that helps people inform their local authority of problems needing their attention, such as potholes, broken streetlamps, etc. In the case of tourists, however, they are primarily interested in enjoying tourism, so mechanisms are needed in order to induce them to participate in such an ecosystem. In the concept of smart tourism, participatory sensing with IoT devices is described as an element to bridge the gap between the real world and the digital realm [12]. However, as far as we have investigated, there are no practical studies on participatory sensing

*https://www.fixmystreet.com/

in smart tourism domain, and it is not known whether an ecosystem based on participatory sensing will actually be established.

In this dissertation, we explore the feasibility of an ecosystem in smart tourism based on participatory sensing for tourists through practical experiments and address the following two research challenges.

Challenge 1 : Design of gamification and tasks that consider the burden on tourists

Participatory sensing is a mechanism that depends on users' voluntary contributions, and the design of incentives for continuous and efficient data collection is a general problem. As a mechanism to induce participants' contributions, gamification, which incorporates the concept and mechanism of games into contents other than games, has been attracting attention. However, it is not yet clear what kind of gamification should be applied to this mechanism in participatory sensing for tourists. In addition, there is a need to efficiently collect the dynamic tourism information required by the system to perform dynamic tourism planning. Therefore, two types of missions were designed to identify gamification factors to induce data collection while considering the burden on tourists. Additionally, we designed a rewarding mechanism within the gamification framework to achieve efficient data collection. These gamification elements were implemented as an application, and their impact on data collection efficiency and tourism behavior was demonstrated through experiments, and an appropriate gamification design was elucidated.

Challenge 2 : Design of an appropriate task allocation interface and interaction, and personalization

Secondly, the interface is important and should be considered in allocating and communicating sensing tasks from the system to participants. Therefore, we adopted a map-based interface, which is commonly used in location-based applications, and an interactive interface, which is becoming more popular in recent years such as chatbots. We show how these different task allocation interfaces affect the efficiency of tourism information collection and tourist satisfaction. In addition, the interactive interface of the agent character with the user is also con-

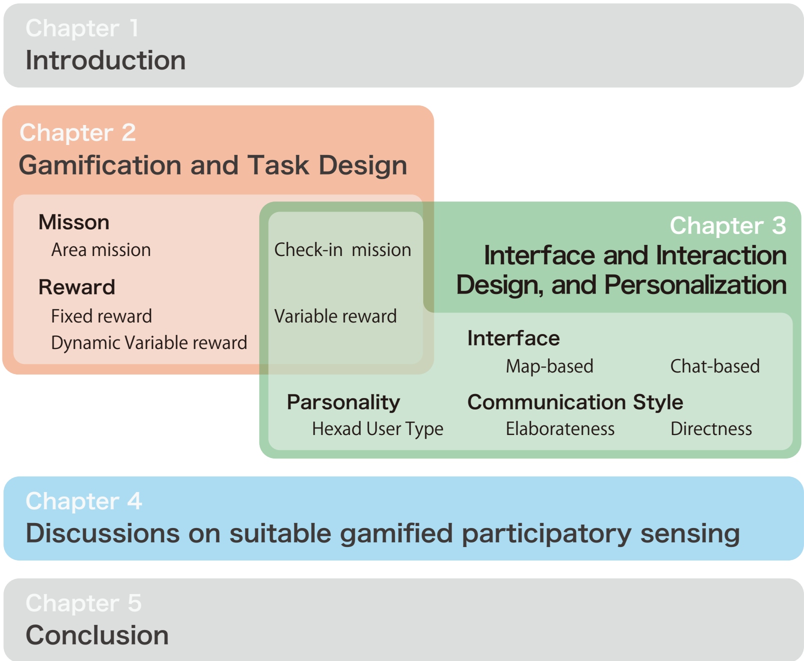


Figure 1.1.: Organisation of Dissertation and Relationship of each Component

sidered to be an important factor in the interactive style. Therefore, we created four dialogue templates based on elaborateness and directness in communication style. We conducted tourism experiments with the ordinary people to elucidate the appropriate interface and interaction design. Finally, since participants have different motivations depending on their personalities, we used Hexad, a user modeling framework for gamification, to examine the relationship between the user types and their tourism behavior and contributions. This work is a collaborative research with Ulm University.

1.3. Organization of Dissertation

The organization of this dissertation and the relationship between the components in each Challenge are shown in Figure 1.1. In Chapter 2, we design and implement basic gamification mechanisms and reward methods for efficient data collection in participatory sensing for tourists. In Chapter 3, we design and implement an interface for allocating sensing tasks based on the gamification mechanics and reward method designed in Chapter 2. In Chapter 4, we discuss the comprehensive design of gemified participatory sensing based on the results obtained in the previous chapter. Finally, Chapter 5 concludes this dissertation and mentions on future direction.

2. Gamification and Task Design

2.1. Introduction

User-generated tourism content is perceived as an effective and reliable information resources for other tourists. In the tourism sector, firms use crowdsourcing to exploit travelers as marketers and actively involve them in their marketing strategies [16]. In addition, social problems such as overtourism, which is defined as “the impact of tourism on a destination, or parts thereof, that excessively influences perceived quality of life of citizens and/or quality of visitors experiences in a negative way” by The World Tourism Organization of the United Nations (UNWTO) [17], caused by an increase in the number of tourists, have recently attracted attention. Collecting crowdsourced user-generated content as well as tourist activity flows can help solve these problems. Furthermore, along with the development of information technology in recent years, a tourism style that decides the next tourist destination during sightseeing such as on-site tour has also appeared. In order to realize more comfortable on-site tour, it is necessary to collect dynamic tourism contexts, such as smoothness of pedestrian flows, crowds in mobility, temporary events and temporary closures of tourist facilities, efficiently and with high spatio-temporal resolution [18].

One method to collect such information, analysis of data from social networking services linked with geolocation information can be considered. In the research field, many analyses using data from Twitter have been conducted, but geo-tagged tweets are reported to be less than 1% of all tweets [19–21]. Additionally, since most people don’t tag their precise location in Twitter, it was officially announced that this ability will be removed *. Then, as a suitable method for accumulating such contents, participatory sensing, which collects various data associated

*https://twitter.com/TwitterSupport/status/1141039841993355264 with location information from a smart device owned by people [2], exists. The widespread use of smartphones [22] with a variety of embedded sensors, such as GPS, camera and accelerometer creates the potential for dense, high-quality participatory sensing. In addition, it is possible to collect not only information obtained from sensor data but also content that can be generated only by humans such as information using human perception and impression through experience. However, the participant must bear the burden with respect to battery consumption, memory/storage capacity, and mobile data traffic and possibly even their behavior and time. It is difficult to collect data continuously relying on only the voluntary participation of people because of these loads. In addition, it is necessary to consider the burden on time especially in tourism situations. Tourism is an invaluable time for people and sometimes it is a once-in-a-lifetime experience. They may need to spend their time to generate content during the trip, and occasionally take detours to upload content before they make their way to their next destination. The design of incentive mechanisms for participation is essential to realize continuous contributions by motivating participants.

Two types of incentives are generally discussed in participatory sensing: monetary incentives and non-monetary incentives [23]. Monetary incentives provide money as a reward for contributing to sensing. A variety of studies have been conducted to determine the impact of the price rate and reward mechanism (e.g., fixed micro-payment, variable micro-payment, lottery and auction), on the participation rate and on the quality and quantity of the collected data [24, 25]. On the other hand, non-monetary incentive is a mechanism that provides intangible value, such as fun, useful information, psychological need satisfaction, and memorable experiences [26]. Among non-monetary incentives, gamification that incorporates game thinking and mechanism into non-game content has attracted attention [27–29]. Gamification has been introduced to the following areas: education [30], health care [31], marketing [32] and social networking [33]. There have been many studies on participatory sensing applying gamification, and the effectiveness of gamification has been demonstrated [26, 34–38]. However, the literature suggests that empirical studies are required in order to clarify the effects of gamification in each participatory sensing context or domain [37, 39–41]. Even in tourism sector, gamification has been applied to improve tourism satisfaction or to generate brand awareness [42]. However, few concrete studies have addressed the appropriateness of the design of gamified participatory sensing for tourists. That is, the purpose of introducing gamification in this study is not to improve tourism satisfaction or to generate brand awareness, but to collect dynamically changing tourism information efficiently through participatory sensing for tourists while taking into account the burden on tourists. In order to realize a sustainable participatory sensing system in the tourism domain, a detailed gamification design should be discussed.

In this chapter, we adopted gamification to participatory sensing in order to efficiently collect dynamic tourism information while taking into account the burden on tourists. We also investigate the effect of gamification on tourist behavior and tourist satisfaction through an experimental case study. We designed several gamification mechanisms, which have different types of sensing tasks and reward mechanisms, and implemented these mechanisms in ParmoSense [43], an integrated participatory sensing platform that we developed. Gamification mechanism design consists of two types of sensing tasks (referred to hereinafter as *missions*): the Area Mission involves for walking around a specific area, and the Check-in Mission involves taking a picture at a checkpoint. There are three types of reward mechanisms, Fixed, Variable and Dynamic Variable reward mechanisms for each mission. In addition, three types of user types (sightseeing, reward, game) were designed according to the motivation of the participant, since it was indicated that the effect of gamification differs according to the participant type [44]. In order to confirm the effects of the designed gamification mechanisms, we conducted a real-world experiment in Kyoto, Japan with 33 participants. Participants used a smartphone application for sensing during sightseeing. After the experiment, we investigate the effect on tourist satisfaction and behavior by analyzing post-survey and collected sensor data. Specifically, the main contributions of the present paper are summarized as follows:

- First, to the best of our knowledge, this is the first study to elucidate suitable gamification in participatory sensing for tourists in order to efficiently collect dynamic tourism information.
- Second, we present the design of two types of mission with different burdens (Area Mission and Check-in Mission) and three types of reward mechanisms

(Fixed, Variable, Dynamic Variable). Then, we implement these elements in our participatory sensing platform application and conduct a subjective sightseeing experiment in the real world.

- Third, we confirm that the tourist behavior is changed due to the proposed gamification design and that the necessary information was collected efficiently from the quantitative evaluation by analysis of collected sensor data and the statistical results of the post-survey.
- Finally, summarizing the results of the present study suggests that suitable gamification to collect tourist information efficiently, considering tourist satisfaction, is achieved by the Area Mission with the Variable reward mechanism and Free posting.

The rest of this chapter is organized as follows. Section 2.2 reviews existing work related to this paper and sums up the challenges of the present study. In Section 2.3, we describe the proposed gamification mechanism design and implementation of the application. Then, we mention our settings of the subjective sightseeing experiment in Section 2.4. We present the experimental results in Section 2.5, and a discussion and the limitations of the present study are provided in Section 2.6. Finally, Section 2.7 concludes this chapter.

2.2. Related Work and Challenges

2.2.1. Incentives in Participatory Sensing

Participatory sensing is leveraging for various domains such as environmental monitoring [45, 46], road condition monitoring [47, 48], and health monitoring [49, 50], through the widespread use of smart mobile devices which are equipped with various built-in sensors such as GPS, camera, accelerometer. Furthermore, various platforms [43, 51] and frameworks [52–54] have been developed with the goal of facilitating participatory sensing in various situations. On the other hand, since the processes of participatory sensing require the participants to use a smartphone, problems, such as consumption of batteries and mobile data traffic, security of data, and quality of data, are encountered by the participants [55]. Active participation of participants is one of the most important factors in collecting data in participatory sensing. Therefore, many studies on the incentive mechanism have been conducted in order to encourage active participation [35, 56]. Incentive mechanisms are generally classified into two types: monetary incentives and non-monetary incentives [57].

Many studies have investigated the effect on sensing participation and the quality and quantity of data obtained from participants introducing monetary incentives in crowdsourcing participatory sensing. Lee et al. [24] proposed a dynamic pricing system for participants based on reverse auctions in which sensing participants set a price when providing data to the organizer (provider). Simulation analysis shows that the proposed method reduces incentive costs and improves incentive fairness. Khoi et al. [25] proposed three types of financial incentive schemes (e.g., lottery-style, fixed micro-payment, and variable micro-payment), and case study experiments in the real world with 230 participants showed that monetary incentives improve the participation rate. However, monetary incentives in the real world are often limited by total budget and have continuity problems.

On the other hand, non-monetary incentives provide experiences, such as fun [58], social contribution, and intrinsic motivation [59]. Gamification, which is defined as "the use of game design elements in non-game contexts" [27] has attracted attention in user-centric systems such as participatory sensing. Gamification refers to design that seeks to, first, increase the motivation of users or participants to engage in an activity or behavior and, second, to increase or otherwise change a given behavior [37]. For instance, Palacin-Silva et al. [41] introduced gamification (e.g., storytelling, challenges, points, and leaderboards) to the environmental sensing domain in order to explore the impact of gamification on engagement and user experience. Through an experiment, they found that gamification affected participant engagement in a positive way (producing more submissions) without improving or compromising the user experience. Berkel et al. [60] adapted points, leaderboards, time restriction and visual feedback as gamification elements to measure the difference in the quality and quantity of responses. Ueyama et al. [34] introduced a novel incentive mechanism employing gamification elements such as points, rankings, and badges, in addition to monetary rewards, to suppress a rapid rise in monetary rewards. The results show that monetary incentives are suppressed and the participation rate is increased by gamification. According to surveys and reviews on designing effective incentive mechanisms, points, rankings/leaderboards, and achievement are often introduced as gamification elements, and affect the user positively, particularly in participatory sensing [37, 57, 61].

As mentioned above, previous research has shown that both monetary and non-monetary incentives increase the participation rate of participants and improve the quality and quantity of the data. However, it has become clear that, especially with respect to monetary incentives, the imbalance between tasks and rewards can cause a decline in the quality of data, and the influence on the control of user withdrawal decreases in long-term experiments (e.g., monetary incentives are exhausted during the campaign) [37, 62]. Therefore, monetary incentives should be implemented cautiously in combination with gamification [37, 63].

2.2.2. Gamification in Tourism

Gamification is often introduced in the tourism domain in order to raise brand awareness, enhance tourist experiences, destination loyalty, consumer loyalty and engagements [16, 32, 40, 42, 64–68]. One of the successful examples of gamification in tourism is TripAdvisor[†], the world's largest travel portal service. It has several website tasks which use various gamification elements. For example, tourists are motivated to upload tourist information such as photos and/or reviews and are presented with points, badges, competitive scoreboard and so on [69]. Moro et al. [70] have shown that some badges and the total amount of badges acquired are the most relevant gamification feature for motivating tourists to write reviews.

In the context of brand awareness, Foursquare [‡] has successful partnerships with many brands which are promoted during game play through check-ins and when sharing their experiences through social media. In addition, there are games based on Facebook, such as Ireland Town and Smile Land Thailand game[§] , which generate brand awareness as a tourist destination and increase user frequency of

[†] `https://www.tripadvisor.com/`
[‡] `https://foursquare.com/`
[§] `http://smilelandgame.com/`

social networking media of local associations. For tackling the problem of waste generated in tourist attractions, a gamification application called Wastapp, has been developed to promote recycling behavior of tourists. In experiments using this gamified application, it has been reported that gamification contributes to the recycling behavior of tourists and improves the image of destinations [71].

Fully-fledged games, which are more about fun and entertainment, also exist to encourage tourism. Geocaching¶ is an outdoor recreational activity, in which participants use GPS-enabled devices, such as smartphones, to find treasure boxes on site. Pokémon Go‖ is one of the most popular augmented reality (AR) games thus far. In the Pokémon GO game, players must catch and fight Pokémon while exploring and experiencing the real world [72]. These were not specifically designed for tourism. However, Geocaching partners with local tourism associations to create special treasure hunt tours and partnering Pokémon GO partners with UNWTO to develop innovative tourism experiences through real-world games**. In both games, players look for hidden treasures or Pokémon at various real-world locations. Through this engagement, players are encouraged to interact with the destination at site [66].

Gamification is widespread in the tourism industry as stated previously. However, according to Xu et al. [66], academic research on the application of gamification specifically in the tourism field is still scarce. There are a few researches which investigating the impact of gamification on dynamic tourism information collection with various gamification mechanics. However, although a comprehensive evaluation using various mechanics was conducted, it is not clear which gamification mechanics had an impact on which outcomes [68].

2.2.3. Challenges

We clarify the positioning of this study in light of related studies. Although full-fledged games such as Pokémon go can be cited as a concept similar to gamification, it is clearly differentiated by the distinction shown in Figure 2.1 by

¶ https://www.geocaching.com

‖ https://www.pokemongo.com/

** https://www.unwto.org/global/press-release/2018-11-20/unwto-partners-niantic-develop-innovative-tourism-experiences-through-real-

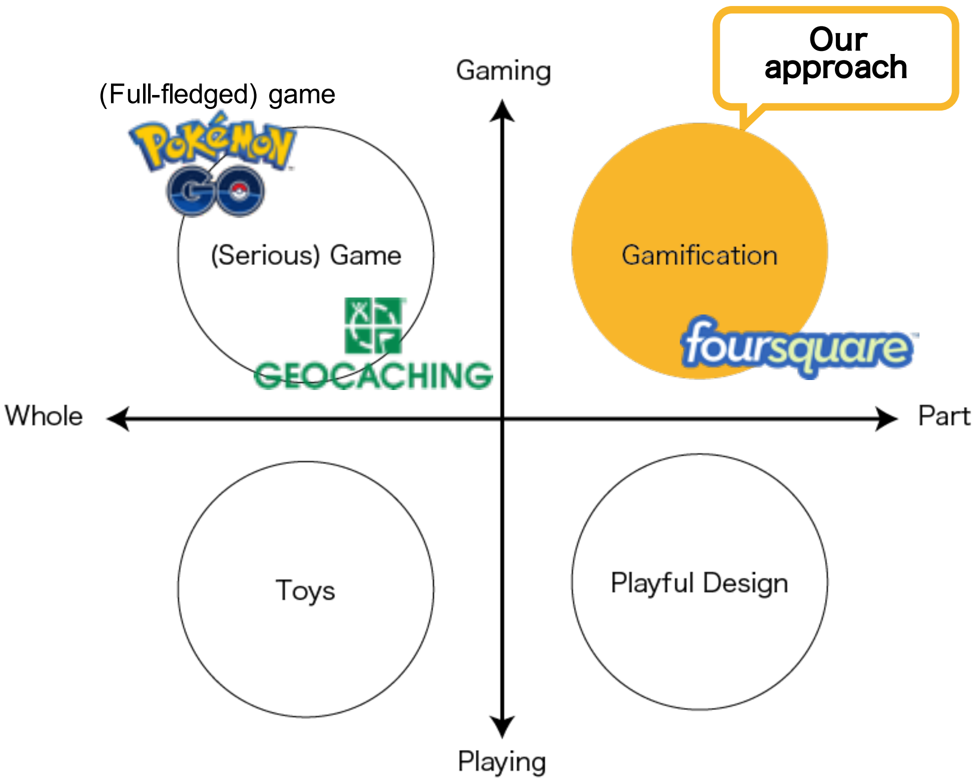


Figure 2.1.: Positioning of our study by distinguishing the concepts related to gamification.

Deterding et al. [27]. Gamification refers to elements of games being used in non-gaming contexts, meaning that there is an instrumental goal to be achieved other than pure entertainment, and the gameful experience of the user is usually supporting the instrumental goals rather than being the focus. Unlike the Full-fledged Game, which focuses on the enjoyment of the game itself, our research is focused on the sustainable collection of spatio-temporal tourism information and partially applies game elements to induce tourists to actively contribute to the data collection.

There have been many studies on motivation to encourage the active participation of users in participatory sensing. In particular, the utility of gamification in user-centric services such as participatory sensing has become clear. However, the literature suggests that empirical studies are required in order to clarify the effects of gamification in each participatory sensing context or domain [37,39–41]. Gamification is often used to raise brand awareness, and enhance tourist satisfaction and engagement in the tourism domain. Even TripAdvisor, which applies gamification actively in the tourism sector, focuses mainly on exchanging and posting tourist information before or after sightseeing [69, 70]. Few academic studies aim at efficient collection of dynamic tourism information with high spatio-temporal resolution by participatory sensing during sightseeing. In the case of crowdsourcing sensing tasks to tourists during sightseeing, participants are burdened by spending not only their device resources but also invaluable time for sightseeing. It is necessary to create a framework which tourists can easily follow and do even during sightseeing, in order to realize efficient dynamic tourism information collection.

Our research question in this chapter is what is the suitable gamification in the participatory sensing for tourists considering tourist satisfaction. An experimental case study is conducted in order to clarify this research question.

2.3. Study Design

In this chapter, we clarify the gamification design that is suitable for user participatory sensing with tourists as participants in order to efficiently collect tourist information without degrading tourism satisfaction. Consumer-generated media (CGM) required for tourism is inertial sensors and GPS built into smartphones, and photos and comments. With the development of human activity recognition research, it is possible to collect information such as tourist behaviors [73] and congestion degree in the surrounding area [74] from sensor data collected from smartphones. Also, photos and comments are very useful information for the next tourist to understand the current situation of the sightseeing spot.

Some of the most commonly used gamification mechanics in participatory sensing or location-based social networks (LBSNs) are points, rewards, levels, badges, leaderboard / ranking, missions and so on [37, 57, 61, 75]. Jordan [76] analyzed how gamification mechanics, especially mayorships and budges, in Foursquare which is one of the most famous LBSNs, can impact people's mobility decisions.

Mayorship was reported to be highly effective in encouraging multiple visits to the same location. It has also been stated that Badge has the effect of influencing a person's mobility to gain a new badge and explore physical space in some active users. Molo et al. [70] have shown that several specific badges and the total amount of badges acquired are the most relevant gamification feature for motivating tourists to write reviews useing TripAdviser's reviewing data. Lee [68] investigated the impact on tourism behavior in cultural heritage cruise tourism using app with gamilication mechanics such as quizzes, avator, and missions. As a result, the effectiveness of gamification apps in improving understanding of cultural heritage was verified. However, although a comprehensive evaluation using various gamification mechanics was conducted, it is not clear which gamification mechanics had an impact on which factors. Since gamification designed for the collection of dynamic tourism information during sightseeing has not been explored in detail so far, we focus primarily on simple gamification mechanics, missions and point-based rewards.

The basic design assumes that each time participants perform a mission requested through the app, the participants are given points in the application. The detail of mission should be designed based on our requirements of tourism information to be collected (i.e., photos, comments, and sensor data) and the acceptability of mission. We designed two kinds of missions with different burdens on participants in order to clarify a suitable gamification design. In order to efficiently collect the information that campaign organizers (e.g. municipality or tourism association) require, we hypothesized that this could be achieved by changing the reward mechanism according to the demand level of information and designed three reward mechanisms. The following explains the details of each mission design, reward mechanism, and an outline of the application that implements these elements.

2.3.1. Mission Design

The priority of sightseeing will vary depending on the burden of the mission on the participants. Here, the priority of sightseeing means a degree of concentration against sightseeing during the mission that the participant performed. The purpose of tourists is obviously sightseeing. Therefore, the mission should not

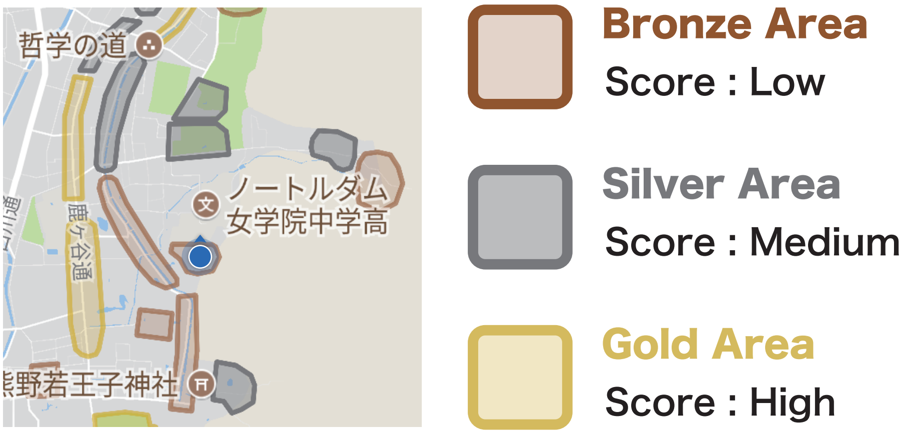


Figure 2.2.: Area Mission

interfere with sightseeing and the burden of the mission must be low.

We designed two types of missions with different workloads for the participants, namely, an Area Mission, which can be implicitly feasible and low-load, and a Check-in Mission, which requires performance explicitly and is high-load. In addition, we designed Free posting, which the participants can perform anytime and anywhere.

Area Mission

The Area Mission is displayed as multiple polygons in a specific sightseeing area on the map, as shown in Figure 2.2. Sensor data (GPS, acceleration, angular acceleration, geomagnetism, and illuminance) are collected by strolling in the displayed area. These sensor data can be used to estimate the context of sightseeing attraction such as the smoothness of pedestrian flows [74], the congestion on the roadway while traveling with a vehicle [77], and the detailed sightseeing behavior of the user [73]. Points are given at fixed time intervals, by collecting sensor data. A gold area, a silver area, and a bronze area are set according to the points to be given.

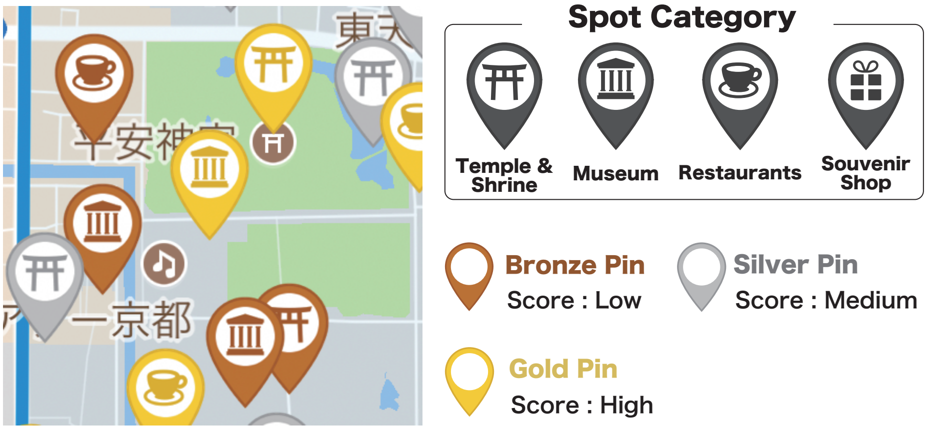


Figure 2.3.: Check-in Mission

Check-in Mission

The Check-in Mission is displayed with a pin at a specific sightseeing spot on the map, as shown in Figure 2.3. It is possible to check in when the user is within a certain distance from the pinned place. By posting photographs and comments on the spot, check-in is completed and points are given. Temples/shrines, museums, restaurants, and souvenir shops, which are commonly mentioned as sightseeing spots, are set as types of pins. Photographs and comments can also be used to estimate the context of tourist site by analyzing these data. In addition, it is possible to directly convey the state of the sightseeing spots. The colors of the pins are set according to the points, similar to the Area Mission.

In addition, free posting is also designed so that the users can freely post photographs of places they find interesting and share them with other tourists. These photographs and comments posted for the Check-in Mission and Free posting will be shared with other tourists through the timeline function shown in Figure 2.4 (6). The characteristics of each mission are summarized in Table 2.1.

	Area mission	Check-in mission
Sensing style	Implicit	Explicit
Data collection ability	Low	High
User burden	Light	Heavy
Sightseeing interference	Low	High

Table 2.1.: Summary of mission characteristics

2.3.2. Reward Mechanism

In participatory sensing, the necessary amount of information and the responsiveness required by the organizer varies according to the spot. Using the concept of dynamic pricing, we hypothesize that changing the points according to the information demand level will be possible to change tourists' behavior and collect the necessary information [78]. We designed three types of reward mechanisms as follows.

Fixed reward Fixed rewards are obtained depending on the type of mission (Area Mission, Check-in Mission).

Variable reward

The rewards vary by spot in the case of Variable reward mechanism. We assume that the event organizer sets the information demand for each spot, and the reward is decided according to the balance between the demand and the supply. In the experiments described in Section 2.4, the number of hits when each sightseeing spot name was searched on the web was assumed to be the demand of information, and the points were determined accordingly. For instance, famous sightseeing attractions already have a lot of information on the web and fresh data may also be supplied naturally because many people visit such sites. Therefore, the demand level of information will decrease and fewer points are to be gained for such places. On the other hand, not well known sightseeing attractions are assigned high point values. This is because the amount of information on the Web and the amount of information supplied are assumed to be comparatively small.

Dynamic variable reward

As one of the problems with variable rewards is that the weights are always fixed, so there is a possibility that the information might be too biased to certain places. To solve this problem, we designed Dynamic variable reward that changes the weights over time. In this reward mechanism, the amount of information collected by participatory sensing is reflected as the demand level of information at fixed time intervals. For example, suppose that a high score is set for an unknown spot, and many tourists posted at that spot in a short period of time. The next participant who completes the mission at that spot will receive a lower reward. On the other hand, if the data is not updated for a long time even for a famous sightseeing attraction, a high score will be assigned. redThis reward mechanism was designed to solve the problem that Variable reward, which always has a fixed weight, may cause the collected data to be too biased toward a certain location. For the sake of simplicity, we set the weight in advance and change this weight every 30 minutes accordingly in the experiment.

2.3.3. Application Implementation

Our smartphone application for participatory sensing is called *ParmoSense* [43] and consists of six screens, as shown in Figure 2.4 (1)–(6). The details of these screens are described as follows.

(1) This is the main screen of the application that indicates sensing tasks with pins or polygons as missions. The ranking and points of a user are displayed in the upper-right corner of the screen.

(2) This screen is displayed when the user taps a mission pin on the map. The screen shows details of the Check-in Mission. Check-in is allowed only when the user is within a certain distance from the pinned place.

(3) This screen is displayed when the user taps the mission button at the bottom of the screen. In this screen, the details of missions in the map are shown in list form.

(4) This screen is displayed when the user taps the check-in button in (2) to capture and upload a photograph or taps the camera button at the bottom

of the screen for Free posting.

(5) This screen is displayed after taking a photograph in (4). The user can input texts on information or impressions of the photograph (spot).

(6) This screen is displayed when the user taps the timeline button at the bottom left corner of the screen. This screen shows photographs and comments posted by other users.

The timestamp, GPS, acceleration, gyroscopic, geomagnetism, and illuminance values of the smartphone are collected at a sampling rate of 10 Hz, while this application is running (even in the background). These data are transmitted to the server every 5 seconds. Sensor data are also collected at the moment when the user takes a photo and is sent to the server along with the captured photograph, independent of the periodic sensor data.

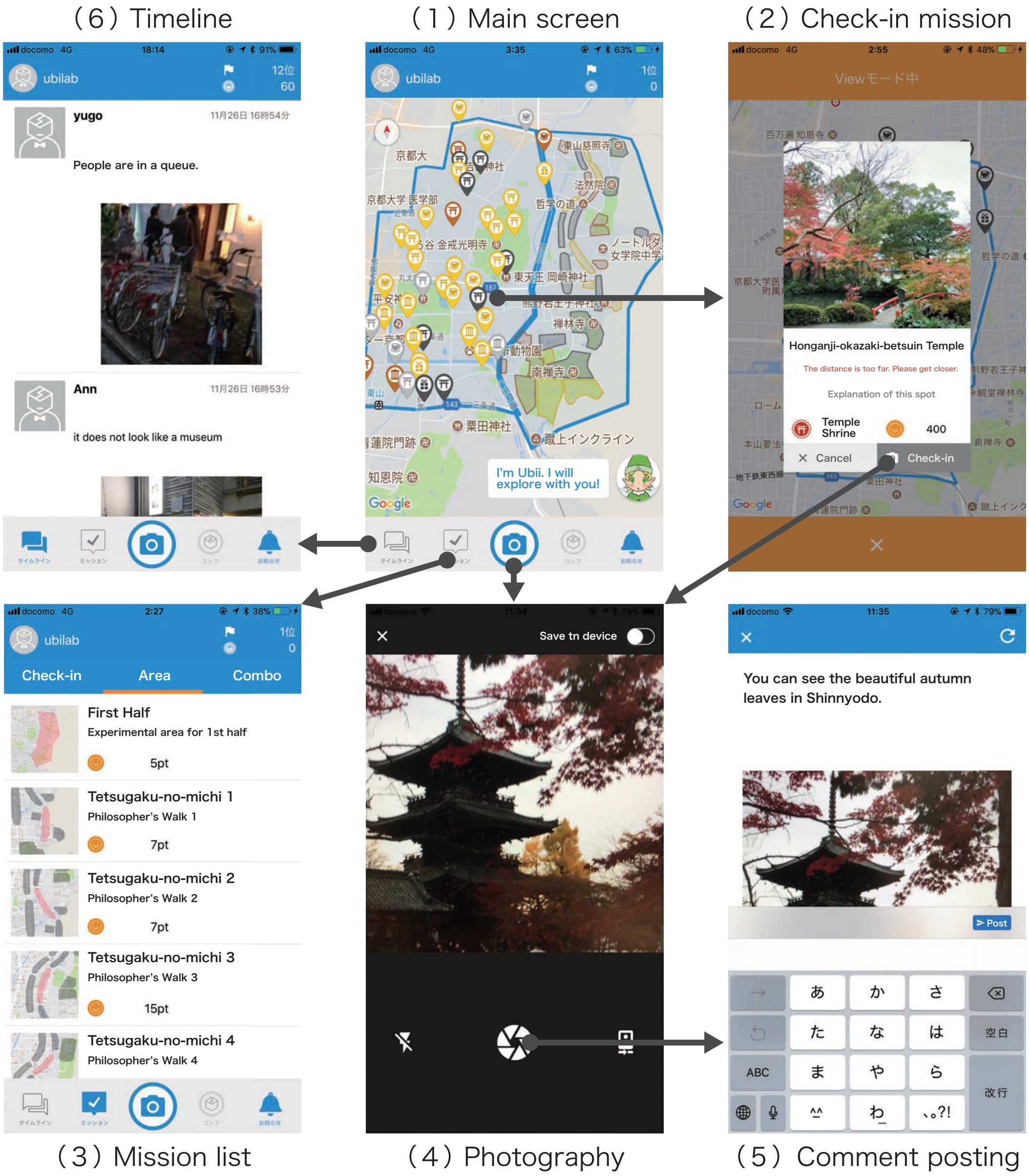


Figure 2.4.: Parmosense's application screens and transition pages

2.4. Sightseeing Experiment

In this section, we describe the sightseeing experiment. We conducted the sightseeing experiment using the developed application in order to investigate the effect of our designed gamification. In the following sub-sections, we explain in detail the participants, the experimental procedure, and the analysis method.

2.4.1. Participants

Participants were recruited from our university by e-mail which described the purpose, details, and remuneration. A total of 33 participants (25 male and 8 female) were recruited. Most of the participants were in their 20s (one participant was in his 30s and one participant was in his 40s). The number of Japanese and non-Japanese participants were 29 and four respectively.

It is important to investigate the influence of each user type by setting the user attributes in gamification [40]. Bartle's classification is a well-known classification of gamers types [44]; Achievers: people who are satisfied with achieving quests in the game, Explorers: people who explore and gain satisfaction from discovery or thrill, Socializers: people who gain satisfaction from social aspects such as interaction with others and Killer: people who gain satisfaction by competing with others. Based on these models, we set up three types of users based on the following questions; "While participating in a stamp-rally that gives a point-based reward, what do you think the most important among the following?" – Enjoy sightseeing (Sightseeing type), Enjoy stamp-rally (Game type), or Attempt to obtain more reward (Reward type).

According to the results of a pre-survey, 17 participants are classified as the Sightseeing type, seven participants are classified as the Game type, and the remaining nine participants are classified as the Reward type. The participants are assigned to these three groups taking into account the gender, nationality, and user type. The size of each group is 11 and the means and standard deviations (SD) for the number of males, Japanese, each user types in each group are follows. #Males: means = 9.67; SD = 0.58, #Japanese: means = 8.33; SD = 0.58, #Sightseeing type: means = 5.67; SD = 0.58, #Game type: means = 2.33; SD = 0.58, #Reward type: means = 3.00; SD = 0. Different reward mechanisms are applied to the groups: a Fixed reward for Group A, a Variable reward for Group B, and a Dynamic Variable reward for Group C.

2.4.2. Experimental Procedure

The experiment was conducted in Kyoto, Japan in November 2017. In this experiment, we asked the participants to perform sightseeing in an area of Kyoto City while earning points by clearing missions. After the experiment, we collected questionnaires from the participants. In order to clarify the effect due to the difference in mission type, we requested participants to engage in Area Mission and Check-in Mission separately in the first and second halves of the experiment, respectively. The experiment time was set to be 4.5 hours in total, which consists of a 2.5-hour course and a 2-hour course planned with reference to the sightseeing model course. Ahead of the experiment, we asked participants to install our developed application on their smartphone. After that, we fully explained the usage of the application and the contents of each mission for each group. We asked participants to travel alone and on foot during the experiment. We paid each participant 5,000 yen as a basic participation fee. It was decided based on an hourly wage of 1,000 yen, taking into consideration the experiment time of four and a half hours and transportation costs. Furthermore, as a monetary incentive, we informed participants that they would be paid additionally from 0 to 2,000 yen, depending on the ranking of the points in each group.

First-half experiment (Area Mission)

In the first half of the experiment, Area Missions were assigned to the participants. The course started from Keage Station to Ginkakuji Temple. The participants were asked to freely sightsee using our application. Points were given to each participant based on the following rules. These were set in consideration of the uniformity of the maximum points that can be obtained in each group in the first half and the second half.

(A) Obtain 10 points every 10 seconds within the experiment area for the first half of the experiment.

(B) Obtain 15, 10, or seven points every 10 seconds within special areas, such as gold areas, silver areas, or bronze areas, respectively.

(C) Special areas are updated every 30 minutes.

The total number of special areas in this experiment was set to be 33 (11 areas for gold, silver, and bronze, respectively). In addition, 30 points are given for Free posting.

Second-half experiment (Check-in Mission)

In the latter half of the experiment, Check-in Missions were assigned to the participants. The course started from Ginkakuji Temple and ended at Higashiyama Station. The participants were asked to freely sightsee using our application. Points were given to each participant based on the following rules:

(A) Obtain 400 points at any check-in spot.

(B) Obtain 730 $\sim$ 620 points, 370 $\sim$ 310 points, or 180 $\sim$ 150 points for checking in with a gold, silver, bronze pin, respectively.

(C) Special check-in spots with colored pins are updated every 30 minutes.

In this experiment, we set 45 special spots; 23 spots for temples or shrines, seven spots for museums, four spots for souvenir shops, and 11 spots for cafes. In addition, the highest number of points for all groups was set to be constant. Similar to the first half, we decided to give 30 points for each text posting.

2.4.3. Experimental Hypotheses

In order to clarify the effect of gamification factors and user type settings that we described above on tourist behavior and satisfaction,these hypotheses are summarized as follows:

- **Hypothesis *H1*: The priority of sightseeing varies depending on the burden of the mission.**

  Participation in sensing imposes a burden on resources such as devices, time, and behavior, and the priority of sightseeing will differ depending on these burdens. Therefore, we designed missions with different burdens on sensing participation, as shown in Section 2.3.1. Area Mission in the first half of the experiment and the Check-in Mission in the second half are conducted, and the effects on mission selection and sightseeing behavior are compared.

- **Hypothesis *H2*: The efficiency of data collection depends on the reward mechanism.**

  The necessary amount of information and the responsiveness required by the organizer varies according to attractions. Using the concept of dynamic pricing, we hypothesize that by changing the points assigned according to the demand for information, it is possible to change the behavior of tourists and collect necessary information.

- **Hypothesis *H3*: Priority of mission and sightseeing differ according to user type.**

  The priority between mission and sightseeing (= extent of contribution to sensing) will differ, depending on the motivation for sensing participation. User type of participant is set according to the participation motivation by the pre-survey, and which of mission and sightseeing is prioritized for each user type is compared from the post-survey.

2.4.4. Analysis Method

Mission logs, location data from the smartphone application, and the post-survey were analyzed to verify our experimental hypotheses. First, we quantitatively analyze the effect of different reward mechanisms on tourist behavior and mission selection using mission logs (for *H2*). For the Area Mission, the duration of stay according to the demand is used as an evaluation index. For the Check-in Mission, the number of check-ins with respect to the demand was used as an evaluation index. In addition, the amount of information collected in each mission was evaluated from photographs and comments obtained at check-in and Free posting. Next, the effect on the route selection is qualitatively evaluated by visualizing the travel route of the participants using the location data (for *H2*). Finally, we investigate the priority of mission and sightseeing through a post-survey in order to confirm the effect of participation in gamified participatory sensing (for *H1* and *H3*). The details of the post-survey are as follows: Q1. Which did you prioritize in the first half (Area Mission) of the experiment, sightseeing or the mission?; Q2. Which did you prioritize in the second half (Check-in Mission) of the experiment, sightseeing or the mission ? These questions were answered using a five-point Likert scale in which 1 = prioritized sightseeing, and 5 = prioritized the mission.

2.5. Results

In this section, we explain the experimental results. Thirty-three participants were divided into three groups of 11 participants, each with different rewarding methods. In the first half, the participants performed the Area Mission, and in the second half the participants performed the Check-in Mission. During both halves the participants engaged in Free posting. After the experiment, we conducted a post-survey about the priority of the mission and sightseeing.

Through the experiment, approximately 830 MB of sensor data (e.g., location and accelerometer), 1,744 photos and comments (688 from the Check-in Mission and 1,056 from Free posting), and 33 post-survey results were collected. In order to clarify the suitable gamification for tourism, these data were used to analyze the effects of each gamification element on tourist behavior and tourist satisfaction according to the indicators shown in Section 2.4.4.

2.5.1. Duration of Stay and Number of Check-in

First, the duration of stay and number of Check-ins for each tourist attraction is calculated using the collected location data, and the effect on tourist behavior is clarified quantitatively. Since the experimental groups are determined by the reward mechanism, the effects of the reward mechanism on tourist behavior are clarified based on the results.

We calculated the duration of stay according to the information demand level for each group. The area according to the demand level set to Group B (Variable reward) was used as a baseline, and it was also applied to Group A (Fixed). In

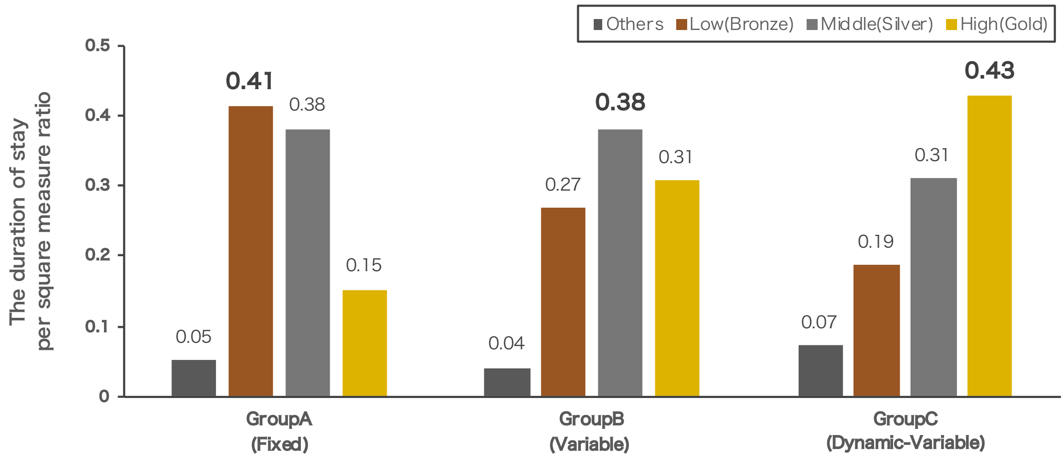


Figure 2.5.: Duration of stay in each area per square measure for each group

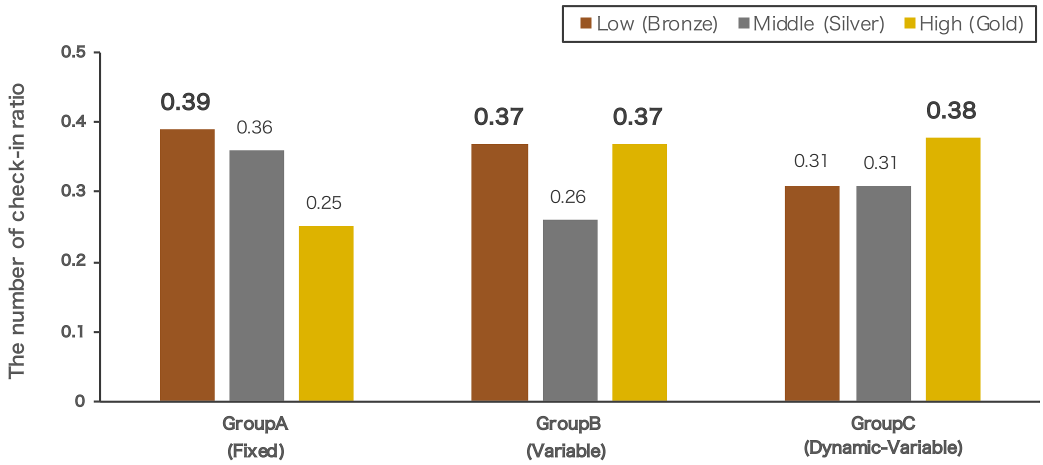


Figure 2.6.: Check-in ratio for each group

Group C (Dynamic variable reward), since the demand level changes every 30 minutes, the duration of stay is calculated for each demand level for each period and their sum is then calculated. Here, we cannot simply compare these groups, since the square-meter area is different for each area. Thus, we decided to use the duration of stay per square measure ratio as an evaluation index. Figure 2.5 shows the duration of area/square measure ratio by group.

The duration of stay in area with low information demand level accounted for more than 40% in Group A. On the other hand, the duration of stay in the area with high demand remained approximately 15%. It is a natural outcome that in Group A, in which a fixed point is obtained at any of the spots, the duration of stay at a well-known sightseeing spot becomes the longest. In Groups B and C, where the information demand level is indicated by the color, it is seen that the duration of stay at less popular sightseeing areas increased compared to the famous sightseeing area.

In the same way, the number of check-ins according to the information demand level is calculated for each group. The demand level of Group B was used for both Groups A and B, and that of Group C was changed for each period. Since the number of check-in spots is different between Groups A, B, and C for each demand, the number of check-in spots is normalized by the coefficient, so that the number of check-in spots is the same. The ratio of check-in spots by group is shown in Figure 2.6. In Group A, since there is no difference in rewards for each spot, check-in at the spot with low information demand occupied approximately 40%, and a result similar to that for the Area Mission was obtained. On the other hand, Groups B and C had the highest number of check-ins at spots with high information demand.

As a result, it was suggested that a Variable reward according to information demand can change the behavior of tourists and collect necessary data for both the Area Mission and the Check-in Mission. In addition, it was also found that users can accept and change their behaviors, even when there are dynamic changes in the demand level at areas or spots, as in Group C. Hence, the hypothesis *H2* is accepted through quantitative evaluation.

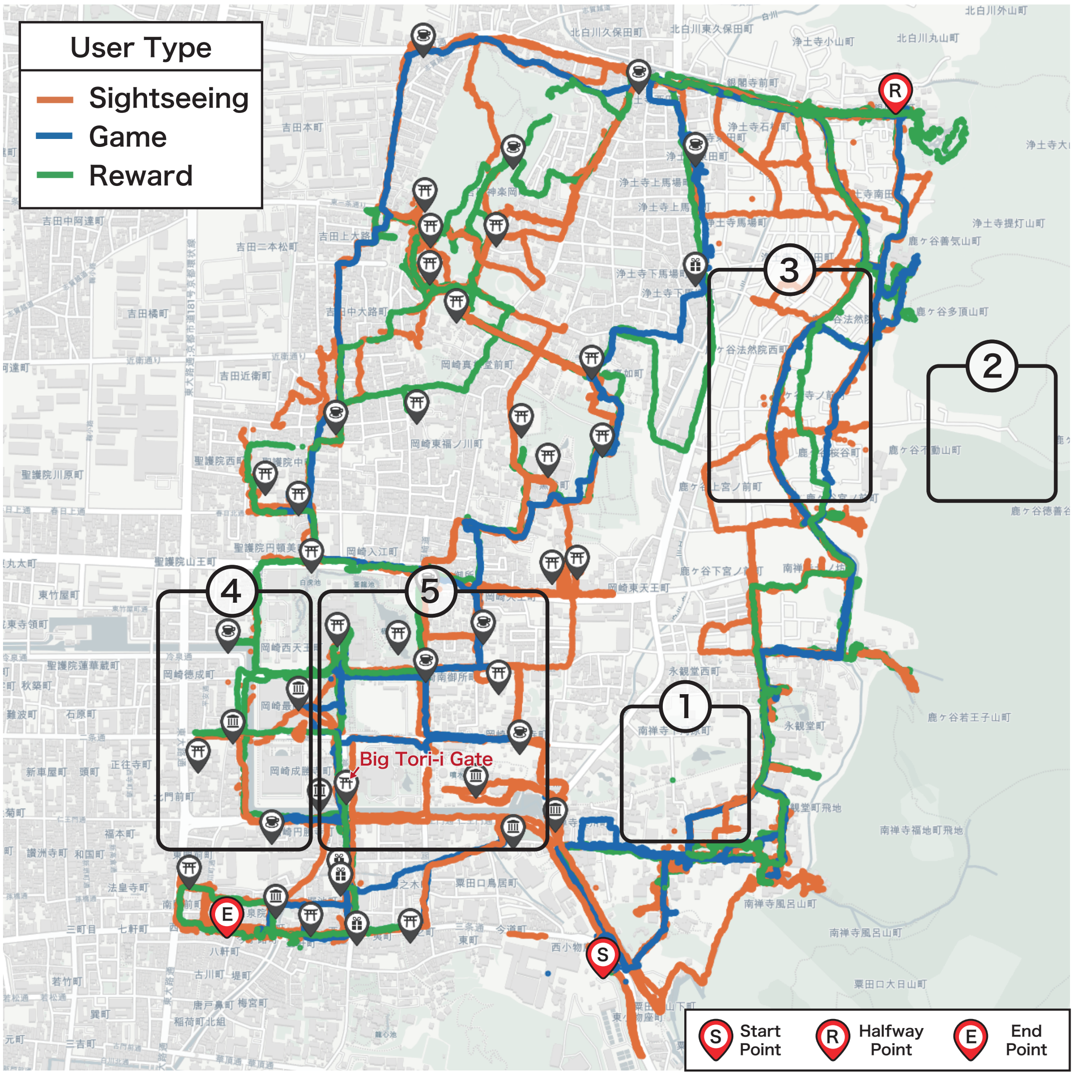


Figure 2.7.: Travel routes visualization of participants : Group A (Fixed reward)

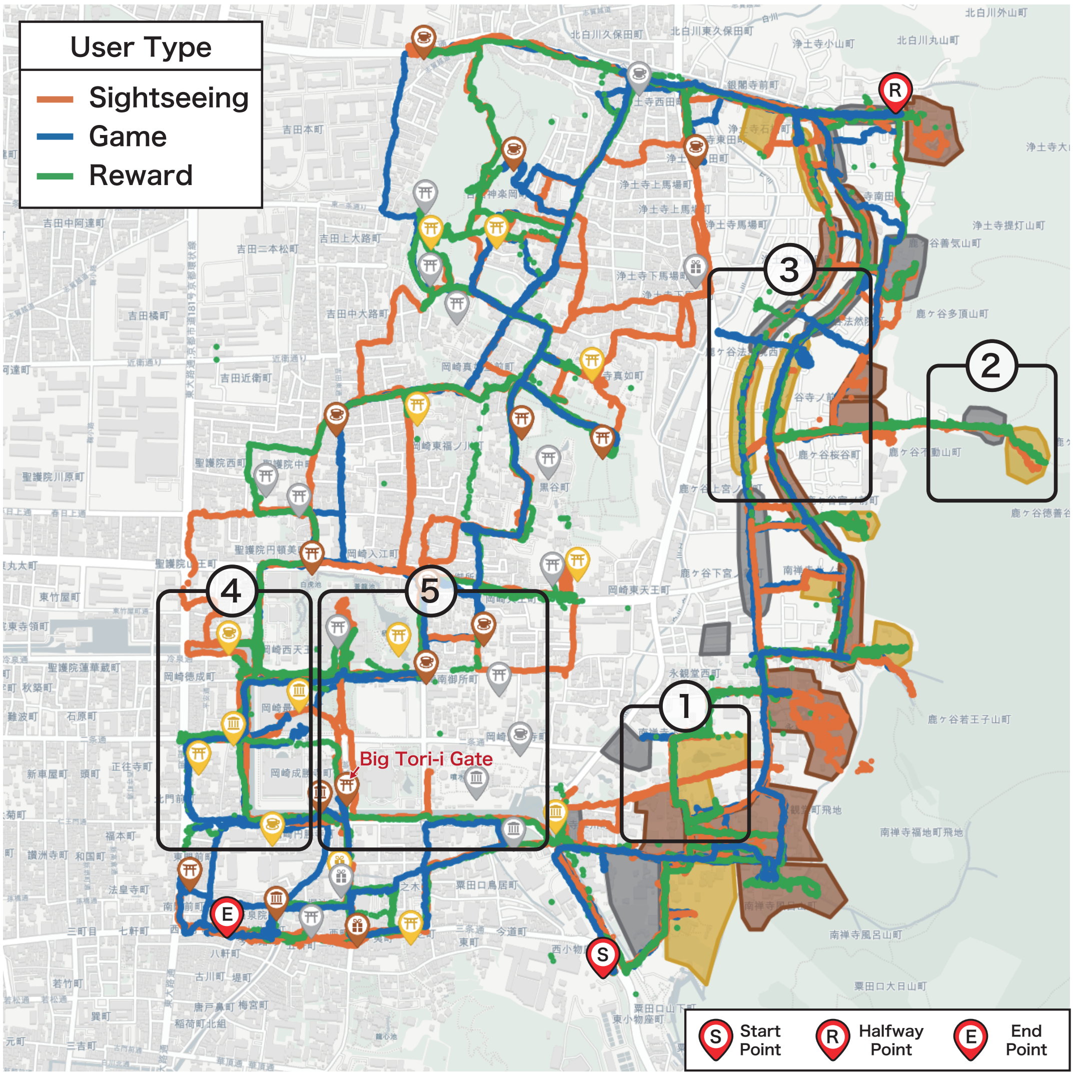


Figure 2.8.: Travel routes visualization of participants : Group B (Variable reward)

2.5.2. Visualization of Tourist Behavior

The difference according to the reward mechanism is qualitatively evaluated by visualizing location information collected during the experiment and comparing the information per groups. Figure 2.7 and Figure 2.8 show travel routes visualization of Groups A and B, respectively. Group C is difficult to represent on paper because the area and check-in spot change dynamically. Therefore, please refer to the video from the following URL [††] (You can see the route visualization video of Groups A and B as well).

In the first half of the experiment, Area Mission, there is an obvious difference indicated ①. ② and ③ in the figure. None of the 11 people chose that route in Group A with a fixed reward. However, multiple participants of different user types selected the route indicated by a gold area where high scores could be obtained. The right-hand side of the two parallel streets indicated by ③ in Figure 2.7 and Figure 2.8, is famous as a tourist attraction called Tetsugaku-no-michi (Philosopher's Walk). In Group A, most of participants chose Tetsugaku-no-michi on the right, while in Group B, several participants chose the ordinary road on the left-hand side.

In the latter half of the experiment (Check-in Mission), there is an obvious difference indicated ④ and ⑤ in the figure. We can see that the participants selected the route by dispersing into the routes of ④ and ⑤ in Group A. Meanwhile, in Group B, most of the participants regardless of user type, chose route ④ in which the gold pins are located densely. The number of check-ins to the gold pins at the area indicated by ④ was compared between Groups A and B. The average numbers of check-ins were 3.8 and 7.8, respectively. We also compared the number of check-ins at Daitorii of Heian-jingu Shrine, which is a well-known tourism attraction indicated by ⑤. All 11 people of Group A checked in, while, in Group B, only five people checked in to this spot.

Even in qualitative evaluation with route visualization, we found that the variable rewarding according to the information demand level can induce tourist behavior and efficiently collect highly demanded information. Hence, the hypothesis *H2* is accepted as well as quantitative evaluation.

[††] `Routevisualizationvideo:https://drive.google.com/drive/folders/1sbVwEsEf3iaWhBFtxCZxF7gIG7fBc7kk?usp=sharing`

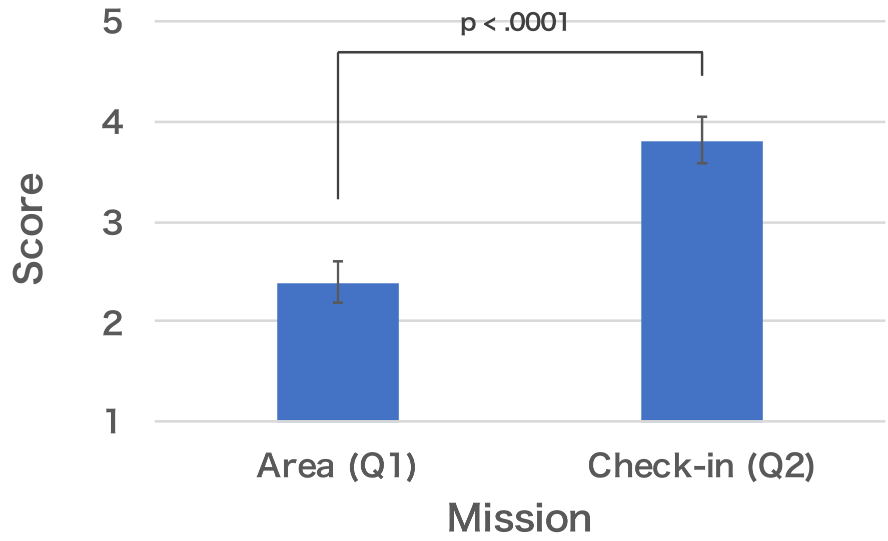


Figure 2.9.: Post-survey results on priority between sightseeing and mission grouped by mission (5 = Highly prioritized mission, 1 = Highly prioritized sightseeing). Error bar represents one standard error around the respective mean value of each mission.

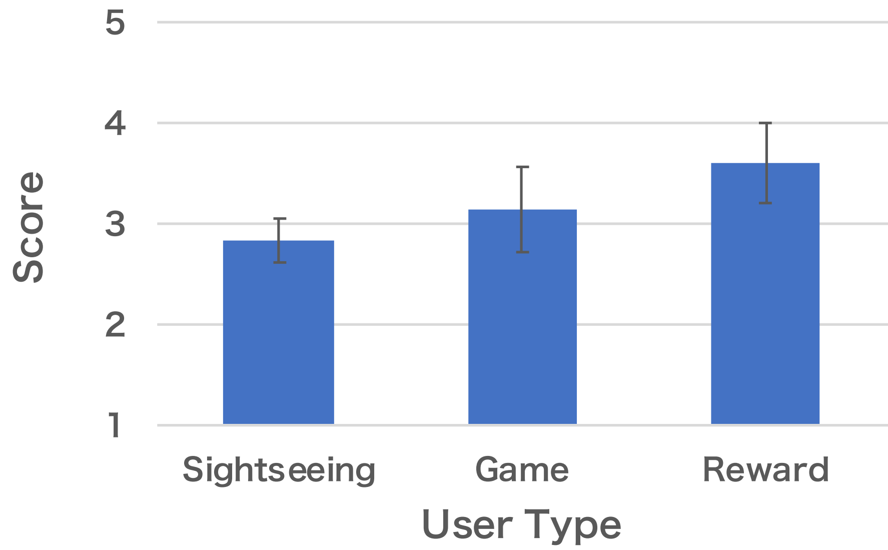


Figure 2.10.: Post-survey results on priority between sightseeing and mission grouped by user types. Error bar represents one standard error around the respective mean value of each user type.

2.5.3. Post-survey

We investgated whether participants prioritized either sightseeing or the mission via the post-survey questionnaire. We used this information to validate the effect of gamified participatory sensing on tourist satisfaction. The results of one-way analysis of variance (one-way ANOVA) between answers to Q1 (Area Mission) and answers to Q2 (Check-in Mission) are shown in Figure 2.9. The average scores for sightseeing and mission priorities were 2.39 and 3.82 for the Area Mission and Check-in Mission, respectively. There was a significant difference between the Area Mission and the Check-in Mission ($p < .0001$). Participants prioritized sightseeing over missions in Area Mission, and prioritized missions over sightseeing in Check-in Mission. Hence, the hypothesis *H1* is accepted. Next, in order to reveal whether the priority of missions and sightseeing changes according to the differences in user type, one-way ANOVA was performed on the answers for each user type. Figure 2.10 shows the result, and the average scores for sightseeing type, game type and reward type were 2.82, 3.14 and 3.61, respectively. There was no significant difference between user types ($p = .18$). Hence, the hypothesis *H3* is rejected.

2.5.4. Summary for Experimental Hypotheses

Here, we summarize the answers for our experimental hypotheses based on the qualitative and quantitative evaluation results shown in Section 2.5.1 – 2.5.3.

H1 : we assumed that the priority of sightseeing varies depending on the burden of the mission and it was evaluated with post-survey. The answers to post-survey on priority between sightseeing and mission were grouped by each mission type, and performed one-way ANOVA. As a result, we could find the significant differences between Area mission and Check-in mission ($p < .0001$) . Consequently, Hypothesis H1 is accepted.

H2 : we assumed that the efficiency of data collection will depends on the reward mechanism, and it was evaluated with mission logs and location data. The impact of different reward mechanisms (experimental group) on mission choice and tourist behavior for each mission was quantitatively compared using mission logs. In addition, the impact on tourist behavior was qualitatively evaluated by visualizing the location data. In the quantitative evaluation, we found a tendency to select missions with higher scores in the Variable Reward and Dynamic Variable Reward for both Area mission and Check-in mission. In the qualitative evaluation through visualization, we also found a change and diversification of tourist behavior in several tourist areas. Consequently, Hypothesis H2 is accepted.

H3 : we assumed that the priority of sightseeing will differ according to user type i.e., motivation to participate and it was evaluated with post-survey. The answers to post-survey on priority between sightseeing and mission were grouped by each user type, and performed one-way ANOVA. As a result, we could not find the significant differences among user types ($p = .18$) . Consequently, Hypothesis H3 is not accepted.

2.6. Discussion and Limitations

In this section, in order to derive a clearer conclusion in the present paper, we discuss the design of gamification suitable for participatory sensing for tourist with the experimental results obtained thus far and the applicability of our results in other contexts. Then, we mention about the limitations of this research.

2.6.1. Discussion

The duration of stay ratio and the check-in ratio by information demand level are shown in Section 2.5.1. We found that setting the rewards according to the information demand level and displaying the rewards with different colors on the map in both missions persuades the tourists to travel to the spots with high information demand level. In other words, it is suggested that the Variable reward can induce tourist behavior changes. This result suggests that it is possible to not only collect necessary tourism information efficiently, but also to control tourist behavior by gamification. One application example that uses this result is to dynamically change rewards according to the degree of congestion. This will affect the decision of the next destination of the tourist and will be useful for supporting the optimization of the congestion degree of the whole tourist attraction.

Next, the post-survey results on the priority of sightseeing and mission were shown in Section 2.5.3. These results indicate that tourists are more likely to prioritize missions in the case of the Check-in Mission. A strong tendency to prioritize missions can be interpreted as essentially tourists not enjoying sightseeing. These results suggest that while Check-in Missions are an effective way to gather specific information, the participants tend to focus more on clearing the mission than on enjoying sightseeing. In addition, although there was no significant difference in the effect due to the difference in user types, it was found that the priority differs for each user type. On the other hands, the following comments were obtained as some examples from the free description in post-survey: "It was able to visit places that I don't usually go.", "I could know sightseeing attractions that I didn't know" and "It gives me the motivation to go to places I hadn't planned in advance." That is, although our system was not intended to increase tourism satisfaction, the use of our system resulted in increased tourism enjoyment as a side effect.

Table 2.2.: Distribution of the ratio of the number of free postings in a 300m diameter hexagonal area by reward mechanism groups

Mission	Ratio(%)	A:Fixed	B:Variable	C:Dynamic Variable
Area	0	243	264	259
	1-25	90	69	61
	26-50	9	8	15
	51-75	1	2	7
	76-100	2	2	3
Check-in	0	333	364	375
	1-25	78	62	51
	26-50	12	4	3
	5175	6	0	2
	76-100	2	1	1

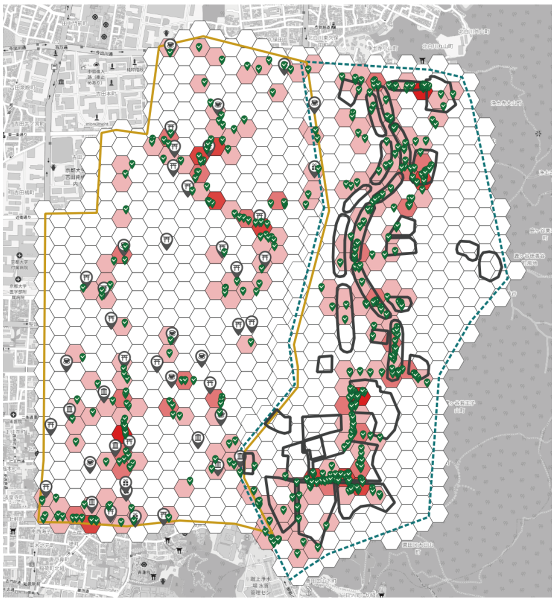


Figure 2.11.: Visualization of the number of postings in a hexagonal area divided by a diameter of 300m in Group A (Fixed)

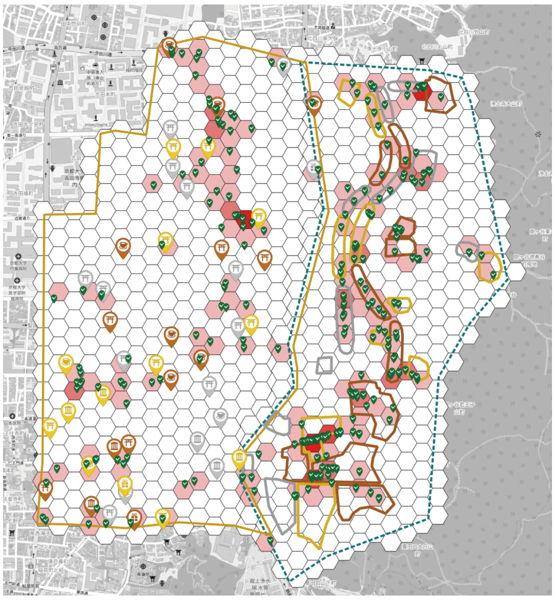


Figure 2.12.: Visualization of the number of postings in a hexagonal area divided by a diameter of 300m in Group B (Variable)

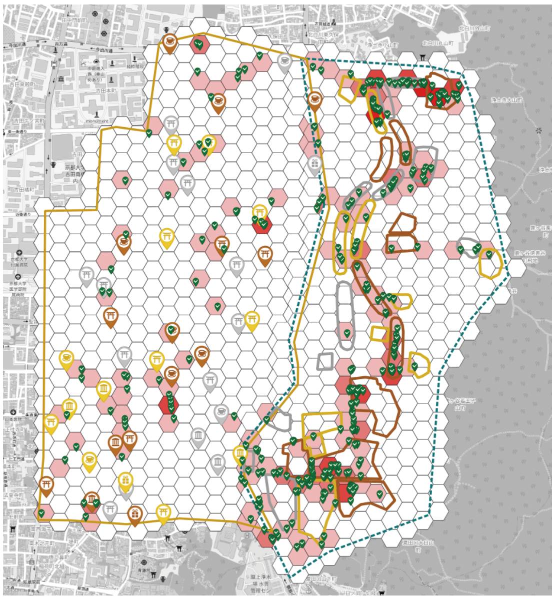


Figure 2.13.: Visualization of the number of postings in a hexagonal area divided by a diameter of 300m in Group C (Dynamic Variable)

Third, we checked the number of photographs and comments received through Free posting and Check-in Missions. We found that approximately 70% of the photos and comments were posted through free posting alone without the application requesting the photographs and comments to be posted as a requirement of the Check-in Mission.

In addition, we calculated and visualized the distribution of free postings and summarized them in Table 2.2 and Figure 2.11-Figure 2.13, respectively. The experiment area was divided into hexagonal grids every 300 meters, and the number of posts in each grid was counted and displayed as a heat map. Since the number of free postings in each reward mechanism group differed greatly (A: 471, B: 265, C: 320), the number of postings in the grid with the most postings was set as 100%, and the color density of the heat map was set by dividing the threshold by 25%. Here, grids with no postings are shown in white. The table shows the number of grids for each threshold by mission. The number of grids with more than one post was 102, 81, and 86 in the Area mission and 98, 67, and 57 in the Check-in mission for experimental groups A, B, and C, respectively. As mentioned above, the difference in the number of grids is thought to be due to the fact that the number of free postings in each group differed greatly. However, it can be seen from the figure that even grids that were not posted in Group A (Fixed reward) were posted in places with high demand and high points in Group B (Variable reward). The reason why the number of free postings differs greatly among the groups is that individual personalities might have a large influence. Since the number of points obtained by free posting is small compared to that of missions, the motivation to post for the purpose of obtaining points is considered to be low. Therefore, it can be said that free posting is done with more intrinsic motivation, such as the desire to share information about their experiences with other users through the timeline.

To summarize these results, we found that by changing the points for each spot according to the level of information demand, the location of photo postings obtained by free posting is also affected. However, it is suggested that the influence of intrinsic motivation other than the acquisition of more points is significant in how many photos are posted. Therefore, we believe that an Area Mission and Free posting should generally be adopted for the gamified participatory sensing in tourism, considering the degree of tourist satisfaction. Moreover we suggest that if specific information is urgently needed, a Check-in Mission should be used.

Fourth, we discuss the applicability of these results in other contexts. This approach is basically designed for urban tourism where there are several sightseeing attractions within easy reach by foot. Therefore, we believe that this approach is applicable to all kinds of urban tourism, regardless of the genre of tourist attractions, such as historical sites in Japan or in other countries. On the other hand, travel with high financial and time costs by a car or a train occurs in the case of sightseeing in a natural area or a circular tour. Since it cannot be said that this approach has the influence to promote behavioral changes that exceed the cost, it is considered to be out of adoption. In addition, since this experiment is based on the assumption of a single person's tourism, so we believe that this approach is applicable for single tourists. In the case of a large group of tourists, it is difficult to apply this approach directly, because of other burdens in the decision-making process, such as consensus for next destination determination.

Finally, we discuss the possibility of introducing other gamification elements and point to notice. In this study, we adopted a simple point-reward mission design because there has not been much research on efficient data collection in participatory sensing for tourists. Then, we explore the possibility of introducing other gamification elements based on the obtained results. The first one is *Ranking* or *Leaderboard*. It is generally used as a competitive element in participatory sensing in other domains and was also incorporated in this experiment [69]. However, we received positive feedback that "I was able to compete with other users and enjoyed it", but we also received negative opinion that "I felt rushed due to the rank." Therefore, it is necessary to pay attention to the introduction of ranking in tourism situations. Next is *Meaningful stories*. It is mainly used for the purpose of acquiring knowledge in tourist spots with a historical background such as heritage [68]. Considering the aspect of tourism information collection, one example would be to show participants why the data collection is necessary and how useful the collected data is to other users. These may encourage some participants to change their behaviors and may motivate them to collect data. Last is *Full-fldged games (Augmented Reality)*.It has been attracting attention as one of the new tourist contents and encouraging the enjoyment of tourism [72]. However, even simple elements such as check-in mission have lowered the priority of tourism, so it is necessary to pay attention to the content design.

2.6.2. Limitations

The first limitation of this study is the lack of a control group in our experiment. We wanted to focus on evaluating the impact of different types of gamification on tourist behavior rather than on evaluating the impact of the presence or absence of gamification. The effectiveness of gamification has been sufficiently shown in prior research, as such we assumed gamification would have a positive impact without the need to compare it to a control group. Additionally, all participants performed the area mission in the first half and the check-in mission in the second half. Therefore, it is considered that order effects might be included in the results.

The second limitation is the amount and homogeneity of the participants. The participants of this experiment were mostly Japanese university students of approximately 20 years in age, although the participants included four non-Japanese and two participants of more than 30 years in age. Therefore, this experimental results cannot be generalized immediately, so we should carry out the experiment in a wild environment with participants of various ages and nationalities.

The third limitation is that, we set the change in demand level manually in the case of a Dynamic Variable reward in the experiment. The reward mechanism was introduced in order to see that the participants can adapt to and follow temporal changes. As a result, we could confirm that the participants adapt to and follow the changes and the reward mechanism can induce a behavior change in participants. However, in this experiment, the weights were changed manually and all participants had the same starting and ending points for sightseeing, so it is considered that these factors might have influenced the results. Creating a Dynamic Variable reward model using, e.g., the number of active users participating, the fundamental information demand level, and the temporal amount of collected information, is considered useful to solve the problem. However, this is beyond the scope of the present study.

2.7. Summary

In this chapter, we adopted gamification for participatory sensing in order to efficiently collect dynamic tourism information while taking into account the burden on tourists. Moreover, we investigate the effect of gamification on tourist behavior and tourist satisfaction through an experimental case study. We designed two types of missions (i.e., sensing task), Area Mission and Check-in Mission, and three types of reward mechanisms, Fixed reward, Variable reward, and Dynamic Variable reward. In addition, we set up three types of user type, Sightseeing type, Game type and Reward type, based on the motivation to participation through pre-survey. We integrated these elements into our participatory sensing platform application and conducted in a real-world sightseeing experiment, with 33 participants in Kyoto, Japan. Throughout the experiment, tourism information (e.g., photographs and comments on sightseeing attractions), sensor data and user location data, and answers to the post-survey were collected. We evaluated the effect of gamification on tourist behavior (i.e., data collection efficiency) and satisfaction quantitatively and qualitatively using these collected data. The following are our primary findings. First, we found that Variable reward and Dynamic Variable reward can induce a change in tourist behavior for efficient data collection in both missions. Second, the participants tended to prioritize sightseeing over the Check-in Mission, which can induce a behavior change, but might impact sightseeing enjoyment. Summarizing to answer our research question, we believe that an Area Mission with a Variable reward and Free posting should be adopted basically in gamified participatory sensing for tourists, considering tourist satisfaction and a mechanism to switch to a Check-in Mission, which has a strong influence on behavior change, should be introduced when the demand level becomes extremely high.

However, we could not find a significant difference between subgroups of user type (sightseeing, game and reward). In the future, we will expand to general tourists and conduct experiments with participants of various demographics (gender, age and nationality) to confirm differences due to user-type subgroup and demographic results.

3. Interface and Interaction Design, and Personalization

3.1. Introduction

The tourism industry has become a major industry accounting for 10.3% of the world's total GDP in 2019, the demand is increasing every year, and services are needed to provide more comfortable tourism for the expansion of the industry in the future *. Information on tourist destinations is very important when deciding on a destination. With the development and spread of information technology, people can easily post and view their own tourism experiences, and the information generated by consumers through their actual experiences is accepted as a more effective and reliable source of information [16]. It is also changing tourism style, and a new of tourism, such as on-site tourism, which determines the next destination while sightseeing, is becoming popular [79]. Research on on-site tourism planning that takes into account the dynamically changing tourism context has been conducted, and the realization of such systems will provide a highly satisfying tourism experience [18]. However, the realization of such systems requires dynamic tourism information with high spatio-temporal resolution. In order to collect such information, the participatory sensing approach, in which mobile devices owned by the general public such as smartphones are used as sensing devices, will be effective. While it has the property of collecting data with high spatio-temporal resolution at low cost, the problem is that the amount and quality of collected data depends on the contribution of the participating users. As an incentive mechanism for improving user contributions and motivation to

*Economic Impact | World Travel and Tourism Council (WTTC): `https://wttc.org/Research/Economic-Impact` (Accessed at 20, August, 2020) participate, gamification that incorporates game concepts and mechanisms into content other than games is attracting attention [27]. Gamification has been applied in a variety of fields and has been shown to be effective so far [34, 35]. According to literature on designing effective incentive mechanisms, points, rankings/leaderboards, and achievement are often introduced as gamification mechanics, and affect the user positively, particularly in participatory sensing [37,57,61]. However, some researches suggest that empirical studies are required in order to clarify the effects of gamification in each participatory sensing context or domain [37, 39, 40]. Additionally, the importance of individually personalizing the gamification design and the interface rather than the full package has also been revealed [80, 81].

In this chapter, we investigate the effects of different task allocation interfaces and gamification user types on tourism information collection efficiency and tourism satisfaction in gamified participatory sensing for tourism. We designed two types of task allocation interfaces, map-based and chat-based, and implemented them on our gamified participatory sensing platform application. Additionally, we designed four different communication style sentences to investigate the appropriate way to ask the sensing tasks through the chat with agent character.

We set these four main research questions:

RQ1 How does the different task allocation interfaces affect the quantity and quality of dynamic tourism information collection?

RQ2 Do the different task allocation interfaces have an impact on tourism satisfaction of the tourists?

RQ3 Is there a relationship between tourism information collection efficiency and interface preference and gamification user type?

RQ4 What is the impact of different communication style sentences in a chat-based interface?

To elucidate these research questions, we conducted a pre-experiment with ten participants and a large scale experiment with 108 participants at actual sightseeing attractions in Nara, Japan. In pre-expeiment, we mainly focused on the validation of RQ1 - RQ3, while large-scale experiment was conducted to obtain more generalized results, including RQ4.

As a result, we found that there was no difference in the effect of each interface on sightseeing satisfaction, but the characteristics of the collected data that, map-based allows for the collection of quantitative data and chat-based allows for the efficient collection of data needed by the system, were different. In addition, we found that different user types had different tendencies for their contribution to sensing and their interface preferences. Moreover, there was a significant difference in the dimension of elaborateness, and elaborate and indirect sentences were preferred.

The rest of this chapter will present the following. First, we describe related work on the application of gamification in tourism and personalization in gamification. Then, we present the design and implementation of our designed two interfaces, and report the results of our pre-experiments and large scale experiments. Finally, we summarize this chapter based on the results obtained from each experiment. This chapter is the result of collaborative research with Prof. Minker's group at Ulm university. The parts of responsibility are as follows. I was mainly responsible for the design of the map-based interface, application implementation, and data analysis. The design of the chat-based interface and communication style was done by Juliana Miehle at Ulm University. Finally, the design of the experiment and paper writing were done in cooperation with both.

3.2. Related Work

3.2.1. Gamification in Tourism

Gamification is often introduced in the tourism domain in order to raise brand awareness, enhance tourist experiences, destination loyalty, consumer loyalty and engagements so far [40, 66]. However, according to Xu et al. [66], academic research on the application of gamification specifically in the tourism field is still scarce. Cesário et al. [82] designed two mobile apps, AR (Augmented Reality) game-based and story-based, to better understand teenage museum tourism behavior and to inform the suitable museum mobile app design. Their study also focused on user personalities and found that story-based strategies are suitable for a broader set of personalities. There are a few researches investigating the impact of gamification on dynamic tourism information collection with various gamification mechanics. Although a comprehensive evaluation using various mechanics was conducted, it is not clear which gamification mechanism had an impact on which outcome [68]. We have previously investigated the impact of different task load and reward mechanisms on data collection efficiency and tourism behavior in a gamified participatory sensing application for tourism as discussed in Chapter 3 [83]. However, there is room to investigate the elements needed to personalize the design, such as the task allocation interfaces and user preferences.

3.2.2. Interface and Interaction Design

The notion that user interface design can be informed by other design practices has a rich tradition in HCI. During the first boom of computer games in the early 1980s, Malone wrote seminal papers deriving "heuristics for designing enjoyable user interfaces" from video games [84]. One of the studies on interface design in terms of data collection is the study of interfaces in online surveys, which was reported by Kim et al. [85]. In this study, a web-based interface and a chatbot-based interface were used .They used formal style as basic style and casual style which is more friendly. The experimental results suggested, the quality of the responses was higher for chatbots than the web interface. Second, high quality answers were obtained in casual conversational style only in chatbots. From these results, it is suggested that differences in interface and conventional style in agent interaction affects the quality of data. Another related study of communication styles is Elaborateness and Indirectness which was proposed by Pragst et al. [86]. Elaborateness refers to the amount of additional information provided to the user and indirectness describes how concretely the information that is to be conveyed is addressed by the speaker. Based on these communication styles, Miehle et al. [87, 88]. conducted a survey on users' satisfaction with the system depending on the communication style, and the results were as follows. First, communication style influences the user ' s satisfaction and the user ' s perception of the dialogue. Second, the preference of communication styles appears to be individual for every person.

3.2.3. Personalization in Gamification

Several studies have explored the relations between gamification design and user motivational factors or personalities in human-computer interaction research area [81,89]. Jia et al. [81] investigated the relationships among individuals ' personality traits and perceived preferences for various motivational affordances used in gamification. Their research showed correlations between each of the Big Five personality traits and the ten gamification factors. Marczewski [90] proposed the Hexad framework which has six gamification user types that differ in their motivational factors. The user types are personifications of people's intrinsic (e.g. self-realization) and extrinsic (e.g. rewards) motivations, as defined by the self-determination theory [91]. Table 3.1 shows the gamification user types defined by the Hexad framework as well as the motivations and characteristics of each user type [90,92]. Tondello et al. [93] proposed the 24-items survey response scale to score the user's preferences towards the six different motivations in the Hexad framework. This measure has the potential to accurately measure user preferences in gamification. There are four survey items related to each user type, and all answers are rated on a 7-point Likert scale. The score of each user type is obtained by adding the answers of each of the four questions, and the highest score is the user type. Note that the Hexad user type is an archetypical categorization where the types represent users for whom certain motivations are stronger than other motivations.

3.3. Study Design

In this study, we investigate the impacts of different task allocation interfaces on dynamic tourism information collection efficiency and tourism satisfaction in gamified participatory sensing. In addition, we investigate whether the degree of the contribution to sensing and the interface design preferences are influenced by the individual personality. We first describe the basic design, including the data to be collected and the assumed environment, in the next section. After that, we describe the details of each interface and its implementation in the application.

Table 3.1.: Gamification user types defined in the Hexad framework

User types	Motivation	Characteristics
Philanthropist	Purpose	They are altruistic and willing to give without expecting a reward.
Socialiser	Relatedness	They want to interact with others and create social connections.
Free Spirit	Autonomy	They like to create and explore within a system. Freedom to express themselves and act without external control.
Achiever	Competence	They seek to progress with a system by completing tasks, or prove themselves by tackling different challenges.
Player	Extrinsic rewards	They will do whatever to earn a reward within a system independently of the type of the activity.
Disruptor	Triggering of change	They tend to disrupt the system either directly or through others to force negative or positive changes.

3.3.1. Basic design

The data to be collected by participatory sensing for tourism and the assumed environment in this study are as follows. The data is dynamic tourism information, specifically photos, comments and inertial sensor data built into smartphones at the sightseeing attractions. With the development of human activity recognition research, it is possible to collect information such as tourist behaviors [73] and congestion degree in the surrounding area [74] from sensor data collected from smartphones. Also, photos and comments are very useful information for the next tourist to understand the current situation of the sightseeing attraction. We use simple gamification mechanics, namely missions and point-based rewards. Participants have our app installed on their own smartphones and posting photos and comments at a specific tourist attraction will appear on the app as a mission. Each time they perform the mission while their sightseeing, the users will receive points as a reward within the app. Based on Chapter 2 [83], we use dynamic rewards that change according to the demand for information at each spot. This is designed under the assumption that campaign organizers (e.g. municipalities and tourism associations) can efficiently collect tourist information on the sightseeing spots they need. In this study, we designed two types of task (=mission) allocation interfaces based on these environments. One is a map-based interface in which the task is selected actively by the participant, and the other one is a chat-based interface in which the task is selected semi-passively based on the suggestion of the chat with agent character.

3.3.2. Task Allocation Interfaces

Map-based

In this interface, all the spots to be sensed are displayed on the map and the user can accomplish the mission when actively checking the information of each spot one by one. A screenshot of map-based interface is shown in Figure Figure 3.1. The pins displayed on the map are colored gold (high demand), silver (medium demand), and copper (low demand) according to the information demand level. The detailed information of each spot and the points are displayed by tapping on the pins. The users can check-in by tapping the pin when they are a certain

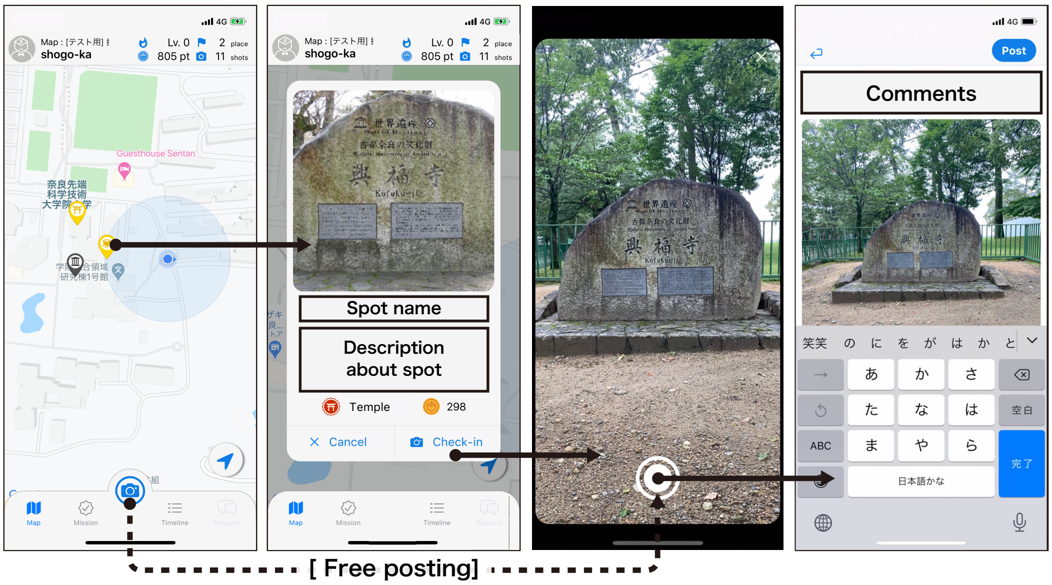


Figure 3.1.: Map-based interface

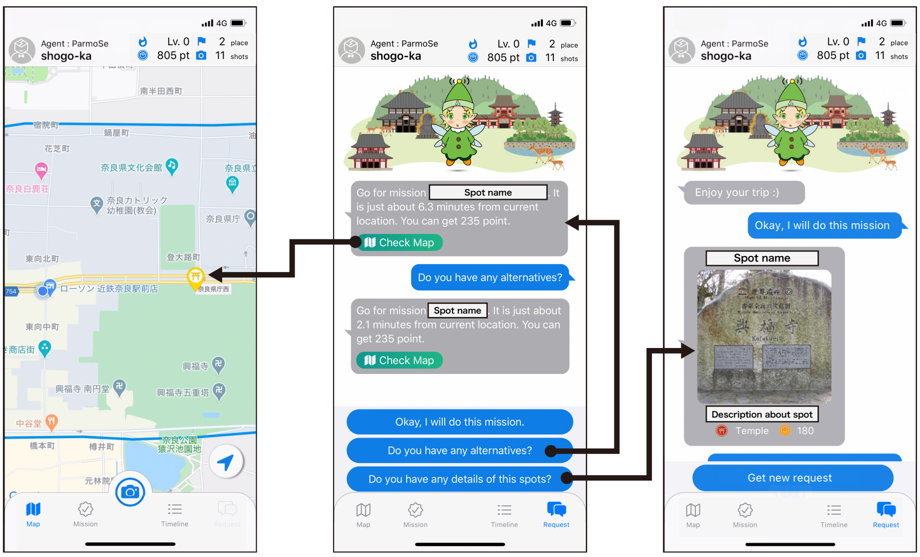


Figure 3.2.: Chat-based interface

distance away from the target spot. After that, the users can take a photo and post it with comment to complete the check-in process and receive a point.

Chat-based
In this interface, the main screen is a chat-based dialogue with the agent character and the user selects the mission during the interaction. A screenshot of the chat-based interface is shown in Figure 3.2. The agent asks the user to do a mission and the user accepts the specific mission in the dialogue and goes to the target spot to execute the mission. The algorithm for determining the requested mission is as follows. The user's current location is obtained and the linear distance between all the spots and the user is calculated. The ten closest spots are selected and sorted by points (the spot with the most points gets the highest priority). At the beginning of the interaction, the agent selects the sightseeing spot with the highest priority (according to the algorithm) and asks the user to do this mission. Then, the user has three choices (blue buttons at the bottom of the screen):

1 Okay, I will do this mission.

2 Do you have any alternatives?

3 Do you have any details of this spot?

In addition, by tapping the "Check Map" button on the chat screen, the specific locations can be seen on the map. Through repeated dialogue, the users receives a mission that they want to do, go to the target spot and execute the mission. The process of executing the mission is the same as for the map-based.

Additionally, we implemented *Free posting* as a common function to both interfaces. This allows participants to freely post any information they find of interest or want to share with other tourists while their sightseeing. Free posting can be done by tapping the camera button at the bottom of the screen.

3.3.3. Communication Style Design in Chat-based Interface

As we mentioned in related research, when employing an interactive interface, the conventional style may affect the data quality and user's satisfaction. In order to investigate the appropriate dialogue sentences and the effect on mission

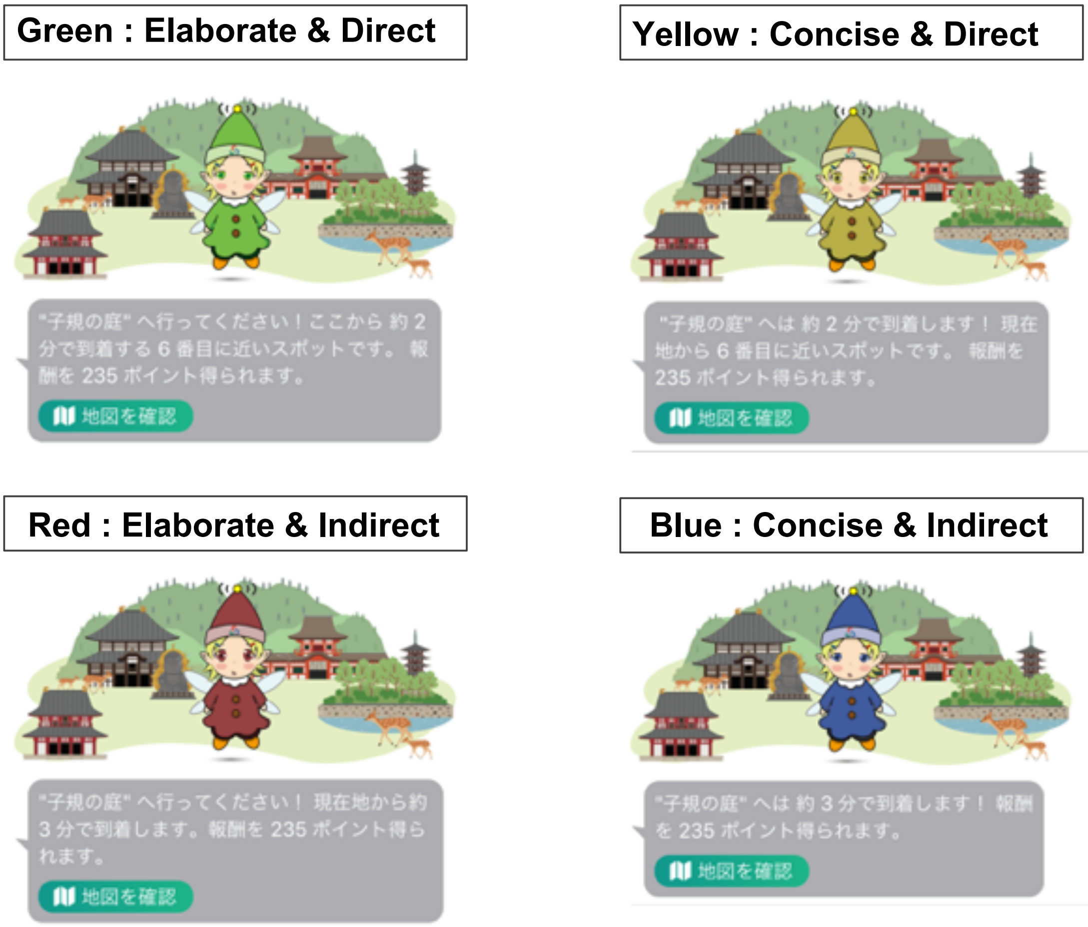


Figure 3.3.: Correspondence of each communication style and agent character

selection by the sentences, we formulated four different types of dialogue templates considering the communication styles *elaborateness* and *directness* in the chat-based interface. As described by Pragst et al. [86], *elaborateness* refers to the amount of additional information provided to the user and *indirectness* describes how concretely the information that is to be conveyed is addressed by the user. Elaborateness has *elaborate* and *concise*, and indirectness has *direct* and *indirect*. By combining these, the following four types of templates were created (The Japanese notation is added, since the experiment was conducted with only Japanese participants). These templates were created by Juliana Miehle from Ulm university.

Elaborate & Direct(ED) ：

English : Go for mission <spot name>. You can get <100> points and it is just about <5> minutes from here. It is the <closest> spot from your current location and the one where you can get the <most> points.

日本語 : <スポット名> へ行ってください！ここから約 <5>で到着し、100 ポイントを獲得できます。現在地から <1>番目に近いスポットで、<1> 番目に多くポイントを獲得できるスポットです。

Elaborate & Indirect(EI) ：

English : You can get <100> points for mission <spot name> which is just about <5> minutes from here. It is the <closest> spot from your current location and the one where you can get the <most> points.

日本語 : ここから約 <5>分で到着する <スポット名> では <100> ポイントを獲得できます！ 現在地から <1> 番目に近いスポットで、<1> 番目に多くポイントを獲得できるスポットです。

Concise & Direct(CD) ：

English : Go for mission <spot name>. You can get <100> points and it is just about <5> minutes from here.

日本語 : <スポット名>へ行ってください！ ここから約 <5> 分で到着し、<100> ポイントを獲得できます。

Concise & Indirect(CI) :

English : You can get <100> points for mission <spot name> which is just about <5> minutes from here.

日本語 : ここから約 <5> 分で到着する<スポット名> では、<100> ポイントを獲得できます！

Elaborate sentences are given additional information on where does requested spot rank in closeness and point among the surrounding spots. In direct sentences, the expression like "Go for mission <spot name>," which directly ask the user to go to the spot.

To make each interaction style more distinguishable, each assigned a different colored agent character. Figure 3.3 shows the correspondence of each communication style and agent character.

3.3.4. Application Implementation

We implemented these task allocation interfaces into our participatory sensing platform application called Parmosense [43]. The timestamp, GPS, acceleration, gyroscopic, geomagnetism, and illuminance values of the smartphone are collected at a sampling rate of 10 Hz while this application is running (even in the background). The data is sent to the server every 5 seconds. Sensor data is also collected at the moment when the user takes a photo and is sent to the server along with the captured photograph, independently of the periodic sensor data.

3.4. Pre-Experiment

The pre-experiment was conducted to clarify whether the design is appropriate for answering our research question. In this experiment, we mainly aim to answer RQ1-RQ3. This experiment was conducted in cooperation with Ulm university.

3.4.1. Participants

We recruited participants from the Nara Institute of Science and Technology using mailing lists. We limited the participants to Japanese to eliminate the influence of nationality. During the application process, we asked to complete a questionnaire about the age, gender, previous tourism experience in the experimental area, and user types using the Hexad Gamification User Types Scale [92]. Finally, there were 16 applicants, and ten participants were selected based on the results of the questionnaire on user types and tourism experience. All participants were male, graduate students, and aged between 22 and 24 years ($M = 22.9, SD = 0.74$). With regard to the tourism experience, three people had never visited the area before, and five people had visited it once. One person had visited it twice and the other had visited it more than three times. In terms of the Hexad gamification user types, three were categorized as Socialiser, three as Free Spirit, two as Player and one as Philanthropist. The remaining one had the highest score in the three user types of Philanthropist, Socialiser, and Free Spirit. Achiever and Disrupter were not included in this experiment.

3.4.2. Experimental Procedure

After the participants were selected, a more detailed explanation of the experiment and the use of the application was given in an online meeting for better understanding of the purpose of the study and the application usage. The experiment was conducted in Nara, Japan in July 2020 [†]. In order to clarify the effects due to difference in task allocation interface, we divided the experimental period into two parts. The user groups were also divided into two groups, to eliminate the effects of the characteristics of the sightseeing area and the familiarity of the application's operation, with separate interfaces for the first half and the second half. This means that group A used the chat-based interface in the first half of the experiment and the map-based interface in the second half while group B used the map-based interface in the first half and the chat-based interface in the second half. The experiment duration was four hours in total, two hours each for the first half and the second half. This duration was decided based on the

[†] In order to prevent the spread of COVID-19, participants were required to 1. wear a mask, 2. avoid long-term stays in crowded places, and 3. stop the experiment immediately if they were not feeling well.

sightseeing model course proposed by the Nara Guide Club[‡]. A total of 80 spots (40 spots in each half) were prepared to visit in Nara City, referring to the tourist guide website. The information demand for each spot was based on the number of ratings posted on each spot in Google Maps. Based on the process that the spots with fewer popularity ratings had higher information demand, the reward for each spot was set according to the following formula:

$$reward_a = \log_{10} \frac{Total\,number\,of\,reviews}{Number\,of\,reviews\,at\,target\,spot\ \mathbf{A}} \times 100$$

Before the main session of the experiment, we explained how to use the application again and the participants got used to operating the application by actually using it. In the main session of the experiment, we asked the participants to do sightseeing alone and only on foot in the designated areas, while clearing missions and earning points. The first half and the second half of the experiment were conducted consecutively, and participants were asked to move between two areas by themselves while being reminded by the messaging tool. After the sightseeing experiment, participants answered to a post-survey about their tourism behavior and satisfaction and the usability of the application. The details of the survey items will be described in Section 3.4.3. We paid each participant 5,000 yen (≒ 50 USD) as a basic participation fee which included the transportation to the venue and the entrance fee. This fee was determined based on an hourly wage of 1,000 yen, taking into account the 4 hours of experimental time, time for questionnaire response and transportation costs.

3.4.3. Post-survey

We conducted a post-survey to subjectively evaluate tourism behavior and satisfaction and the usability of the application through the experiment we designed. The survey was divided into three main categories: tourism satisfaction, preferences of interface, and application usability. The tourism satisfaction was assessed by the following questions on priorities between tourism and mission and on the enjoyment of tourism:

[‡]Nara Guide Club: `https://nara-guide-club.com/en/course/` [Last accessed on 25th August, 2020]

Q1&Q2 Which did you prioritize in the map-based / chat-based interface, sightseeing or the mission?

Q3&Q4 Did the map-based / chat-based interface application make tourism more enjoyable for you?

For Q1 and Q2, these questions were answered using a five-point Likert scale in which 1 = prioritized sightseeing and 5 = prioritized the mission, and they were asked for the reason of their answers using an open question. In Q3 and Q4, these questions were answered using a five-point Likert scale in which 1 = Not at all fun and 5 = Very fun, and they were also asked for the reason of their answers using an open question. Preferences of interface were evaluated with the following question: When you participate in similar experiments in the future, would you prefer to use a map-based interface or a chat-based interface? Finally, the application usability of each interface was evaluated with System Usability Scale [94], which allows us to easily get the usability score (min:0, max:100) of a system with ten items.

3.4.4. Results

Through the experiment, approximately 142MB of sensor data (e.g. gps data and acceleration data), 308 photos and comments, and ten post-survey answers were collected. In order to answer our research questions, the data analysis was conducted with the following aspects: quantity and quality of the collected data, post-survey analysis, and trends by Hexad user types.

Quantity and Quality of the Collected Data

Out of the 308 collected posts, 140 have been obtained from the map-based interface, 96 were obtained from the chat-based interface and 72 from free posting. The average number of check-ins per user in each interface was as follows:

Map-based: 14.00 ($SD = 5.42$)

Chat-based: 9.60 ($SD = 4.27$)

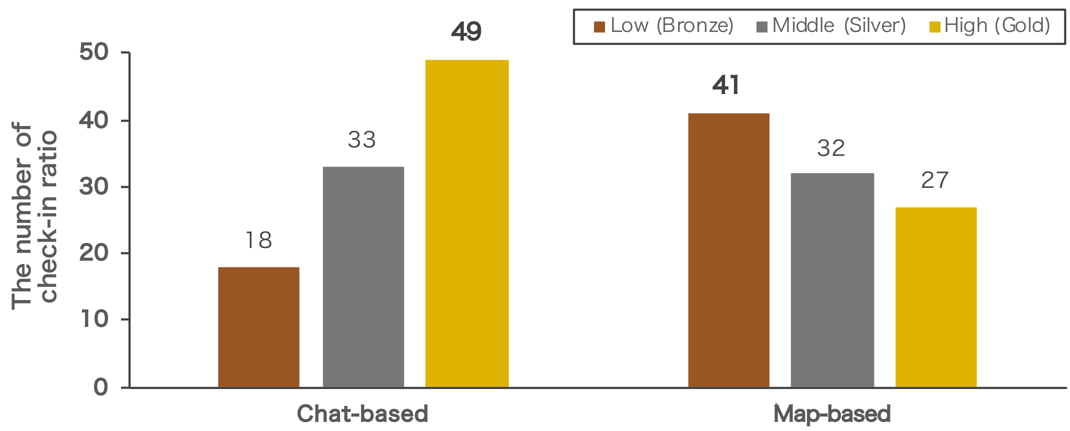


Figure 3.4.: Check-in ratio according to the information demand level

The quality of the data was evaluated by use of the check-in ratio according to the information demand of each sightseeing attraction (indicated with gold pins at high demand spots, silver pins at middle demand spots, and bronze pins at low demand spots). The check-in ratio according to the information demand level in each interface is shown in Figure 3.4. In can be seen that the chat-based interface is more efficient in collecting data for spots with higher information demand. The average number of check-ins for each demand level in each interface is as follows:

Map-based: 3.80 ($SD = 1.75$) high demand, 4.40 ($SD = 2.37$) middle demand, 5.80 ($SD = 2.25$) low demand

Chat-based: 4.7 ($SD = 1.64$) high demand, 3.20 ($SD = 2.15$) middle demand, and 1.70 ($SD = 1.06$) low demand

Post-survey Analysis

The summary of the post-survey answers is shown in Table 3.2. The median value of tourism and mission priority was 2.5 for the map-based and 4 for the chat-based. Hence, there was a tendency to give more priority to missions than to tourism in the chat-based interface. However, this might be explained by the design of our request algorithm: The agent character in chat made the sightseeing spot suggestions based on the points the user can get when completing

Table 3.2.: Summary of post-survey answers in pre-experiment

Interface	Map-based		Chat-based	
Item	Priority	Enjoyment	Priority	Enjoyment
Median	2.5	4	4	4
Average	2.8	3.9	3.3	3.9
SD	1.6	0.9	1.6	0.9

this mission (see Section 3.3.2). Hence, the agent gives priority to the mission, which is taken over by the user. The median value of enjoyment was 4 (Fun) in both cases. This means that the use of the app made their sightseeing experience enjoyable. Regarding the interface preference, seven people preferred the map-based interface and three people preferred the chat-based interface. Finally, the average System Usability Scale (SUS) scores for each interface were as follows:

Map-based: 81.5 ($SD = 11.32$)

Chat-based: 68.8 ($SD = 17.96$)

Trends in Gamification User Types

In order to examine whether there is a relationship between user type and tourism information collection efficiency and interface design preference, we have calculated the average number of check-ins for each user type. As a result, the average number of check-ins was 31.5 for Player, 24.75 for Socialiser, 20 for Free Spirit and 14 for Philanthropist. This means that Player and Socialiser performed more missions than other user types. Moreover, we calculated the average number of free postings by user types. The result is 12 for Player, 11.5 for Philanthropist, 5 for Free Spirit and 4.25 for Socialiser. This shows that Philanthropist and Player tended to contribute more to the free postings which were performed voluntarily. Moreover, all three participants who chose the chat-based interface as their interface preference were Free Spirit.

3.4.5. Discussion

We answer to each research question based on the results that have been described in Section 3.4.4:

RQ1: How does the different task allocation interfaces affect the quantity and quality of dynamic tourism information collection?

As mentioned in Section 3.4.4, the map-based interface was able to collect about 1.4 times more data in terms of quantity, while the chat-based interface was able to collect high-demand data preferentially and efficiently. We believe that the reason why the map-based interface collected more data than the chat-based interface is because the procedure to execute the mission is shorter than that of chat-based interface. On the other hand, the missions are requested in order of proximity and demand, according to the user's location information in chat-based interface. This ensures the collection of high-demand data in the chat-based interface.

RQ2: Do the different task allocation interfaces have an impact on tourism satisfaction of the tourists?

With regard to tourism satisfaction, we examined aspects of priorities between tourism and mission, as well as aspects of enjoyment. We confirmed that the positive reasons given for choosing "prioritize the mission" in the open question, such as "I don't have many spots that I am interested in" and "I follow the request because I don't know many tourist spots well". It is possible that these positive reasons raised the score. On the other hand, in terms of enjoyment, we obtained similar results in both cases, and the use of the app made the tourists enjoy their sightseeing.

RQ3: Is there a relationship between tourism information collection efficiency and interface preference and gamification user type?

We found that Socialiser and Player contributed more to the data collection by mission, while Player and Philanthropist contributed more to the data collection by free posting. Since user type is archetypical categorization in Hexad framework [92], we additionally investigated the correlation between the number of posts (mission, free posting) and each user type score. The normality of the number of posts and the user type score was confirmed by the Shapiro-Wilk test, and the results all followed a normal distribution. Therefore, we used the Pearson product-moment correlation coefficient to obtain the correlation coefficient. The results showed that a positive correlation between the number of missions and Socialiser's score ($r = 0.59, p = 0.07$), and a positive correlation between the number of free postings and Philanthropist's score($r = 0.65, p = 0.04$). As for interface design preferences, Free Spirits user tended to prefer the chat-based interface. It is assumed that they prefer map-based interface, because Free Spirits user type prefers freedom to express themselves and act without external control. Therefore, the relationship between interface design preference and user type should be investigated in more detail in the future.

3.4.6. Summary of Pre-experiment

This pre-experiment aimed to investigate the effects of task allocation interfaces and user types on tourist information collection efficiency, tourist behavior and tourist satisfaction in a gamified participatory sensing system for tourists. Therefore, we designed and implemented two types of task allocation interfaces (map-based and chat-based) and conducted a sightseeing experiment with 10 participants in an actual sightseeing spot (Nara, Japan). The results showed that the map-based interface collected a larger amount of data while chat-based interface collected the data needed by the system more efficiently. In addition, there was no significant difference in the tourism satisfaction between the two interfaces. However, we found different trends for the contribution to sensing and the interface preference by user type. The results obtained from this pre-experiment were published at proceedings of Mobiquitous Workshop as a joint publication.

3.5. Large Scale Experiment

Based on the results from the pre-experiment, we conducted a large-scale experiment with 108 participants of various age groups to obtain more generalized results. Additionally, in order to investigate the appropriate dialogue sentences and the effect on mission selection by the sentences, we implemented the four different communication styles in chat-based interface application which described at section 3.3.3. This experiment was also conducted in cooperation with Ulm university.

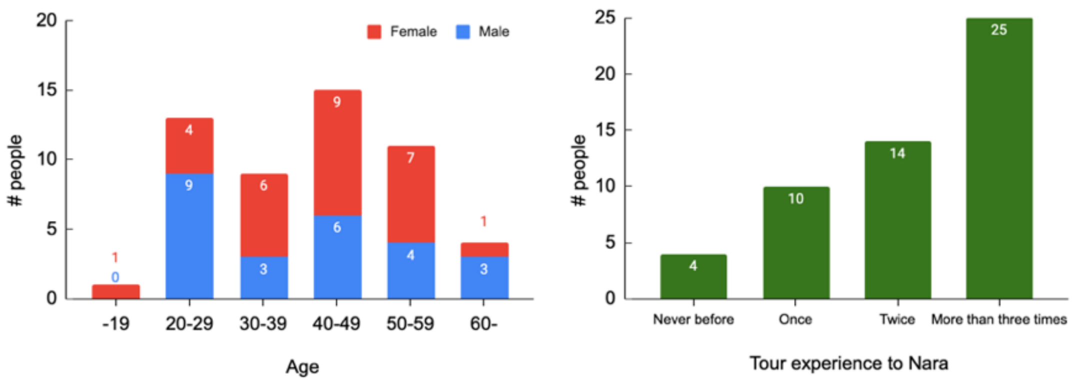
3.5.1. Participants

We recruited participants through research participant recruitment company. Participants were limited to those who were Japanese, over 18 and under 80 years old, and living outside Nara Prefecture where the tourism experiment is conducted. As well as the pre-experiment, we asked to complete a questionnaire about the age, gender, previous tourism experience in the experimental area, and user types using the Hexad Gamification User Types Scale [92] during the application process. Finally, there were 157 applicants, and 110 participants were selected based on the results of the questionnaire on user types and tourism experience. However, we describe the data and results from 108 participants because two of them could not collect the data normally.

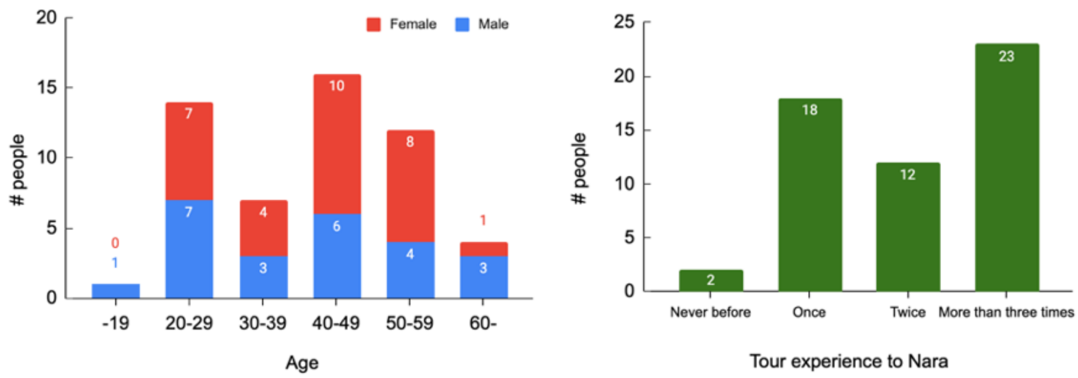
There were 50 male and 58 female and aged between 19 and 71 years ($M = 41.0, SD = 13.9$). With regard to the tourism experience, six people had never visited the area before, and 28 people had visited it once. 26 people had visited it twice and 49 people had visited it more than three times. In terms of the Hexad gamification user types, 49 people as Free Spirit, 46 people were categorized as Philanthropist, 21 people as Player 17 people as Socialiser and 14 people as Achiever (There were some participants with multiple user types, the total number of user types exceeds 108.). Disrupter were not included in this experiment. In this experiment, we divide the experimental group into two: one group using the map-based interface and the other group using the chat-based interface. The distribution of males and females by age group and their tour experiences to Nara are shown in Figure 3.5.

Table 3.3.: Number of participants by experimental group for each date

Date	Oct. 3rd	26th	28th	31st	Nov. 1st	4th.
Group A	4	10	11	11	9	8
Group B	4	10	9	10	14	8
Total	8	20	20	21	23	16



(a) Group A : Map-based interface



(b) Group B : Chat-based interface

Figure 3.5.: User attributes for each experimental group

3.5.2. Experimental Procedure

The experiment was conducted in Nara, Japan in October 3rd, 26th, 28th, 31st, November 1st, and 4th, 2020§. About 10 to 20 people were assigned to each of the above dates, taking into account the available dates of the participants. The number of participants for each dates were shown in Table 3.3.

Detailed explanation of the experiment was given to the participants through documents and any questions about experiment were accepted at any time. The experimental application was installed on a participants' own smartphone in advance using TestFlight, a beta app delivery platform provided by Apple. The use of the application was explained through documents and YouTube videos¶. On the day of the experiment, the participants were gathered at the Kintestu-Nara station as start point of the experiment, and we explained the overview of the experiment, cautions on the experiment, and how to use the application one by one. In addition, we answered individually to participants who had questions on the experiment and how to use the application. The duration of the experiment was four hours, and unlike the pre-experiment, the participants used the assigned interface at all times during the experiment. The number of tourism spots and rewards is same with pre-experiment, which we described at section 3.4.2. In the main session of the experiment, we asked participants to do sightseeing alone and only on foot in the designated areas, while accomplishing missions and earning points. After the sightseeing experiment, participants answered to a post-survey about their tourism behavior and satisfaction, the usability of the application, and impressions throughout the experiment. The details of the post survey will be described in Section 3.5.3. We paid each participant 8,000 yen ($\fallingdotseq$ 80 USD) as a basic participation fee including transportation fee to This fee was determined based on an hourly wage of 1,000 yen, taking into account the 4 hours of experimental time, time for questionnaire response. In addition, since only people living outside Nara Prefecture were targeted in this experiment, an additional

§This experiment is carried out with the approval of ethics review committee of NAIST. In order to prevent the spread of COVID-19, participants were required to 1. wear a mask, 2. avoid long-term stays 6 crowded places, and 3. stop the experiment immediately if they were not feeling well, as well as pre-experiment.

¶YouTube Video: https://www.youtube.com/playlist?list=PLjsutZEg_aTd6MzdNkhcKg5TWsd8vhdH1

3,000 yen was paid for round-trip transportation fee.

3.5.3. Post-survey

We conducted a post-survey to subjectively evaluate tourism behavior and satisfaction and the usability of the application through the experiment. The survey was divided into four categories: tourism satisfaction, interface preference and communication styles, application usability, and impressions throughout the experiment.
Tourism satisfaction: The tourism satisfaction was assessed by the following questions on priorities between tourism and mission and the enjoyment of tourism.

Q1 Which did you prioritize sightseeing or the mission?

Q2 Did the application make tourism more enjoyable for you?

For Q1, participants answered this question with a five-point Likert scale in which 1 = prioritized sightseeing and 5 = prioritized the mission, and and we asked the reason of their answers using an open question. In Q2, they also answered this question with a five-point Likert scale in which 1 = Not at all fun and 5 = Very fun, and we asked the reason of their answers using an open question.
Interface preference and communication styles: In this experiment, each participant used only one interface, so we asked them about their preference for the interface app. For the communication style, we asked the participants who used chat-based interface application if they noticed any differences in sentences and which communication style they preferred, as follows.

Q3 Do you like the map-based/chat-based style user interface?

Q4 Did you notice any changes to the sentence or appearance in your interactions with agents?

Q5 Which agent did you think was the best? Please pay attention to the sentence and answer it.

	Demand Level			Free	
	Low	Middle	High	Posting	Total
Total Posts	562	470	480	290	1802
Average	10.60	8.87	9.06	5.47	34.00
Median	10	8	8	2	32
SD	4.21	5.03	5.60	7.51	15.37

Table 3.4.: Summary of the collected posts in map-based interface

For Q3, participants answered this question with a five-point Likert scale in which 1 = Don't like it at all and 5 = Like it very much, and and we asked the reason of their answers using an open question. Q4 was answered with binary option, yes or no, and Q5 was answered 1-4 options with sample screenings shots pasted for each communication style; 1: Elaborate & Direct, 2: Elaborate & Indirect, 3: Concise & Direct, 4: Concise & Indirect.

Application usability: The application usability of each interface was evaluated with System Usability Scale [94], which allows us to easily get the usability score (min:0, max:100) of a system with ten questionnaire items. You can see Appendix C for details of questionnaire items and the scoring.

Impressions throughout the experiment: Finally, we asked them for their impressions throughout the tourism experiment with open questions.

3.5.4. Results

Through the whole experiment, approximately 1.53 GB of sensor data, 3148 photos and comments, and 108 post-survey answers were collected. In order to investigate the impact of different task allocation interfaces on tourism information collection efficiency tourism behavior and tourism satisfaction in participatory sensing for tourists, a quantitative evaluation using the collected log data and a qualitative evaluation using the questionnaire results were conducted.

	Demand Level			Free	
	Low	Middle	High	Posting	Total
Total Posts	166	258	532	390	1346
Average	3.02	4.69	9.67	7.09	24.47
Median	2	4	9	2	22
SD	3.00	3.24	5.52	10.91	14.77

Table 3.5.: Summary of the collected posts in chat-based interface

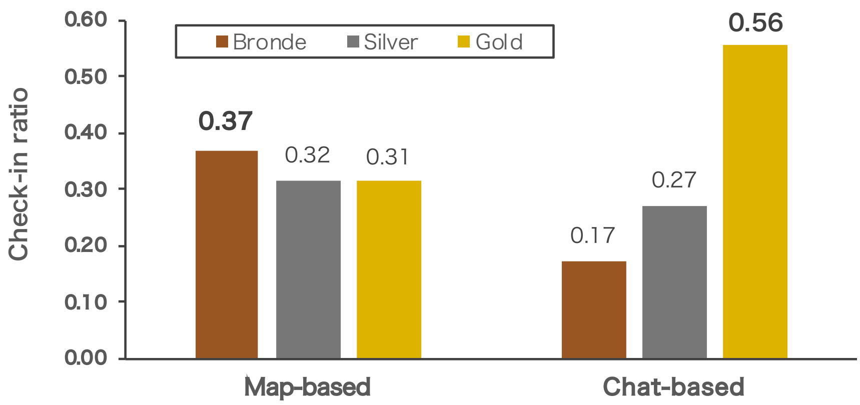
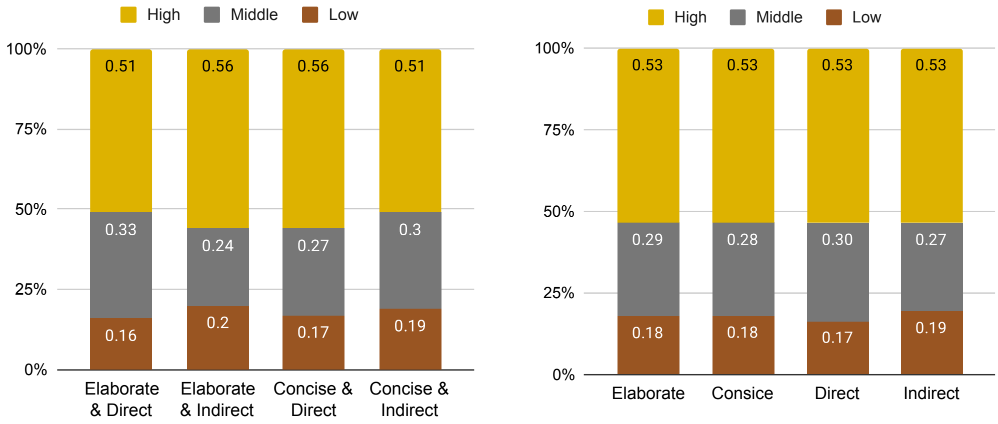


Figure 3.6.: Check-in ratio according to the information demand level in large scale experiment

Quantitative Evaluation using Collected Data

The summary of the collected posts in the map-based interface and chat-based interface are shown in Table 3.4 and Table 3.5, respectively. The 1512 posts (average 28.5 posts per person) are submitted as check-in missions, the 290 posts (average 5.5 posts per person) are submitted as free posting and 1802 posts are obtained in total from map-based interface. On the other hand, the 956 posts (average 17.4 posts per person) are submitted as check-in missions, the 390 posts (average 7.1 posts per person) are submitted as free posting and 1346 posts are obtained in total from chat-based interface. The absolute number of posts obtained by the check-in mission was about 1.55 times greater on average for the map-based interface. However, the absolute number of submissions obtained by



(a) Four communication styles

(b) Elaborateness and Indirectness

Figure 3.7.: Check-in rate by communication style in chat-based interface

free posting was about 1.42 times greater on average for the chat-based interface. When both were combined, the posts was about 1.39 times greater on average for the map-based interface.

A statistical significance test was performed to determine if there is a significant difference for differences in the number of posts obtained for each interface. First, we performed a Shapiro-Wilk test to check the normality of the number of posts obtained in the check-in mission and free posting at each interface. The results show that the total number of accomplished missions for the chat-based interface follows normality ($p = 0.22$), but the rest does not follow. We therefore ran the Mann-Whitney U test on the number of accomplished missions and free posting obtained for each interface. As a result, we found significant differences only between the posts obtained for the check-in missions in each interface. We found that the number of posts from the check-in missions was significantly greater in the map-based interface. On the other hand, the average number of posts obtained from free posting was grater for the chat-based interface, but the significant difference was not found.

Next, the quality of the data was evaluated by the check-in ratio according to the information demand of each sightseeing attraction. The check-in ratio according to information demand level in each interface is shown in Figure 3.6.

In the map-based interface, the rate was the highest for the low-demand spots, which are colored with bronze and assigned to more famous spots. On the other hand, the participants were more likely to complete in the high-demand spots colored with gold.

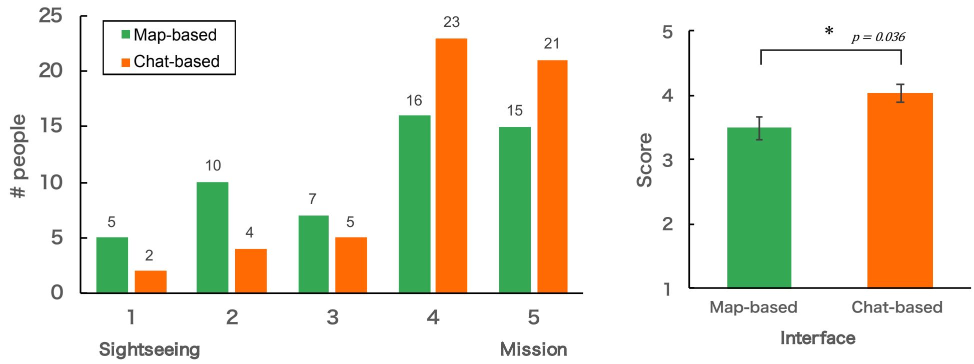
Finally, we will elucidate whether the efficiency of data collection differs depending on the communication style in the chat-based interface. Figure 3.7 shows the check-in ratio for each communication style; the results are shown for each of the four communication styles in (a), and the results are tabulated for each dimension of Elaborateness and Indirectness in (b). In Figure 3.7 (a), the ratio of high demand missions in Elaborate & Indirect and Direct & Concise is slightly higher, but similar results are obtained in almost all styles. In addition, similar results were also obtained for all items when we see the results from the two dimensions in (b).

Quantitative Evaluation using Post-survey

Tourism satisfaction:

The summary of the answers to Q1 on priorities between tourism and mission is shown in Figure 3.8; (a) shows the distributions of answers for each interface and (b) shows the average score of the answers. The average and median scores for the map-based interface were 3.44 and 4.00 (S.D. = 1.37), and for the chat-based interface were 4.04 and 4.00 (S.D. = 1.05). This result shows that missions are prioritized over tourism in both interfaces. It was also found that there is a tendency to prioritize missions over map-based interface in the chat-based interface. To determine if this difference is statistically significant, we performed a significance test. The normality of the answers to Q1 for each interface was confirmed by the Shapiro-Wilk test, and the results both did not follow a normal distribution. Therefore, we used the Mann–Whitney U test, and we found a significant difference between them ($p < 0.05$). We found that tourists are significantly more likely to prioritize missions with the chat-based interface than with the map-based interface.

Next, we summarize the results obtained by free description of the reasons for the responses. In the map-based interface, the most common reason given by the participants who answered 5 or 4, i.e., who more prioritized the mission, was

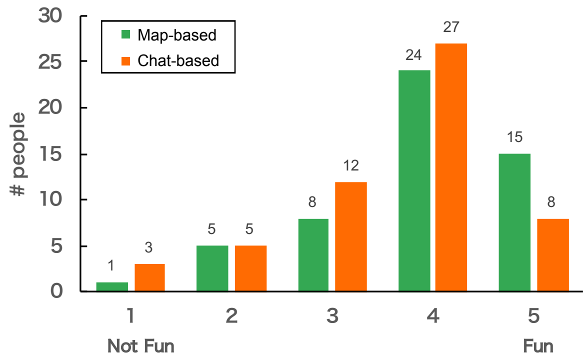


(a) The distribution of answers (b) Average score

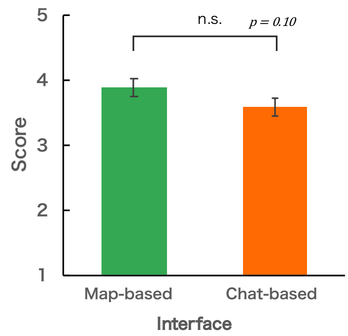
Figure 3.8.: Summary of the answers to Q1 on the priority of mission and sightseeing

the “Gameplay”, with 17 participants answering. For example, the participant P71 (Female, 46) responded, *“I wanted to go to the place with the highest points as much as possible because it became fun like a game.”* and the participant P66 (Male, 48) answered, *“I was focusing on sightseeing until the middle of the tour, but since I’m the type of person who wants to compete when I’m given a ranking, so I became mission-oriented from the middle.”* The second most common answer was “For sightseeing reference”, with 6 respondents. On the other hand, 15 participants answered, “For sightseeing reference”, which was the most common reason for prioritizing missions in the chat-based interface. For instance, the participant P29 (Female, 22) responded, *“I thought there would be many places that I could only learn about through the app,”* and Participant P49 (female, 21) responded, *“I didn’t know this area well, so I followed the mission to go sightseeing.”*. The second most common answer was “Gameplay”, with 10 respondents. In addition, as a characteristic answer of the chat-based, 8 people answered “Sense of duty”, and as an example, the participant P47 (Female, 45) answered *“Because the agent character asked me the mission.”*.

These responses indicate that in the map-based interface, gamification elements such as points and ranking were the factors that made people prioritize the mission more. In the chat-based interface, the passivity of asking a spot and the algorithm of prioritizing minor spots with high information demand were found



(a) The distribution of answers



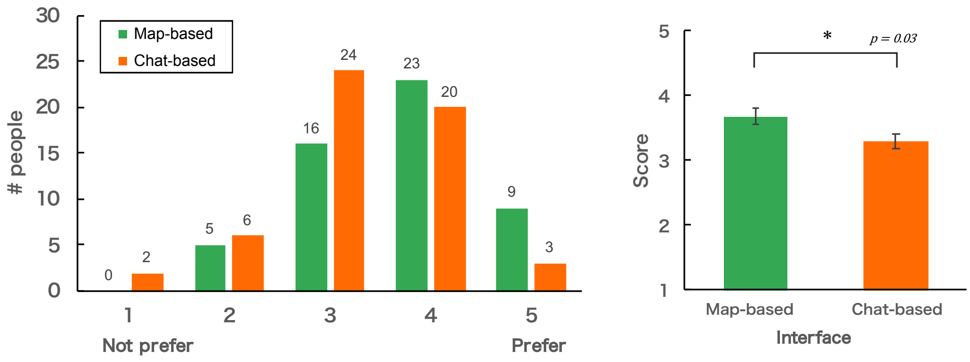
(b) Average score

Figure 3.9.: Summary of the answers to Q2 on the sightseeing enjoyment

to be factors.

The answers to Q2 on sightseeing enjoyment are summarised in Figure 3.9; (a) shows the distribution of answers for each interface and (b) shows the average score of the answers. The average and median scores for the map-based interface were 3.87 and 4.00 (S.D. = 0.99), and for the chat-based interface were 3.58 and 4.00 (S.D. = 1.03). This result shows that both interfaces make tourism more enjoyable. It was also found that the map-based interface tend to make tourism more fun than the chat-based interface. Similarly, we conducted a significance test to determine if there is a significant difference. We used the the Mann–Whitney U test, since the results of the Shapiro-Wilk test did not follow a normal distribution. The results of test showed that there is no significant difference between the enjoyment of sightseeing with the chat-based interface and with the map-based interface ($p = 0.10$). That is, the enjoyment of tourism does not differ significantly between the different interfaces.

Next, we summarize the reasons for the answers regrading enjoyment. The most common answer for the participants who answered 5 or 4, i.e., who responded that they enjoyed sightseeing more than usual, was “Chance encounter”, with 17 and 22 participants in the map-based and chat-based, respectively. For example, Group A participant P70 (Male, 69) responded, *“I went to places I would not have normally gone to, but there were spots nearby. This leads to awareness.”* and Group B participant P58 (Male, 22) answered *“I was able to visit minor places*



(a) The distribution of answers (b) Average score

Figure 3.10.: Summary of the answers to Q3 on the interface preference

that I would not have chosen on my own.”. The reason for the larger number of respondents in the chat-based interface, it is assumed that lesser-known spots are preferentially requested by agent characters. The second most mentioned factor was “Gameplay”, with 9 and 6 respondents, respectively. The examples are follows, Group A participant P76 (Male, 24) mentioned, *“I thought I would sightseeing would be neglected, but I felt a sense of accomplishment by visualizing the trip with points and recorded the places I visited.”* and Group B participant P102 (Male, 39) answered, *“Normally, it takes time to decide a tourist spot, but I felt that I was able to go around a lot by making it a mission by this application. ”*.

Interface preference and communication styles: The summary of the answers to Q3 on interface preference is shown in Figure 3.10; (a) shows the distribution of answers for each interface and (b) shows the average score of the answers. The average and median scores for the map-based interface were 3.69 and 4.00 (S.D. = 0.86), and for the chat-based interface were 3.29 and 3.00 (S.D. = 0.88). This result shows that the participants prefer the map-based interface over the chat-based interface. The Mann-Whitney U test was performed as well, since the distribution of answers did not follow normality. The results showed that there is significant difference between the preference of map-based interface and chat-based interface ($p < 0.01$). It is clarified that the map-based interface is significantly preferred to the chat-based interface.

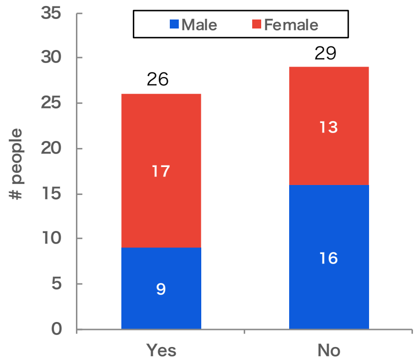
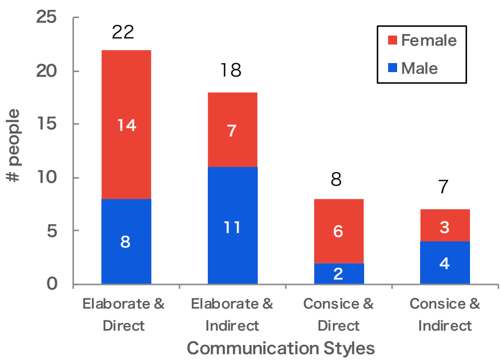
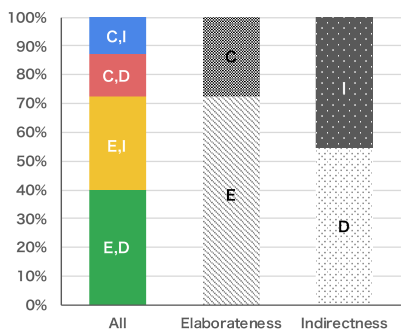


Figure 3.11.: The answers to Q4 on whether the participants noticed the differences of sentence and appearance of agent characters

The answers to Q4 on where whether they noticed the differences of sentence and appearance of characters is shown in Figure 3.11. 26 out of 55 people answered yes and 29 answered no, and we found that 47% of participants noticed the differences of sentence and character appearance. Seventeen of the 26 respondents (65%) were female, and this result suggests that female might be more sensitive to notice these changes. We conducted a chi-square test to determine if there is a significant difference in awareness by gender. However, there was no significant difference in the awareness of these differences between gender.

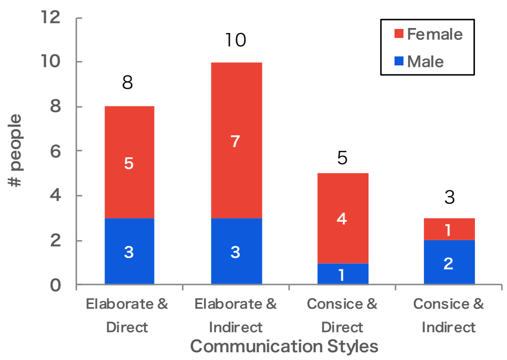


(a) The distribution of answers by gender

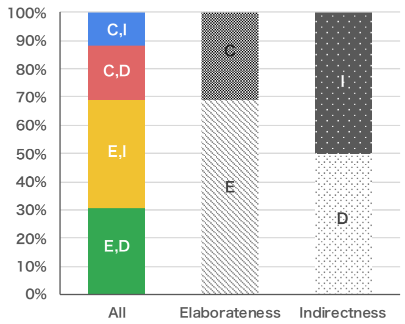


(b) Answer ratio for each communication style dimension

Figure 3.12.: The all answers to Q5 on communication style preferences



(a) The distribution of answers by gender

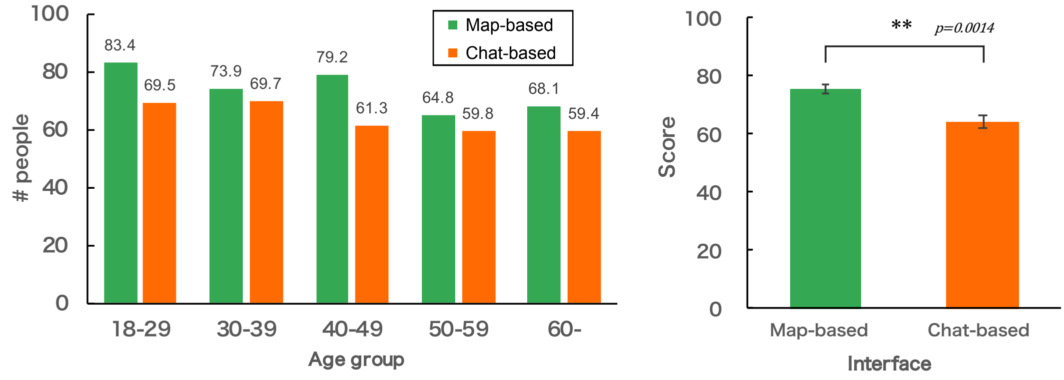


(b) Answer ratio for each communication style dimension

Figure 3.13.: The answers to Q5 on communication style preferences which obtained from participants who noticed the differences

The summary of all answers to Q5 on communication style preferences is shown in Figure 3.12 and the answers to Q5 which obtained from the participants who answered yes in Q4 is shown in Figure 3.13; (a) shows the distribution of answers by gender and (b) shows the answer ratio for each communication style dimension. Forty people, who account for 72% of the total, chose 1: ED or 2: EI. From this result, it was found that there is a strong tendency to prefer Elaborate sentences with a large amount of information. This tendency is the same even when limited to participants who answered yes in Q4. Chi-squared test for given probabilities is performed to find out whether people significantly choose elaborate sentences. We found significant differences in both the overall responses and the responses of only the participants who noticed the difference ($p < 0.001$, $p < 0,05$, respectively). The results showed that people significantly preferred the elaborate sentence.

Next, we summarize the reasons for the responses, and we found that most of participants mentioned about the Elaborateness dimension. 25 people chose 1 or 2 because of the elaborate sentence, for example, the participant P102 (male, 39) mentioned, *"The information was just easy to get because it simply showed the required time, earnable points and their ranking."*. On the other hand, nine participants chose 3 or 4 because of the concise sentence. For instance, participant P26(Female,43) responded *"A simple text is easier to read on the smartphone while walking."*. Only three people mentioned the Indirectness dimension, such as



(a) Average SUS score by age group (b) Total average score

Figure 3.14.: Summary of the application usability evaluation using SUS score

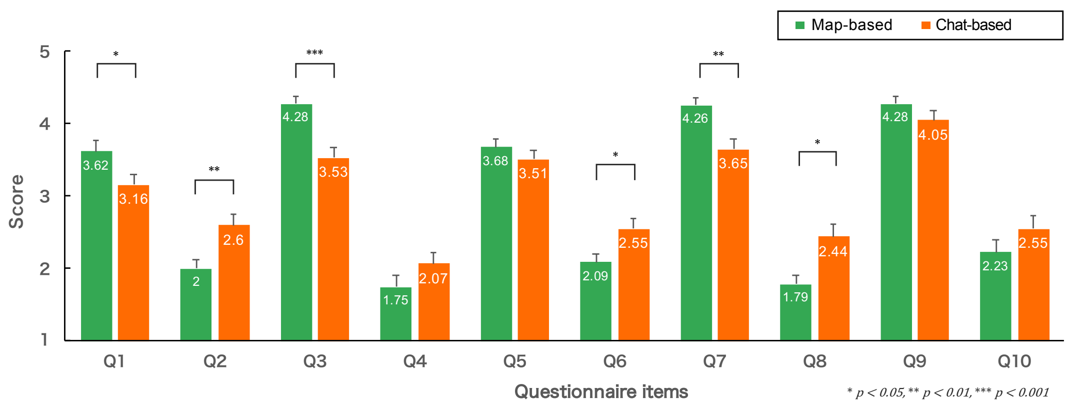


Figure 3.15.: The average score for each of the ten items in each interface

"Since it is clearly stated how close the spot is, and not in an imperative tone.".

These results indicate that in general, most people prefer elaborate sentences with more detailed information, and should adopt indirect sentences, although they do not care much about the directness of the sentences.

Application usability: The summary of the application usability evaluation using SUS score is shown in Figure 3.14; (a) shows the average SUS score by age group and (b) shows the overall average score of the answers. The average and median SUS scores for the map-based interface were 75.6 and 75.0 (S.D. = 12.7), and for the chat-based interface were 64.3 and 67.5 (S.D. = 17.6). In order to clarify whether there is a significant difference between them, the Mann-Whitney U test was performed since each SUS score did not follow normality in each interface and a significant difference was found between them ($p < 0.01$). That is, the map-based interface was found to be a significantly more usable interface than the chat-based interface. Next, in order to clarify the items that affected the difference in usability, the Man-Wittny U test was conducted to the responses for each of ten items. Figure 3.15 shows the average score for each of the ten items in each interfaces, and items for which significant differences were found are indicated by asterisks on the bars. As a result, significant differences were found for questionnaire items Q1 ($p < 0.05$), Q2 ($p < 0.01$), Q3 ($p < 0.001$), Q6 ($p < 0.05$), Q7 ($p < 0.01$), and Q8 ($p < 0.05$). Items Q2, Q3, and Q8 are related to complexity of application, and the scores for all items were more positive for the map-based interface. Item Q6 is related to consistency of the application and the Q7 is related the need for training until they can use the app, and the all scores were more positive for the map-based interface as well. Due to these results, the map-based interface scored higher in Q1 about if they want to use this app frequently. On the other hand, the items that did not find significant differences were Q4 and Q10 regarding the needs for support, Q5 regarding the consistency of the app, and Q9 regarding the confidence for using the app. That is, there was no difference in the degree to which the users could use the application confidently without support once they start using the application, regardless of the interface.

Impressions through the experiment The following is examples of the free description impressions through the experiment. First we sum up the coments given from the participants who used map-based interface. Participant P23(Female, 46) answered, *"Thanks to the app, I was able to visit places for the first time and know the places where I want to go in the next time, and I enjoyed sightseeing."*. P32(Female, 32) responded, *"I could know there are various tourist spots, but I sometimes could not concentrate on one tourist spot because I thought like "I want to go here! and there too!". However, I was able to continue to enjoy sightseeing in Nara without getting bored."* P70 (Male, 69) mentioned, *"I've been to Nara before, but I was able to find out places I didn't know through this experiment. I felt that if I could enjoy sightseeing with this app in the future, I would want to go to more places."*. Some of participants gave us the another aspect of views, like *"Group travel is often avoided with this Corona situation, but I think this app can be a new way to share the joy of sightseeing."* from participant P69 (Female, 42).

The following is the feedback that we got from the chat-based interface. P38 (Female, 22) responded, *"I became attached to Nara, through this experiment. Additionally, I've been Nara several times before, but I became more familiar in this time. I felt a little lonely because I was sightseeing alone, but it was good to be able to go around at my own pace. In addition to famous sightseeing spots, I was able to visit tourist spots that I didn't know or passed by if they weren't displayed in the app, and it was good to study history."* P50 (Male, 57) answered, *"I had a meaningful experience in a place I didn't know well."* P77 (Female, 46) mentioned, *"I was able to meet new places and beautiful scenery, and after reading the explanation of the points, I became more and more interested in Nara, thanks to this experiment. I arrived at my destination with peace of mind even on narrow roads, thanks to this app. I would like you to make it at other tourist spots. I think it would be great if a multilingual version was made and could be used by foreign tourists."* In addition, as a characteristic opinion in the chat-based interface, the following answer is obtained from Participant P49 (Female, 22) ; *"Even though I was sightseeing alone, it was fun to feel like I wasn't alone while using the application."*.

As mentioned above, most of the impressions obtained through the experiment were positive, but some participants gave us the following opinions. Participant P95 (Male, 34, Map-based) mentioned, *"With the points and ranking displayed on the app, I tried my best and walked too much."*. Participant P61 (Female, 20, Chat-based) described, *"It was better for me to have no guidance. However, I think it was good that game elements such as ranking format were incorporated."*

Correlation between Behaviours and User Types

Here, we clarify whether there are differences in data collection characteristics, tourism satisfaction, and interface preferences depending on the personality and user type of the participants. The responses obtained by the 5-likert scale in the post-survey is used as an interval scale, and Pearson's product-moment correlation and test of Non-correlations will be used. The significance level is set at

$p < 0.05$, and $0.1 > p > 0.05$ is considered as marginally significant. First, we discuss the correlation with the data collection tendency. We found a weak negative correlation and a marginally significant with Free Spirit in the map-based interface ($r = -0.26, p = 0.06$). In the total number of postings including free postings, there was also a weak negative correlation and significant difference with Free Spirit ($r = -0.38, p < 0.01$). When calculated the correlation with all free postings, no correlation or significant difference was found. However, a weak positive correlation and significant difference between the number of free postings and Philanthropist was found when the test was performed on the number of free postings of participants who had posted at least once ($r = 0.34, p < 0.01$). This tendency was similar when tested with the map-based ($r = 0.40, p < 0.01$) and chat-based ($r = 0.32, p = 0.05$) interfaces respectively.

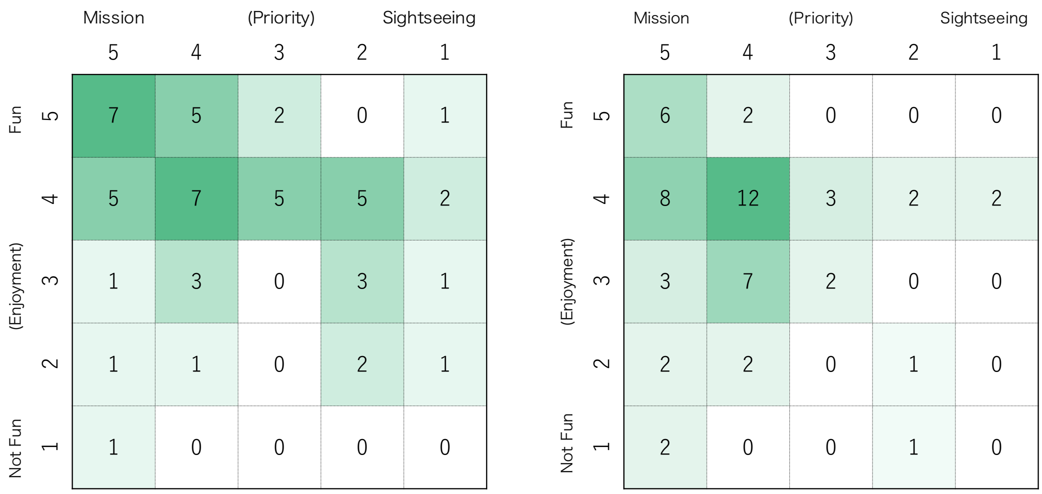
Next, we describe the correlation with tourism satisfaction. In the chat-based interface, a weak negative correlation and a marginally significant were found between tourism priority and Free Spirit ($r = -0.24, p = 0.08$). In terms of tourism enjoyment, there was a weak positive correlation and a significant difference in the attribute value of Player in the Map-based interface ($r = 0.37, p < 0.01$).

Finally, we discuss the correlation with interface preference. Weak positive correlation and marginally significant between interface preferences and Player were found for the map-based interface ($r = 0.25, p = 0.07$). In the chat-based interface, a weak positive correlation and a marginally significant were found with Achiever ($r = 0.26, p = 0.05$).

3.5.5. Discussion

In this section, we discuss the answers to our research questions based on the results obtained through the large scale experiment.

RQ1: How does the different task allocation interfaces affect the quantity and quality of dynamic tourism information collection? Regarding the quantity of the collected data, the map-based interface could collect about 1.39 times, and we found a significant difference between the interfaces. On the other hand, the chat-based interface could collect the high-demand data preferentially and efficiently. The results were the same as those of the pre-experiment, and the large-scale experiment allowed us to generalize each interface's properties



(a) Map-based (b) Chat-based

Figure 3.16.: The correspondence table between Q1:priority and Q2:enjoyment

more.

RQ2: Do the different task allocation interfaces have an impact on tourism satisfaction of the tourists? From questionnaire Q1 and Q2, it was found that the mission was significantly more prioritized in the chat-based interface, but the interface difference did not affect the impact on the enjoyment of sightseeing. The correspondence table between Q1: priority and Q2: enjoyment is shown in Figure 3.16. This result shows that the map-based interface has become a factor that makes sightseeing more enjoyable while balancing sightseeing and missions. The same tendency can be seen in the chat-based interface, but the participants more prioritized to the mission.

RQ3: Is there a relationship between tourism information collection efficiency and interface preference, and gamification user type? First, we describe the difference in data collection efficiency by user type. A negative correlation was found between the number of mission posts and the Free Spirit attribute value in the map-based interface. Free Spirit is a user type that is motivated by autonomy and is not constrained by external control. It is assumed that participants with high autonomy might grasp missions as external controls and tend to perform them less frequently, while participants with relatively low autonomy tend to follow the missions and perform them more frequently. Additionally, there was a negative correlation between Free Spirit and priority of sightseeing although in chat-based interface. From these results, it is considered that the tendency to prioritize tourism and missions differs depending on the degree of autonomy, and participants with higher autonomy are more likely to prioritize their own tourism, resulting in a decrease in the number of posts. On the other hand, there was a positive correlation between Philanthropist attribute value and the number of free posting, which allows participants to actively post at their own timing during sightseeing and obtains fewer points. Philanthropists focus on purpose as their motivation and tend to act altruistically without the extrinsic rewards. The number of free postings for the purpose of sharing the situation in the tourist attractions with the other participants is quite large, as shown in the open-ended responses for the purpose of free posting, such as "when I find a place that is dangerous for people using the app or something I have never seen before" (P2, Female, 38, Map-based), "when I find a place that I want everyone to visit. (P25, Male, 28, Chat-based). These factors suggest that users with high Philanthropists' attribute values tend to post more in order to share their situations at sightseeing spots with other participants by free posting and solving the timeline. As examples of the reason for free posting, we obtained such comments, "To tell people about dangerous places. Or when I find something I have never seen before." (P2, Female, 38, Map-based), " When I found a place that I wanted everyone to visit. " (P25, Male, 28, Chat-based). These results suggest that participants with high Philanthropist attribute value tend to post more in order to share their situations at tourist attractions to other participants through free posts and timelines.

Next, we discuss the relationship between interface preference and user type. There was a positive correlation with the Player attribute value in the map-based interface. Players are mainly motivated by extrinsic rewards and will try to earn rewards from the system regardless of the type of activity. In the map-based interface, all missions can be seen on a map, and they can see at a glance that the points to be obtained differ depending on the spot. Therefore, it is expected to stimulate the motivation of Player users who try to obtain higher points. We found also a positive correlation between the enjoyment of sightseeing and the Player attribute value in map-based interface. That is, participants with a high

Player value visit spots where they can get higher points, and enjoy sightseeing more while getting points, which may have increased their preference for the map-based interface. On the other hand, there was a positive correlation with Achiever attribute value in the chat-based interface. Achiever is mainly motivated by competence and seeks to perform the task given by the system. In the chat-based interface, the agent character asks the participant to go to the spot where the system needs information as needed. Therefore, it is considered that participants with high Achiever attribute value are more motivated to complete the given missions one after another, which in turn increases their preference for the chat-based interface.

RQ4: What is the impact of different communication style sentences in a chat-based interface? As can be seen from Figure 3.7, the influence of communication style on participants' mission selection was not significant. On the other hand, there was a difference in communication style preference as obtained from the post-survey, with participants significantly preferring informative and elaborate sentences. In addition, some participants did not prefer the direct expression with authoritative tone. These results indicate that although the difference in communication style does not significantly affect the selection of mission, there is a significant difference in the preference of sentences and elaborate and indirect sentences are mostly preferred. However, in this experiment, we created four different styles for only one sentence as shown in Section 3.3.3. Therefore, these results are evaluation of sentences, which might be insufficient for evaluating the communication style. In addition, the impact will differ depending on cultural differences as shown in the previous study by Juliana et al. [95, 96]. Since this experiment was conducted with only Japanese participants in Japan, it is necessary to conduct experiments with participants from different cultures or nationalities in order to obtain more general results.

3.5.6. Summary of Large Scale Experiment

In this study, we conducted a tourism experiment in a participatory sensing application for tourists that incorporates gamification and implemented both map-based and chat-based interfaces for 108 people between the ages of 19 and 71. The absolute number of posts was about 1.4 times greater for the map-based interface than the chat-based interface, but the chat-based interface was more efficient in obtaining the data required by the system. As for the free posting, there was a weak positive correlation between the number of contributions and the value of Philanthropist user type for the users who posted more than one contribution. participants with a high Philanthropist attribute value contributed more by free posting. There was no significant difference in the impact of the different interfaces on the enjoyment of tourism. On the other hand, the usability of the application was higher for the map-based interface in terms of SUS score. In the case of the communication style, the respondents preferred the more informative and Elaborate sentence, and there were few opinions on the Directness dimension, but since some respondents did not like the imperative base, they preferred the indirect style. The overall impression of the experiment was generally positive, for example, that using minor tourist attractions as checkpoints would give a sense of serendipity to tourism. Many participants also requested features such as information on the entrances to tourist attractions, restrooms, and navigation.

3.6. Summary

The purpose of this chapter was to investigate the effects of task allocation interfaces and user types on tourist information collection efficiency, tourist behavior, and tourist satisfaction in a gamified participatory sensing for tourists. We designed and implemented two types of task allocation interfaces (map-based and chat-based), and we used four different communication styles based on two dimensions, Elaborateness and Indirectness, to elucidate the appropriate dialogue requests in the chat-based interface. As a user type, we introduced the Hexad gamification user type which defined by Tondello et al. [93]. Then, we set four research questions and these were clarified through two sightseeing experiments in Nara. We conducted a pre-experiment with 10 students to check the validity of our research design for our research questions, and then conducted a large-scale experiment with 108 ordinary people aged between 19 and 71 to obtain more generalized results. We found the following through these experiments. The absolute number of contributions was about 1.4 times greater for the map-based interface than the chat-based interface, but it was more efficient in obtaining the data required by the system. In addition, there was no significant difference in the tourism satisfaction between the two interfaces. However, we found different trends for the contribution to sensing and the interface preference by user type. As for the free posting, there was a positive and weak correlation between the number of contributions and the Philanthropist attribute value for the participants who posted more than one contribution. That is, the higher the value of Philanthropy, the higher the number of free contributions. There was no significant difference in the impact of the different interfaces on the enjoyment of tourism. On the other hand, the usability of the application was higher for the map-based interface in terms of SUS score. In the case of the communication style, the respondents preferred the more informative and Elaborate text, and there were few opinions on the Directness dimension, but since some respondents did not like the imperative base, they preferred the indirect style. The overall impression of the experiment was generally positive, for example, that using minor tourist attractions as checkpoints would give a sense of serendipity to tourism. Many participants also requested features such as information on the entrances to tourist attractions, restrooms, and navigation.

4. Discussions on suitable gamified participatory sensing

In this chapter, we summarize the results obtained in Challenge 1 and Challenge 2, and then discuss the design of participatory sensing suitable in the collection of spatiotemporal tourism information based on these findings. In addition, the scope of the applicability of our results to smart city environments is mentioned.

4.1. Findings by Integrating Two Challenges

4.1.1. Summary of Findings

In Challenge 1, we conducted on the design of gamification and reward mechanisms to achieve efficient information collection while considering user satisfaction and burden. As a result, our obtained results suggested that area missions employing variable reward or dynamic variable reward might encourage tourists to change their behavior and move to high information demand areas while giving priority to sightseeing compared to check-in missions. We also qualitatively confirmed an increase in the amounts of free postings in those areas. In Challenge 2, we designed two types of task allocation interfaces, and found that the chat-based interface was more efficient in collecting information that the system needed while maintaining tourism satisfaction. In addition, the number of free postings was not affected by the difference in interface, and was more related to personality (especially Philanthropist). However, the absolute number of postings was higher in the map-based interface, and this could be a factor to make sightseeing more enjoyable, especially for Player-type users, who aim for a higher ranking based on the points.

The following findings can be summarized from these results.

- Check-in mission with variable reward (dynamic variable reward) and map-based interface can be applied to Player-type users to realize efficient data collection while enjoying sightseeing more.
- The chat-based interface is generally accepted as an interface to collect the information needed by the system more efficiently while enjoying sightseeing.
- The amount of free postings depends on the user type, although the location of posts can be controlled by area missions with variable reward or dynamic variable reward.
- The ranking function works differently depending on the individual personality. For some users, especially the Player type, the ranking function can work positively as a competitive element to reach a higher rank, but on the other hand, it can also be a factor that decreases the satisfaction level of tourists by rushing them.

However, it is necessary to clarify the effect of requesting area mission to participants through a chat-based interface, as a remaining research challenge.

4.1.2. Influence of Participation Rewards

In this dissertation, we basically focused on gamification, which is a non-monetary incentive, but we paid some money as a participation fee in the experiment. In this section, we discuss the validity and impact of these monetary rewards. First, the participation fee is calculated based on 1,000 yen per hour for the time spent in the sightseeing experiment and answering the questionnaire. In the experiment in Challenge 2 (Chapter 3), only people who live outside Nara Prefecture were targeted, so an additional 3,000 yen was paid for the round-trip transportation fee. In other words, these participation costs are considered to be a reasonable price to pay for the time commitment to participate in the experiment. Furthermore, We have conducted a survey on the appropriateness of the participation fee in the Challenge 1 experiment. As a result, 26 out of 33 participants answered that it was reasonable. Three of them responded that they would participate even if the fee was less than 3,000 yen, and one of them would participate even if there were no payment. The remaining three respondents answered that they would need around 10,000 yen to participate. These questionnaire result clearly show the appropriateness of the participation fee. However, in order to realize a more natural environment, it would be necessary to conduct an experiment by recruiting participants under the condition that no participation fee or only transportation expenses are provided.

Next, we consider the impact of additional rewards based on contribution. In the experiment in Challenge 1, an additional monetary reward was given in the ranking of the points obtained, and not in the experiment in Challenge 2. Although the locations and the participants' attributes are different, the method of calculating the points obtained at each spot is the same. Under these assumptions, we obtained similar results in the check-in rate in the variable reward group of the check-in mission in Challenge 1 and the results obtained in the map-based interface in Challenge 2. In addition, we found that the check-in rate in the variable reward group of the check-in mission in Challenge 1 (Group B at Figure 2.6) and the results obtained in the map-based interface of Challenge 2 (map-based at Figure 3.6) showed that the percentage of posts in high-demanded areas was higher in Challenge 1 than in Challenge 2. In the results obtained from the map-based interface of Challenge 2, Challenge 1 has a slightly higher percentage of postings in high-demanded areas than Challenge 1, but a similar trend is observed. These results suggest that although there might be some impact from additional payment, the impact from the reward mechanism is sufficiently larger.

While previous research suggests that monetary rewards may decrease intrinsic motivation [97], there are external rewards (e.g., money) for intrinsic motivation. In the Massung et al. [98] and Preist et al. [99] experiments, the combination of gamification and financial rewards was found to increase the participation rate compared to gamification alone. In their experiment, they found that the combination of gamification and monetary reward can increase the participation rate compared to gamification alone. On the other hand, Ipeirotis and Gabrilovich [62] pointed out that the quality of output from paid crowdsourcing may deteriorate because the monetary reward might reduce the intrinsic motivation to accomplish quality work.

From the above reasons, the involvement of motivation by additional monetary rewards should be carefully considered in terms of its impact on the quality of the posted photos and comment content. Therefore, the impact of the presence or absence of additional payment on the quality of posted content needs to be clarified in the future.

4.2. Extending Smart Tourism to Smart City

We have focused our discussion on smart tourism domain so far. We will discuss possible applications in other domain under smart city environments based on our results in this section.

Participatory sensing has been used in other domains in smart city environments, include environment monitoring [3,4], public health [5], urban safety [6],education [7], transport [8]. Among these, our results are applicable to the fields that need to be linked to location information, such as environment monitoring, urban safety and transportation. The research on participatory sensing in environmental monitoring that has been published in the early 2010s has mainly focused on the discussion of the feasibility and accuracy of environmental sensing using smartphones [3, 4], there has been an increase in research on gamification and incentive design for efficient data collection from the late 2010s to 2020. For example, Palacin-Silva et al. [41] applied participatory sensing using gamification for the purpose of monitoring ice coverage of sub-arctic lakes in the environment monitoring domain. They implemented gamification elements such as points as reward, storytelling to convey the severity of environmental problems, interactive maps to present the progress status, and conducted a study comparing the amount of data collected and the persistence rate with those from a participatory sensing application without gamification elements. However, the differences in task design, interface, and contribution by user type have not been clarified. Therefore, when designing the details of gamification in this field, we believe that more efficient information collection can be achieved by changing the points obtained depending on the collection status using dynamic variable reward or using a chat-based interface.

To summarize, we believe that our results can be applied to applications that require information collection linked to location information in smart city environments, such as environment monitoring, urban safety and transport. In the field of HCI research, each domain has different requirements that should be taken into account, so it is necessary to clarify these requirements through practical experiments.

5. Conclusion

5.1. Summary

In this dissertation, we have addressed the following two research challenges to achieve a sustainable collection of dynamic tourism information, which is necessary to collect exhaustive spatiotemporal information, encouraging tourists to participate in sensing behavior considering their tourism satisfaction: (1) design of gamification and tasks that consider the burden on tourists, and (2) design of an appropriate task allocation interface and interaction, and personalization. In challenge (1), we introduced mission, point, and ranking functions as gamification elements. There are two types of missions: check-in mission to post photos and reviews at the designated tourist attraction and area mission to collect sensor data at the designated tourist attraction. We also designed three types of reward methods that differ in setting points obtained when completing missions. We conducted a tourism experiment with 33 participants to investigate our gamification designs' effect on the efficiency of tourism information collection and tourism satisfaction. The results show that area missions should be adopted when considering tourism satisfaction and that the variable reward method effectively collects tourism information without decreasing the satisfaction. In challenge (2), we designed two types of interfaces: a chat-based interface in which the user selects the spots on the map with markers and an chat-based interface in which the agent character in the application passively selects the spots at the request of the user. For the chat-based interface, we developed four dialogue templates based on the indexes of elaborateness and directness to elucidate the appropriate dialogue sentence. We conducted a tourism experiment with 108 participants to investigate the interface's effect on information collection efficiency and tourism satisfaction. The results show that the absolute amount of collected data is about

1.4 times larger in the chat-based interface, but the chat-based interface was able to efficiently collect high-demanded spot information. There was a significant tendency to prioritize the mission over tourism in the chat-based interface. Moreover, there was a significant difference in the index of elaborateness among the agents, and more elaborate sentences were preferred. The results of these experiments show the effectiveness of gamification in participatory sensing to collect dynamic tourism information and the appropriateness of our designed task and interface in building an ecosystem that includes tourists in realizing Smart Tourism.

As a result of an integrated discussion of these two research challenge results, the following findings were obtained.

- Check-in mission with Variable reward (Dynamic Variable reward) and Map-based interface can be applied to Player-type users to realize efficient data collection while enjoying sightseeing more.

- The chat-based interface is generally accepted as an interface to collect the information needed by the system more efficiently while enjoying sightseeing.

- The amount of posts depends on the user type, although the location of posts can be controlled by area missions with Variable reward or Dynamic Variable reward.

- The ranking function works differently depending on the individual personality. For some users, especially the Player type, the ranking function can work positively as a competitive element to reach a higher rank, but on the other hand, it can also be a factor that decreases the satisfaction level of tourists by rushing them.

Furthermore, the possible scope of the application when extending these discussions from smart tourism to smart cities, our results can be applied to applications that require information collection linked to location information in smart city environments, such as environment monitoring, urban safety, and transport.

Finally, the contributions of this dissertation to academic knowledge is summarized with the following three aspects. First, as a scientific aspect, this is the first study that clarified the feasibility and appropriate overall design of spatiotemporal tourism information collection through gamified participatory sensing in a smart city environment, especially, smart tourism. Next, as a technical aspect, the designed gamification elements and interface design were implemented into an application to build a system that can be operated in practice. Finally, as a practical aspect, we conducted a tourism experiment using that system to investigate our hypothesis and demonstrate the effectiveness of the system with 151 participants in total.

5.2. Future Direction

5.2.1. Dynamic Variable Rewarding Algorithm

In this dissertation, we designed Dynamic Variable Reward as a point rewarding mechanism, and found that it can efficiently collect the high-demanded data. However, in our experiments, we manually set the weights in advance and changed them at regular intervals. Therefore, one of the future works is to establish an algorithm to automatically change the weights. For this purpose, we can refer to the previous research on dynamic pricing algorithms. Chen et al. [78], for instance, have investigated the impact of dynamic demand-based dispatch pricing on the User Platform, an automatic taxi dispatch service. We believe that it is possible to form an algorithm that matches the demand of the system with the destination of the person seeking a taxi, and the tourist with the taxi, at a reasonable price in the car allocation service. By replacing the system's demand with destinations for people seeking taxis, and tourists with taxi drivers, and adding the past collection status as other parameters, we believe that it might be possible to form an algorithm that changes the weights for each user.

5.2.2. From Chat-bot to Agent

We designed a chat-based interface with characters and examined the effects of the interface on tourism satisfaction and information gathering efficiency compared to the conventional map-based interface in Chapter 3. However, there are currently only three patterns of interaction: "Requesting a tourist spot to be sensed," “Giving details of the destination,” and “Receiving a mission”. In addition, since the investigation of the effects of communication style differences during dialogue was conducted for a single sentence, the scope of the effects may have been limited. Therefore, it is thought that the usefulness of the interactive interface will be further clarified by making chat-bot smarter and increasing the number of interaction patterns, such as initiating a dialogue according to the context of tourists from the system side.

5.2.3. Automatic Customization based on User Personality

By user modeling using Hexad gamification user types, the contribution to sensing behavior and interface preferences for each user type were clarified in Chapter 3. However, user type identification using the Hexad scale requires users to answer a questionnaire consisting of 24 questions, and users need to answer many questions in order to make a predetermination. However, user type identification using the Hexad scale requires users to answer a questionnaire consisting of 24 questions, which is a heavy burden for users. Altmeyer et. al. have conducted a study to identify user types more easily from the smartphone data, such as categories and amounts of installed apps and phone calls [100]. We believe that by using these methods to identify user types more simply and then dynamically changing the user interface and the types of missions that are prioritized according to the results, we can achieve more efficient data collection while increasing user satisfaction. However, the trends and preferences of contributions by user type to mission types (Area, Check-in) were not examined in this dissertation and need to be clarified in the future work.

5.2.4. Multicultural and Long-term Study

The experiments in this dissertation were conducted mainly with Japanese people at a tourist spot in Japan. Therefore, it is not clear whether our obtained results can be directly applied to people of other cultures (e.g., Europeans, Americans) or for foreign tourist destinations. Therefore, it is necessary to conduct experiments with participants from different cultures or outside Japan.

In addition, each experimental participant was limited to people who had never used our participatory sensing application before. Therefore, it is not clear how the contribution to sensing would change with continued use. In the Large-scale experiment in Challenge 2, we received feedback from the participants that they would like to use the app in other sightseeing spots, suggesting the possibility of obtaining positive results even when the app is used repeatedly. However, we think it is necessary to investigate how the contribution to sensing behavior changes during continuous use.

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Appendix

A. Ten Item Personality Inventory (TIPI)

The user personality traits score is calculated with following questionnaire as shown in Table A.1 [101]. We used the Japanese version of TIPI which established by Oshio et al. [102] as shown in Table A.2, since our participants were only Japanese. These items were answered with 7 point Likert scale; 1: Disagree strongly, 7: Agree strongly. We asked the participants that *Please write a number next to each statement to indicate the extent to which you agree or disagree with that statement. You should rate the extent to which the pair of traits applies to you, even if one characteristic applies more strongly than the other.* TIPI scale scoring is as follows ("R" denotes reverse-scored items): Extraversion: 1, 6R; Agreeableness: 2R, 7; Conscientiousness; 3, 8R; Emotional Stability: 4R, 9; Openness to Experiences: 5, 10R.

Table A.1.: Ten Item Personality Inventory (TIPI)

Disagree strongly	Disagree moderately	Disagree a little	Neither agree nor disagree	Agree a little	Agree moderately	Agree strongly
1	2	3	4	5	6	7

I see myself as:

1. ______ Extraverted, enthusiastic.
2. ______ Critical, quarrelsome.
3. ______ Dependable, self-disciplined.
4. ______ Anxious, easily upset.
5. ______ Open to new experiences, complex.
6. ______ Reserved, quiet.
7. ______ Sympathetic, warm.
8. ______ Disorganized, careless.
9. ______ Calm, emotionally stable.
10. ______ Conventional, uncreative.

Table A.2.: Japanese version of Ten Item Personality Inventory (TIPI-J)

全く違うと思う	おおよそ違うと思う	少し違うと思う	どちらでもない	すこしそう思う	まあまあそう思う	強くそう思う
1	2	3	4	5	6	7

私は自分自身のことを……

1. (　　　　) 活発で, 外交的だと思う
2. (　　　　) 他人に不満をもち, もめごとを起こしやすいと思う
3. (　　　　) しっかりしていて, 自分に厳しいと思う
4. (　　　　) 心配性で, うろたえやすいと思う
5. (　　　　) 新しいことが好きで, 変わった考えをもつと思う
6. (　　　　) ひかえめで, 大人しいと思う
7. (　　　　) 人に気を使う, 優しい人間だと思う
8. (　　　　) だらしなく, うっかりしていると思う
9. (　　　　) 冷静で, 気分が安定していると思う
10. (　　　　) 発想力に欠けた, 平凡な人間だと思う

B. Gamification User Types Hexad scale

Hexad is a gamification user type model consisting of six types to personalize the gamification design according to the user's personality [93]. The Gamification User Types Hexad scale is a 24-items survey response scale to score users ' preferences towards the six different motivations in the Hexad framework [92]. It is calculated with following questionnaire as shown in Table B.1. We translated them into Japanese as show in Table B.2 since our participants were only Japanese and use it in our experiments . We asked the participants to rate how well each item describes them in a 7-point Likert scale ; 1: Strongly disagree and 7: Strongly agree; without identifying the corresponding type. The user type scores are calculated that separately add the scores of the items corresponding to each subscale. Basically, the one with the highest value in each subscale is used as the representative user type, but it is an archetypical categorization in Hexad framework.

Table B.1.: The Gamification User Types Hexad scale

User Types	#	English Items
Philanthropist	P1	It makes me happy if I am able to help others.
	P2	I like helping others to orient themselves in new situations.
	P3	I like sharing my knowledge.
	P4	The well being of others is important to me.
Socialiser	S1	Interacting with others is important to me.
	S2	I like being part of a team.
	S3	It is important to me to feel like I am part of a community.
	S4	I enjoy group activities.
Free Spirit	F1	It is important to me to follow my own path.
	F2	I often let my curiosity guide me.
	F3	I like to try new things.
	F4	Being independent is important to me.
Achiever	A1	I like defeating obstacles.
	A2	It is important to me to always carry out my tasks completely.
	A3	It is difficult for me to let go of a problem before I have found a solution.
	A4	I like mastering difficult tasks.
Player	R1	I like competitions where a prize can be won.
	R2	Rewards are a great way to motivate me.
	R3	Return of investment is important to me
	R4	If the reward is sufficient I will put in the effort.
Disruptor	D1	I like to provoke.
	D2	I like to question the status quo.
	D3	I see myself as a rebel.
	D4	I dislike following rules.

Table B.2.: The Gamification User Types Hexad scale in Japanese

User Types	#	Japanese Items
Philanthropist	P1	他人を手助けできることは，私を幸せにしてくれる
	P2	他人が新しい環境に順応するために 手助けすることが好きである
	P3	自分の知識を共有することが好きである
	P4	他人の幸福は私にとって重要である
Socialiser	S1	他人との交流は私にとって重要である
	S2	チームに属することが好きである
	S3	自分がコミュニティの一員であると 感じることは重要である
	S4	グループでの活動を楽しむ
Free Spirit	F1	自分の道を進むことは自分にとって重要である
	F2	自分の好奇心に導かれることが多い
	F3	新しいことに挑戦することが好きである
	F4	自立していることが私にとって重要である
Achiever	A1	困難に打ち勝つことが好きである
	A2	常に自分の仕事を完璧にこなすことが大事である
	A3	解決方法を見つける前に問題を手放すことは難しい
	A4	難しい仕事をこなすことが好きである
Player	R1	賞がもらえるコンペが好きである
	R2	報酬は私を動機づけるための最適な方法である
	R3	投資に対する利益は私にとって重要である
	R4	報酬が十分であれば、私は努力を惜しまない
Disruptor	D1	挑発することが好きである
	D2	現状に対して疑問を持つのが好きである
	D3	私は自分を反抗的な人間だと思っている
	D4	ルールに従うことを好まない

C. System Usability Scale (SUS)

The SUS is a simple, ten-item scale giving a global view of subjective assessments of usability [94]. It is calculated with following questionnaire items. The Japanese sentence used in the experiment is described in the second line of each item. The questionnaire is answered with 5 point Likert scale; 1: Strongly disagree and 5: Strongly agree.

1. I think that I would like to use this system frequently.
   このアプリを今後も繰り返し使いたいと思う.
2. I found the system unnecessarily complex.
   このアプリは必要以上に複雑出会った.
3. I thought the system was easy to use.
   このアプリは容易に使いこなすことができると思った.
4. I think that I would need the support of a technical person to be able to use this system.
   このアプリを使えるようになるには,専門家のサポートが必要であると思った.
5. I found the various functions in this system were well integrated.
   このアプリの様々な機能がよくまとめられていた
6. I thought there was too much inconsistency in this system.
   このアプリでは一貫性のないところが多々あったと感じた.
7. I would imagine that most people would learn to use this system very quickly.
   たいていの人はこのアプリをすぐ使えるようになると思う.
8. I found the system very cumbersome to use.
   このアプリはとても使いづらかった.
9. I felt very confident using the system.
   このアプリを利用できる自信がある.
10. I needed to learn a lot of things before I could get going with this system.
    このアプリを使い始める前に, 多くのことを学ぶ必要があった.

To calculate the SUS score, first sum the score contributions from each item. Each item's score contribution will range from 0 to 4. For items 1,3,5,7,and 9 the score contribution is the scale position minus 1. For items 2,4,6,8 and 10, the contribution is 5 minus the scale position. Multiply the sum of the scores by 2.5 to obtain the overall value of SUS.

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