Gamification-Based Incentive Mechanism for Participatory Sensing

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***Abstract*—Since participatory sensing relies on users' active participation, several monetary incentive mechanisms for attracting users' participation have been proposed. However, to make users participate in "heavy" sensing tasks (either physically or mentally), stronger incentive is required. Thus, the total amount of rewards paid by the client will quickly rise. In this paper, we propose a novel incentive mechanism based on gamification for participatory sensing to reduce the total amount of rewards paid by the client. The proposed incentive mechanism incorporates a status level scheme depending on earned reward points like airline's mileage services, so that users with higher status can earn more reward points. We also introduce a ranking scheme among users and a badge scheme based on gamification so that users are attracted by getting not only monetary reward points but also sense of accomplishment. We formulate the problem of sensing given PoI (points of interest) with minimal reward points and devise a heuristic algorithm for deriving the set of users to which requests are sent and appropriate reward points for each request. The algorithm requires the participation probability distribution for each tuple of a user, reward points, and the burden of a sensing task. To obtain the probability distribution, we implemented a prototype of a participatory sensing system with the proposed incentive mechanism and conducted an experiment with 18 users for 30 days. As a result, we confirmed that the gamification mechanism increased participation probability from 53% (without gamification) to 73%.**

I. Introduction

Participatory sensing [1], [2] leverages users with mobile phones as sensors to collect various information at *PoI* (points of interest) in a city without deploying fixed sensors. Applications of participatory sensing include real-time monitoring of weather conditions[1] and road congestion[2]. In participatory sensing, however, encouraging potential mobile users to actively participate in sensing tasks requires some incentives. A typical incentive used in existing systems is that a client pays monetary rewards to the users who participated in sensing tasks. To make users participate in "heavy" sensing tasks (either physically or mentally), stronger incentive is required. Thus, the total amount of rewards paid by the client will quickly rise. Existing studies have reduced the total amount of rewards by employing a game theory-based approach [3][4] and by applying the reverse auctions [4][5]. These studies, however, focus only on the monetary incentive, thus the rise of rewards cannot be avoided when the burden of sensing tasks increase.

In this paper, we propose a novel incentive mechanism based on gamification [6] for participatory sensing. The proposed incentive mechanism allows users to get not only monetary rewards but also satisfaction (i.e., a sense of accomplishment) by obtaining badges and prizes in ranking from gamification. Gamification will make users participate even in heavy sensing tasks with lower rewards, thus the total amount of rewards paid by the client could be reduced.

We target a participatory sensing system, which sends a request indicating reward points and a sensing task to users nearby each of given PoI. Each user who receives a request can earn the designated reward points by completing the sensing task. Here, the probability of each user to participate in the sensing task depends on the reward points, content of the sensing request, the user's enthusiasm for gamification, and so on. As for the client, it is desirable that all PoI are sensed and the total amount of reward points paid is minimized. However, if there are small number of users exist near a PoI or the requested sensing task is too heavy, no one might participate in the sensing task. To avoid such situations, the client needs to offer sufficiently high reward points for each sensing task, taking into account the number of users nearby the PoI and the burden of the sensing task. In our proposed method, to suppress rapid rise of reward points, we introduce a novel incentive mechanism employing gamification in addition to monetary rewards. The proposed incentive mechanism employs a *status level scheme* which classifies users into several status levels depending on earned reward points, like airline companies' mileage services, so that users with higher status can earn more reward points than those with lower status for each sensing task. We also introduce a *ranking scheme* that sorts users in decreasing order of earned reward points. This ranking is shared among all users. In addition, we introduce a *badge scheme* where users will get a badge and earn the corresponding bonus points when they satisfy a condition predetermined for the badge. It is expected that these gamification-based schemes will encourage users to actively participate in sensing tasks even when the reward points are rather small.

To realize the proposed participatory sensing system, we need probability of each user to participate in sensing tasks depending on reward points, burden of sensing, whether gamification is introduced or not, etc. To derive the probability distribution of users' participation in sensing, we implemented a prototype of a participatory sensing system with gamification using the foursqure API and conducted experiments with 18 users for 30 days. As a result, we confirmed that gamification mechanisms increase the participation probability from 53% (without gamification) to 73% on average, leading to more successful sensing of PoI with smaller number of users.

[1]http://weathernews.com/global.html
[2]http://www.honda.co.jp/internavi/LINC/about/

II. Related Work

In this section, we review existing studies on incentive mechanisms for participatory sensing, and give an introduction to gamification, which is used by our proposed mechanism.

A. Incentive Mechanisms

In [3][4], the game theory used to derive the minimum rewards that the client should pay for the accomplishment of the sensing tasks. They modeled interactions between users and the client as a two-stage Stacklberg game [9]. By following this model, the client can determine an optimal value of the total rewards paid by predicting the decision making of each user.

In [4][5], an incentive mechanism based on the reverse-auction concept was proposed. In a reverse-auction, the user who bids with the least reward obtains a right to participate in a sensing task. As a result, the client can suppress the total rewards paid for the users.

In general, a client needs to pay higher rewards when requesting users to participate in high burden sensing tasks. However, the afore-mentioned studies focus only on the monetary incentive, thus the client cannot suppress the rise of the total rewards paid when the burden of sensing tasks increases.

B. Gamification

Gamification [6] is a technique to motivate users to do some tasks in a non-gaming context by employing game mechanisms. Examples of game mechanisms include *level scheme* based on points, *badges*, *mission*, and *visualization* of ranking, etc. The users gain a satisfaction (i.e., a feeling of accomplishment) when using services with gamification. Application examples of gamification are Foursquare[3], and the mileage systems of airline companies[4]. Furthermore, usefulness of gamification is shown in some studies which tackle the image-labeling problem [7] and the training problem in major incident triage [8].

Gamification gives users mental motivation. Our proposed incentive mechanism uses both monetary incentive and gamification to motivate users to participate in sensing tasks. Therefore, it is expected that our method could reduce the total rewards paid by the client compared with the methods which employ only the monetary incentive.

III. Assumptions on Client and Users

We assume that there are a client and multiple mobile users. The client issues *sensing requests* to ask the users to participate in sensing tasks through the Internet. We suppose sensing requests such as "I want to confirm if there is a vacant seat in a cafeteria near Tokyo station," "I want to know the degree of congestion in Highway 101 near Golden Gate Bridge," etc. The users decide whether to participate in a sensing task or not within a certain probability. Since timely collection of sensed data is important for participatory sensing in many cases, the users need to complete their sensing tasks within a time constraint, which is specified by the client in advance.

[3]https://foursquare.com/

[4]http://www.jal.co.jp/en/jalmile/flyon/status.html

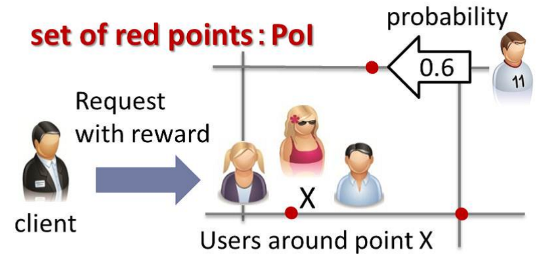

Fig. 1. The overview of our participatory sensing system

Fig. 1 shows an overview of our target participatory sensing system. The assumptions on the clients and the users are given below.

Assumptions on the client

- The client has a device that can connect to the Internet.
- The set of locations that the client is interested in is denoted by PoI. To issue a sensing request, the client specifies the PoI and a content m (i.e., sensing task) for each location of PoI.
- For each location $s \in PoI$, the client can know the set of users U_s near s.
- The client selects a subset of the users $U'_s \subseteq U_s$.
- For a location s, the client sends a sensing request $M_s = \{m, r, l\}$, which contains the content m, the reward points r, and the time limit l, to each user $u \in U'_s$.
- The client receives the sensed data for each location in the PoI from the users.
- The sensing task is completed when all the data for all the locations in PoI are received by the client within the time limit l.

Assumptions on users

- Each user has a mobile phone with sensors, which can connect to the Internet.
- For each pair of a user u and a sensing request M_s, the participation probability $p(u, M_s)$ of u is given.
- If a user determined that he/she participates in a sensing task, the user needs to send the sensed data that conforms to the content of the sensing request to the client within the time limit.
- Each user receives the reward r from the client after the user achieves the sensing task.

IV. Incentive Mechanism

In the incentive mechanism proposed in this paper, the users participating in sensing tasks receive a reward from the client. Each reward is earned as *points* that can be stored every time a user senses a location in PoI, and the user can exchange their points with the corresponding amount of money at any time. In the following, we introduce the three types of gamification-based schemes used in our incentive mechanism.

Level Scheme

Each user is categorized into one of several status levels based on the points earned by the user. The users with higher level earn more points than the users with lower levels even if they have completed the same sensing task. By participating in many sensing tasks and earning many points, the users can reach the upper level and earn more points at the next time they participate in a sensing task. Thus, the users have an incentive to actively participate in sensing tasks in order to increase their level.

Badge Scheme

When a user who participated in several sensing tasks satisfies a certain condition, the user can obtain a badge, which represents a title of respect on the community, with points based on the degree of difficulty of satisfying the condition. Typical examples of the condition for obtaining badges are like "the total number of participation has been reached a pre-defined number of times," or "the user has participated a pre-defined number of times at a specific city," etc. Each user can confirm own badges and badges of other users through a Web page. By this scheme, users are motivated to obtain badges and to earn more points, and also for their mental satisfaction.

Ranking Scheme

In the proposed incentive mechanism, the system maintains the ranking that is based on the amount of points stored by each user. Since this ranking can be accessed by anyone through the Internet, the users are motivated to participate in sensing tasks in order to gain mental satisfaction by making their position in the ranking as high as possible.

V. Reward Points Minimization Problem

In this section, we formalize the problem that minimizes the reward points to be paid by the client and describe the basic idea to solve the problem.

A. Problem Definition

Let us consider the situation where the client sends a request of a sensing task M_s for $s(\in PoI)$ to a set of users $U'_s(\subseteq U_s)$. The reward points $r(u)$ to be paid by the client to each user $u \in U'_s$ is defined as:

$$r(u) \triangleq \beta(lv(u))r_0, \tag{1}$$

where r_0 is the *standard reward points*, which is presented to all users who receive the request for s in order to ensure fairness among the users, $lv(u)$ is the user's level determined based on the stored points and is an element of a set of levels $LV = \{1, 2, ..., n\}$, and $\beta(lv(u))$ is the preferential weight to the points earned and satisfies $\beta(i) < \beta(j)$ iff $i < j$.

We assume that the client can know the participation probability $p(u, M_s)$ of each user for the sensing task M_s. The probability that the location s is sensed by at least one user is denoted by $P(U'_s, M_s)$ and is calculated as:

$$P(U'_s, M_s) = 1 - \prod_{u \in U'_s} (1 - p(u, M_s)). \tag{2}$$

Then, the expected value of the reward points to be paid by the client for the sensing task M_s is calculated as:

$$E[R(M_s)] = \sum_{u \in U'_s} p(u, M_s)r(u). \tag{3}$$

Since the client needs to send requests for all of the locations contained in PoI, the expected value of the total reward points to be paid by the client is calculated as:

$$E[R(PoI)] = \sum_{s \in PoI} E[R(M_s)]. \tag{4}$$

Each location in PoI must be sensed by the probability that is equal to or larger than a certain threshold. For this requirement, we introduce a threshold denoted by $\alpha(0 < \alpha < 1)$ and enforce the following constraint:

$$\forall s \in PoI, \alpha \leq P(U'_s, M_s). \tag{5}$$

Now we can formulate the optimization problem that minimizes the expected value of the total reward points to be paid by the client for a set of users U'_s, each sensing location for each user in U'_s, and the standard reward points r_0, as follows:

$$\begin{aligned} &\textbf{minimize } E[R(PoI)], \\ &\qquad \textbf{subject to } (5). \end{aligned} \tag{6}$$

B. Basic Idea to Solve the Problem

In this subsection, we describe the basic idea to solve the problem defined above. In Equation (6), since it is necessary to minimize the total reward points while ensuring the probability of successful sensing, we adopt an approach that selects users in the order of decreasing *performance per cost* (also called CP hereafter), which is the ratio of participation probability to reward points and is defined as:

$$CostPerformance(u, M_s) \triangleq \frac{p(u, M_s)}{r(u)}. \tag{7}$$

By selecting the users with higher performance per cost, the threshold α should be satisfied with a smaller number of users and less required reward points.

In the following, we give an example of selecting users from a set of users $U_s = \{u_1, u_2, u_3\}$ located near s for given parameters of users as shown in Table I.

TABLE I. Parameters of users

User	$p(u, M_s)$	$r(u)$	CP
u_1	0.5	10	0.05
u_2	0.6	15	0.04
u_3	0.7	20	0.035

Suppose that the case where $\alpha = 0.7$. First, the user u_1 with the highest CP is selected. Then, the probability that the location s is sensed is 0.5, which is less than the threshold, thereby we continue the process of selecting users. Next, the user u_2 is selected, because u_2 has the highest CP among the remaining users. Then, the probability that the location s is sensed becomes $1 - (0.5 * 0.4) = 0.8$. Since this probability is more than the threshold, we finish the process of selecting users, and the expected value of the total reward points to be paid by the client is calculated as $(10*0.5)+(15*0.6) = 14$.

VI. Evaluation

In our system, to select the optimal set of users, the client needs to estimate the participation probability $p(u, M)$ for a sensing request M in advance. The participation probability of a user depends on the factors such as the burden of a sensing task, the reward points, and the user's enthusiasm to gamification. To investigate the impact of the aforementioned factors on participation probability, we developed a prototype participatory sensing system and conducted an experiment with multiple subjects who are asked to participate in various sensing tasks with varieties of settings on the content of sensing requests, on the reward points, and on the availability of gamification schemes. After the experiment, we used questionnaires to evaluate our gamification schemes in terms of their effectiveness in motivating users to participate in sensing. Using the participation probabilities obtained from the experiment, we evaluated the effectiveness of our gamification schemes by comparing the number of users required by systems with and without gamification schemes to satisfy the constraint defined in Section V.

A. Experimental Setup

We implemented a participatory sensing system called *NAIST Photo*, which was developed as a foursquare application. Using the system, we conducted a 30-day experiment with 18 subjects. Throughout the experiment, 481 sensing requests were issued. The system automatically selected the PoI of each sensing request in regions that the subjects visited — namely Japan, Taiwan, and Europe. The PoI were classified into types such as restaurants, school facilities, train stations, and so on. The total numbers of sensing requests issued for each type and region are shown in Tables II and III, respectively.

TABLE II. The number of sensing requests issued for each PoI type

PoI Type	Number of Requests
school	167
station	153
restaurant	48
outdoor	46
shop	40
entertainment	17
book and video	7
bar	3

TABLE III. The number of sensing requests issued for each region

Region	Number of Requests
Japan	413
Europe	42
Taiwan	26

In NAIST Photo, when a user arrives at a PoI, the user registers the PoI through foursquare. This registration process is called *check-in*. The check-in information is forwarded to the NAIST Photo server. The server then sends the user an email that contains the content of the sensing request related to the PoI where the user checked in, the reward points, and the time limit. The user can complete the sensing task by sending the sensed data that conforms to the content of the sensing request to the server within the time limit. If the task conforming to the request is completed within the time limit, the user earns the specified reward points. In the experiment, for all sensing requests, we set the time limit to 15 minutes. Fig. 2 shows the overview of NAIST Photo.

In the experiment, the users can earn reward points by participating in sensing tasks. Reward points can then be exchanged at any time to Japanese Yen with a conversion ratio of 1:1. There are two types of sensing requests: (i) a sensing request with both a monetary incentive and a gamification-based incentive and (ii) a sensing request with only monetary incentive. The former is called an *SP request*, while the latter is called a *normal request*. Each user has two accounts for reward points: *SP points* earned by completing SP requests and *normal points* earned by normal requests. After each check-in with foursquare, the user receives a sensing request via e-mail. The type of the sensing request is selected randomly.

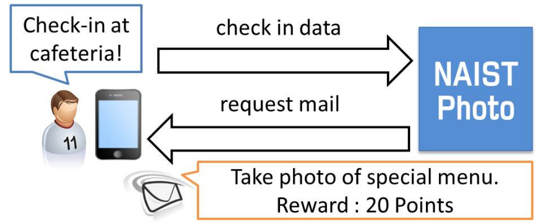

Fig. 2. The overview of NAIST Photo system

When a user completes an SP request a pre-defined number of times for each PoI type shown in Table II, the user obtains a badge based on the PoI type. The user also earns SP points corresponding to the number of SP requests completed, as shown in Table IV. The user's level and the position in the ranking are determined based on the SP points earned by the user. To reach the level lv, the user needs to earn SP points greater than or equal to $low(lv)$, which is shown in Table V. As shown in Table VI, based on the value of the coefficient $\beta(lv(u))$ in Equation (1), the users with higher levels are prioritized more than the users with lower levels in terms of the SP points to be earned in the next SP request. The standard reward points r_0 in Equation (1) is set to 10 points for all SP requests. Users can check their earned points, obtained badges, current level, and ranking at anytime using the Web interfaces shown in Figs. 3, 4, and 5.

TABLE IV. SP points to be earned by SP requests

Number of Times Completed	SP Points
1	10
5	20
10	30

TABLE V. Required SP points to reach each level

Parameter		Value
	lv	
$low(lv)$	1	-
	2	100
	3	300
	4	600
	5	1000

TABLE VI. The values of $\beta(lv(u))$ for each level

Parameter		Value
	lv	
$\beta(lv)$	1	1.0
	2	1.2
	3	1.5
	4	2.0
	5	3.0

For normal requests, users can earn normal reward points when they complete sensing tasks. However normal points do not affect the status levels, badges, or rankings of users. The reward points earned for a normal request is determined at random as 15, 20, 30, or 40 points.

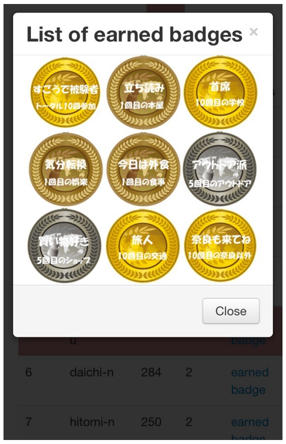

Fig. 3. List of badges gained

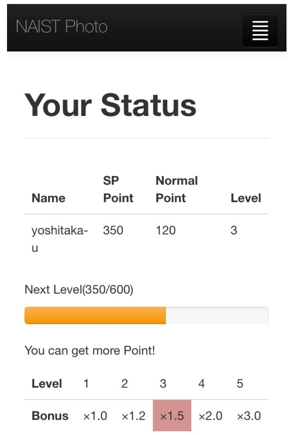

Fig. 4. Current level and points earned

Fig. 5. The ranking

B. Results

In the experiment, we investigated the impact of factors such as gamification schemes, reward points, and content of sensing requests on the participation probabilities of sensing tasks. Fig. 6 shows the participation probabilities for SP requests and normal requests of seven users who received 20 or more requests. Fig. 7 shows the participation probabilities compared to reward points. Table VII shows the participation probabilities for sensing requests with differing content, from which 20 or more samples exist regardless of the type of sensing request.

In Fig. 6, we see that the participation probabilities of SP requests are higher than those of normal requests for all seven users. This indicates that the gamification schemes motivated users to participate in sensing tasks to some extent. We also see individual differences in the participation probabilities between the two types of sensing requests from among the users. This indicates that the degree of enthusiasm for gamification is different among the users. For example, in Fig. 6, users B, D, and G have higher degrees of enthusiasm for gamification than others, because of the large disparities between the participation probabilities of their SP and normal requests.

Fig. 7 shows that for normal requests, the participation probability does not change depending on the reward points in the range [15:40]. In contrast, for SP requests, the participation probability increases as reward points increase. However, for SP requests, since the users with higher status levels can earn more reward points and users with higher participation probabilities tend to reach higher levels, the amount of reward points does not always have a large impact on the participation probability. Table VII shows that participation probability varies depending on the content of sensing request, that is, the degree of difficulty of completing a sensing task affects the participation probability.

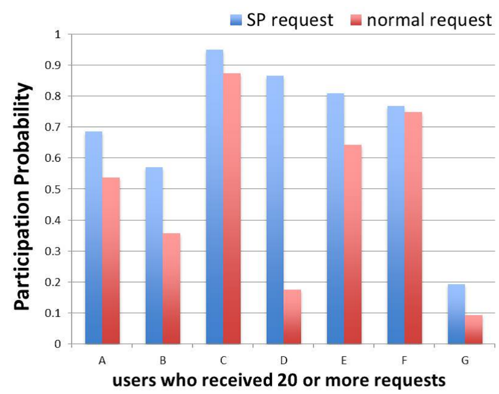

Fig. 6. Participation probabilities among users

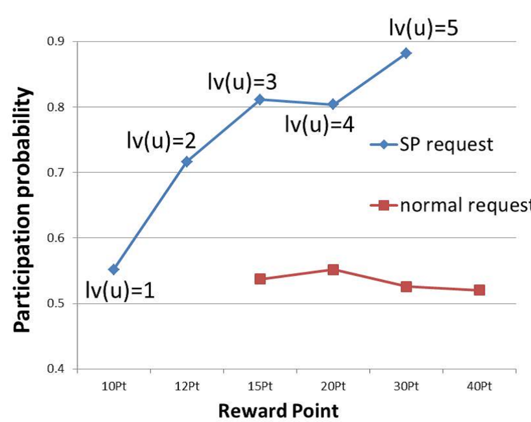

Fig. 7. Participation probability vs. reward points

C. Subjective Evaluation

After the experiment, the subjects were given a questionnaire on why they participated in SP requests. As shown in Table VIII, we prepared the five answers of participation in SP requests for the questionnaire. The subjects were asked to sort the answers in ascending order, based on their impression during the experiment.

Table VIII shows the number of times the subject chose an answer as first or second. From the table, we see that the status level scheme is the most effective among our gamification schemes. We also see that the ranking scheme

TABLE VII. PARTICIPATION PROBABILITIES OF SENSING REQUESTS WITH DIFFERENT CONTENTS

Content of Sensing Request	Probability	
	SP	Normal
Take photo of landscape	0.93	0.67
Take photo of staying condition of laboratory	0.91	0.75
Take photo of parking usage	0.89	0.69
Take photo of shop's exterior	0.83	0.63
Take photo of train	0.69	0.48
Take photo of restaurant's limited menu	0.56	0.48
Take photo of congested level of facility	0.36	0.5

TABLE VIII. NUMBER OF USERS WHO CHOSE THE ANSWER AS THE FIRST OR SECOND PRIMARY REASON OF PARTICIPATION IN SP REQUESTS

Answer	First	Second
Everybody participated	6	3
Wanted to reach higher levels	4	4
Wanted to increase the position in the ranking	2	3
To earn reward points	1	1
To obtain badges	0	1

is effective, because some of the subjects chose the reasons "Everybody participated" or "Wanted to increase the position in the ranking." In contrast, the impact of the amount of reward points on participation probability is rather small, because only one of the subjects chose the answer "To earn reward points." In addition, in Table VIII, we could not confirm the effectiveness of the badge scheme. One possible reason is that we did not explicitly inform the users of the condition for obtaining badges in the system.

D. Effectiveness of Gamification Schemes

We also evaluated the effectiveness of the gamification schemes based on the result of the experiment. Table IX shows the average participation probability of all subjects in SP and normal requests. Based on Table IX, we calculated the number of users required to sense a PoI satisfying the constraint (6) for different values of the threshold α. Table X shows that the required number of users for $\alpha = 0.90, 0.95$, and 0.99. Note that, in this evaluation, we assume that there is only one location in PoI.

TABLE IX. AVERAGE PARTICIPATION PROBABILITY OF ALL USERS

Type of Sensing Request	Average Participation Probability
SP request	0.73
Normal request	0.53

TABLE X. NUMBER OF USERS REQUIRED FOR SENSING OF A POI SATISFYING THE CONSTRAINT (5)

Threshold α	Required Number of Users	
	SP Request	Normal Request
0.90	2	3
0.95	3	4
0.99	4	6

Table X suggests that the success probability of sensing a PoI increases when gamification schemes are available, because the number of users required is smaller in SP requests than in normal requests. That is, using the proposed gamification schemes, the client can accomplish PoI sensing at a higher probability even if the number of users near each PoI is small.

VII. CONCLUSIONS

In this paper, we proposed a novel incentive mechanism based on gamification for participatory sensing. The proposed incentive mechanism uses (1) a status level scheme, (2) a ranking scheme, and (3) a badge scheme based on gamification to attract users for sensing. We formulated the problem of sensing given a PoI with minimal reward points and devised a heuristic algorithm for deriving the set of requesting users and reward points for each sensing task. The algorithm requires the participation probability distribution of users and reward points. Thus, we implemented a prototype of a participatory sensing system with the proposed incentive mechanism and conducted an experiment with 18 users spanning a duration of 30 days. As a result, we confirmed that gamification increased the participation probability from 53% (without gamification) to 73%.

For future work, we plan to investigate the impacts of reward points and time to deadline to participation probability distributions in greater detail. We will also construct an accurate participation probability distribution model based on the result and conduct experimental validations of the proposed incentive mechanism through larger scale simulations. Furthermore, we will investigate whether the proposed incentive mechanism can actually reduce the total reward points paid by the client compared to a case without gamification schemes.

VIII. ACKNOWLEDGMENT

This work was supported in part by the JSPS KAKENHI Grant Number 25280031 and SCOPE (Strategic Information and Communications R&D Promotion Programme).

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