Mobile Information Systems

Mobile Collaborative Technologies and Data Science for Smart Systems

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Editorial Board

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Editorial

Mobile Collaborative Technologies and Data Science for Smart Systems

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The society, technologies, and sciences undergo a rapid and revolutionary transformation towards ambient intelligence (AmI). Systems that technologies design, create, and utilize are growing in their smart capabilities and ease collaboration among people while learning and working for benefits of the human being (Internet of things (IoT), cloud computing, smart grids, etc.). Mobile systems could enhance the possibilities available for designers and practitioners. However, a number of requirements must be fulfilled, and complexities resolved before such systems generate reliable, accurate, and timely information which is really trusted and appreciated by users. The main source and asset for making smart systems are data, which our information age made easily accessible. The next main challenge we face is to effectively and efficiently extract knowledge from huge amounts of data from heterogeneous sources to make the systems self-contained and autonomous. To ensure data quality, accurate results and reliable (visual) analysis support in human-centered artificial intelligence applications, additional collaboration issues, and privacy and security requirements should be addressed within a throughout verification and validation management. Major industrial domains are on the way to perform this tectonic shift based on big data, collaborative technologies, smart environments (SmE) supporting virtual and mixed reality applications, multimodal interaction, and reliable visual analytics.

Research on AmI and SmE in urban and rural areas presents great challenges: AmI depends on advances in sensor networks, artificial intelligence, ubiquitous and persuasive computing, knowledge representation, and spatial and temporal reasoning. SmE builds upon embedded systems, smart integration, and an increasing fusion of real and virtual objects in the IoT. Customized sensor networks are used to detect human behavior and activities; evaluation logic and process mining are needed to replace people's cognitive abilities in ambient assisted living (AAL) applications, detecting recurring activities without being noticed and hurting their privacy. As digitization has become an integral part of everyday life, data collection has resulted in the accumulation of huge amounts of data that can be used in various beneficial application domains. Effective analysis, quality assessment, and utilization of big data are key factors for success in many business and service domains, including the domain of smart systems. However, a number of challenges must be overcome to reap the benefits of big data. As big data handles large amounts of data with varying data structures and real-time processing, one of the most important challenges is to maintain data security and adopt proper data privacy policies. In general, there is a strong need to gain information of interest from big data analysis and, at the same time, prevent misuse of data so that people's trust in digital channels is not broken. To ensure data quality, accurate results and reliable analysis support in health care applications, additional collaboration issues, and privacy and security requirements are addressed within a throughout verification and validation management.

Our time is an exciting period in mankind evolution. We see many research efforts are currently being done to address the challenges we mention above. Certainly, once they mature, they will substantially solve the obstacles that prevent AmI becoming a significant step towards the well-being of the human beings.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

A Chatbot System for Mental Healthcare Based on SAT Counseling Method

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In recent years, mental health management of employees in companies has become increasingly important. As the number of psychotherapists is not enough, it is necessary for employees to be able to keep their mental wellness on their own. A self-guided mental healthcare course using VR devices has been developed, and its stress reduction effect has been validated previously. This study proposes a new version of the course using smartphones and chatbots to enhance its convenience for use and to maintain user motivation for daily and repeated use. The effects of stress reduction and motivation maintenance were acknowledged.

1. Introduction

Research of online courses on mental healthcare has become active, as the importance of keeping good mental health has been widely recognized. Keeping employees' good mental health in companies has even been legislated recently in Japan. This resulted in sudden increase of the number of potential clients for mental counseling most of whom are not in sick, whereas the number of psychological experts or counselors who usually carry out counseling does not increase. To cope with this issue, it is in high demand to provide the means to take care of their mental health by themselves and to utilize the data of employees' mental health for more effective collaborative support by experts.

In order to realize such means, firstly, Kamita et al. [1–3] started to have converted the SAT (structured association technique) counseling method [4] into a digital content and developed a self-guided mental healthcare system with wearing a VR (Virtual Reality) head-mounted display (HMD) and eventually obtained good stress relief evaluation.

However, when using VR in a company, it is assumed that a dedicated HMD will be installed in a shared location, such as a healthcare room or relaxation room. Due to the limited location available, it was impossible for employees to use anytime when they wanted to reduce their daily stress or solve problems, and there were problems in their practicability. In the SAT method of therapy, visual stimulation with images encourages intuitive associations and inspiration, and the effect is established by frequent stimulation with repeated viewing of the images [5, 6]. Continuous use of the self-guided mental healthcare course is important, but motivation to promote the use of course for employees who do not necessarily actively engage in self-care is a challenge.

Therefore, we propose a self-mental healthcare course using chatbot (Chatbot course) on LINE, a SNS platform that is commonly used as a communication tool using a widely used smartphone terminal from the viewpoint of practicality and motivation. In this study, we conducted a comparative intervention experiment with the Chatbot course and non-chatbot course built as web contents (Web course) to investigate the efficacy of chatbot in a self-guided mental healthcare course from the two perspectives of whether the Chatbot course performed on a smartphone without the use of VR would also have a stress reduction effect and whether chatbot induction would enhance user motivation.

2. Related Works

2.1. Use of a Smart Phone for Mental Healthcare. In recent years, research studies have been conducted to apply psychotherapy to digital contents and use them with mobile devices as a complementary tool for treatment and counseling, or a training tool. Research studies on one of the major psychotherapy, cognitive behavioral therapy (CBT), have especially progressed [7–9], and there are many commercially available mobile applications [10]. In the CBT session, the counselor modifies the negative cognitive distortion of the client through dialogue with the client to encourage positive thinking and behavioral change. After the session, clients are given a home work called the diary or column method in which they write their daily thoughts and the counselor analyzes them in the next session for use in therapy. The CBT application is mainly digital content of this homework part and does not cover the entire CBT process. Therefore, it is hard for users to realize effect of stress reduction or stress problem solving in one-time use. While it may be an effective auxiliary tool for professional support, in case of using as a self-guided tool, users are required to be fully aware of the program and to maintain a high level of motivation to continue using it.

The cognitive bias modification (CBM) approach has attracted attention as a counseling technique, mainly in Europe and the United States, and is being used extensively in research and psychology [11]. Cognitive bias refers to the assumption that people with high levels of anxiety or depression are more likely to negatively interpret vague information that can be interpreted positively or negatively. CBM-supported smartphone applications include Mood Mint, a training tool to reduce anxiety and depression [12]. In the Mood Mint, a screen displays a smile and three negative faces, all four of which are scored by immediately tapping the smile. Repeated implementation may increase the speed of response to positive images and reduce the focus on events with negative cognition. However, one-time use of Mood Mint is not intended to reduce stress or solve problems, so the user will continue to train repeatedly without knowing the stress-reducing effect. As with CBT applications, users themselves are required to maintain motivation. Mood Mint uses a system to provide point incentives for the token economy [13] as a method to encourage its use.

Mindfulness stress reduction using meditation (MBSR) and mindfulness cognitive therapy (MBCT) are also increasingly used in research and psychological clinics in Europe and the United States [14, 15] and are widespread in Japan [16]. In the United States, changes in brain function were measured after 8 weeks of meditation, confirming the effectiveness of meditation [17]. MBSR refers to the "state of focus here," which is conducted in groups and individuals in combination with sedative meditation, walking meditation, and breathing techniques. Research and development on digital content of meditation has been advanced [18], and "Headspace" [19] is available in the smartphone application. In this application, courses are provided for each purpose, such as anxiety and depression, and the user performs 10 to 30 10-minute sessions per course in accordance with voice guidance. However, because some of the functions of therapy are implemented, and the main objective is to guide meditation, a single practice is not implemented with a sense of the effectiveness of stress reduction or problem solving. Thus, as with CBT and CBM applications, users themselves need to maintain high motivation. Some studies have found that meditation poses a risk of increasing discomfort and pain [20], and some aspects of the study aim require careful handling as a self-care tool.

2.2. Mental Healthcare Using a Chatbot. Chatbot, a program that automatically talks through texts and voices, has been developed since ELIZA [21] was developed in 1966.

In 2016, the development environment was opened as a messaging function of two social networking service platforms, Facebook ("Facebook" is a registered trademark of Facebook, Inc.) [22] and LINE [23], which enabled us to offer chatbots through SNS.

Chatbots in the field of mental health care have been developed to support interpersonal skills as a training component of a depression treatment program rather than therapy [24]. In addition, chatbots specialized to cope with stress problems have been also studied. Based on the Perceptual Control Theory, a self-help program MYLO in the form of a chatbot has been developed. In comparison with ELIZA on MLYO effectiveness, MYLO and ELIZA led to relief of pain, depression, anxiety, and stress and MYLO was thought to be more useful for problem solving [25].

Besides that, an automatic conversational chatbot "Woebot" using Facebook messenger has been developed based on CBT [26]. As a result of an evaluation experiment using "Woebot" for college students, it was found that the participants' depressive symptoms were significantly reduced. They commented that using "Woebot" was more receptive than traditional therapies. However, same as the CBT application mentioned above, Woebot does not cover the whole process of CBT but mainly provides programs of psychoeducation for stress coping. Users are required to maintain their motivation for a certain period of time before the achievement can be realized.

This study aims to realize a self-guided mental healthcare tool that assumes the use of a large number of employees with varying degrees of motivation to self-care. This program is to provide self-care measure when experiencing stress, to realize the effectiveness of stress reduction even in one-time use, and to realize a tool that can be used continuously to solve stress problems on a daily basis.

3. SAT Method

3.1. Overview of SAT Method. The SAT method is an interview-style counseling and therapy techniques developed by Munakata [4]. Unlike conventional counseling technique, which uses language stimuli obtained through dialogue with a counselor to act on thoughts, the SAT uses visual stimuli obtained by viewing image images to quickly identify unrecognized real feelings and desires by functioning associations, inspiration, and intuition. The SAT method consists of several techniques. Techniques to clarify the problem and characteristics of the client and to motivate the client to solve the problem include temperament coaching method, health coaching method, and emotional clarification method to clarify intrinsic emotional needs. Techniques for reducing stress and solving problems include SAT imagery method, which consists of emotional stabilization therapy, behavioral modification therapy, problem solving therapy and so on. The counselor reviews the client's main complaint, stress conditions, psychologic characteristics, and progress and effectiveness of counseling, selecting and administering appropriate techniques. We developed a digital-content technique using the emotional stabilization therapy.

3.2. Emotional Stabilization Therapy. The emotional stabilization therapy is a technique that can be used to reduce or solve daily stress problems, such as current problems, problems in the past, and alleviate physical symptoms, and can be administered for oneself if trained during counseling or by a training seminar. The counselor throws structured questions (Table 1) to the client, who then replies or enhances his or her image in his or her mind, and proceeds with the treatment. First, the person should be reminded of a stress situation, and aversive feelings associated with discomfort may trigger the sensation of discomfort by the body, such as a stomach stick or chest stuffiness. This is followed by focusing attention on body discomfort and providing an image of mild warm lights printed on paper media (Figure 1), which allows the client to select a comfortable image and to recall an image of the light that is surrounded and healed by the body discomfort (the light imaging method) [5]. In addition, a list of smile face images that symbolize joy is presented, allowing the client to select the images that the client likes, and to recall the sense of security and safety that the client enjoys and protects. Hence, self-affirmation and stress reduction can be achieved by encouraging the client to recognize his or her own persistence and captivity, changing his or her sense of perception to change the meaning and interpretation of the problem, and allowing the client to anticipate a constructive outlook for solving the problem (the surrogate representation imaging method) [5].

4. Digital-SAT Method

In the emotional stabilization therapy, the counselor checks the treatment effect from conversation with the client, color of face, gestures, etc., asks the client condition, induces eye closure, and returns to the previous procedure if the effect is judged to be insufficient. The digital-SAT method enables the self-guided mental healthcare based on the SAT method without the guidance of the counselor using the system. In the digital-SAT method, original questions for the emotional stabilization therapy were subdivided to provide one question at a time, and the questionnaire was simplified (Table 1). The Chatbot course based on this digital-SAT method was developed.

4.1. Structure of Digital-SAT Method. Based on the structure of the SAT method, the composition and procedures of the digital-SAT method are classified into three categories: (1) to clarify the problem and characteristics of the client and to motivate the client to solve the problem (assessment part), (2) to reduce stress and solve problems (solution part), and (3) to learn psychological knowledge for maintaining mental wellness and increasing resilience against mental disorder (learning part). In this study, we deal with assessment part and solution part.

4.1.1. Assessment Part. In the assessment part, a mental characteristic check test (Table 2) is conducted, using the SAT six psychological scale to measure the mental condition and characteristics and record the changes before and after the use of the course.

4.1.2. Solution Part. The solution part follows the digital-SAT method questions in Table 1. First, the stress currently held (Q.1-1, 2, and 3) is recalled, and the aversion to the stress is illustrated by color and shape (Q.2-1, 2), which stimulates perception of body discomfort and is clearly visualized by concrete numerical images of the degree of stress (Q.3-1, 2, and 3). Next, the physical discomfort is relieved by using light images (Q.4-1 and 2), and a smile face image is used to foster a sense of security and safety (Q.5-1 and 2), and stress levels are reduced (Q.6-1). Subsequently, conditions with reduced stress responses can provide positive personality images and encourage the perception that different ways to catch stress problems are encountered (Q.7-1, 2, and 3). In addition, by choosing one of the most worrisome smile face images and imagining messages that the person with the smile face gives to user's self, the user can remember the words the user needs in the context of stress (Q.8-1 and 2) and finally, confirm and terminate the extent to which the initial stress problem was encountered (Q.9-1, 2, and 3).

5. Implementation of the Chatbot Course

In the conventional self-mental care method, withdrawal of users is the biggest problem [35, 36]. Even in the SAT method, frequent stimulation of smile face images can improve the mental health improvement effect and the practice of course repeating is important. To solve this problem, we devised the Chatbot course using a chatbot with conversational guidance. In this research, we adopted LINE which is widely used as a chat tool in Japan and developed a self-mental care system for practicing the Chatbot course.

5.1. System Configuration. Figure 2 shows the configuration of this system. The numbers in the figure show the flow of data processing. As a chat tool, we provide a chatbot service on the LINE application of the most popular SNS service in Japan. A chatbot application server is built on a commercial HEROKU ("Heroku" is a registered trademark of Heroku, Inc.) server

Table 1: Question items comparison defined in SAT and Digital-SAT.

Q.	SAT	Q.	Digital-SAT
1	Do you have any problems that you would like to solve with your current stress problem? (If unanticipated, chose one item from the stress source checklist) Which of the following is to be taken up this time?	1-1 1-2 1-3	Remember that you feel stressed now What is it (select from the stress source checklist)? What are the stresses? (5-point scale)
2	Please close your eyes and think the stress problem. If you represent an aversive image or feeling of the stress in color and shape, which color do you image? Red, brown, or black etc.? Which is its shape, such as square, sharp, etc..?	2-1 2-1	Please close your eyes and think the stress problem. If you represent an aversive image or feeling of the stress in color, which color do you select? (Select from options) If you represent an aversive image or feeling of the stress in shape, which shape do you select? (Select from options)
3	Please image something with the selected color and shape and tell me at which your body part you feel the body discomfort, "head, face, throat, etc.", and how you feel around the body part, "heavy, painful, choked, etc.". And tell me the level of stress caused by the body discomfort. Please answer by percentage between 0% and 100%	3-1 3-2 3-3	When you image something with the selected color and shape, which your body part you feel the body discomfort? (Chose from options) How do you feel around the body part? (Chose from options) How much is your stress level by percentage? (Select from options from 0% to 100%)
4	(Show a list of light images) which light image may make your body discomfort relaxed and decrease your stress level to 0%? Please answer with inspiration. You can select images as many as you want	4-1 4-2	Which color may make your body discomfort relaxed? (Select from options) When you are covered by the color, how many percentages will be? (Chose from options)
5	(Show a list of smile face images) when you look at the smile face images list, while looking at the selected light image, which face are coming into your eyes or do you think you like? Once you're looking at all smile faces (if the client cannot select it, change your word, for example, "which face does you make warm or bright?")	5-1 5-2	Select smile face images which are coming into your eyes or you think you like. (Chose from options) How do you feel surrounded by the selected people? Are you healed or relaxed? If your feeling does not change, please change the images
6	If you look at the selected smile face images, how many percentages will the level of your stress be reduced? If the percentage become 0%, you adopt the images. (If the percentage does not reach 0%, ask the client to repeat Q4-Q5 on the remaining percentage to achieve 0%.)	6-1	How many percentages will the level of you stress be reduced? (Select from options from 0% to 100%)
7	If you look at all the smile face images you found here, what type of personality can you imagine yourself? Big-hearted? Bright? Positive? If you have such personalities, what kind of behavior do you do in the stress situation? What would you expect results of the coping? (Free answer)	7-1 7-2 7-3	When you look at these smile face images, what type of personality can you imagine yourself? (Select from options) If you have such personalities, what kind of behavior do you do in the stress situation? If you do such a behavior, is it likely work?
8	Which is the best one of you selected face images? If you look at the one, what messages is the person likely to give you? (Free answers)?	8-1 8-2	Which is the best one of you selected face images? What messages is the person likely to give you?
9	If you look at all the smile face images that you found here, how does your feeling to the stress problem first thought become? If the client can select "unworried," "comfortable," "happy," etc., the therapy is completed	9-1 9-2 9-3	When you look at all the smile face images that you found here, how does your feeling to the stress problem first thought change? (Select from options) When you were covered by the light image, your stress percentage is xx %. How about now? (Select from options from 0% to 100%) How much does your stress level become? (5-point scale)

[37], and LINE server is provided by LINE. And, the Messaging API [38] program provided by LINE is used for servers' linkage. The Messaging API is an application programming interface that allows data to be exchanged between the chatbot application server and the sending and receiving server of LINE.

5.2. Start Screen. The user adds the LINE @ account of the chatbot. Select the added chatbot from the list on LINE's "Friends" screen and press the "Talk" button on the next screen to display the start screen (Figure 3). The function menu at the bottom of the screen has three buttons, "Start," "Questionnaire," and "Help". Click "Start" to start the course. When "Questionnaire" is pushed, it transits to the web page screen (Figure 4) of the mental characteristic check test of the assessment part.

5.3. Assessment Part. The limitations of the features that can be implemented on the chat screen preclude, for example, the ability to select from a list of multiple options and images. The mental characteristics check test used by the Assessment part consists of 80 questions and is created on

Figure 1: The list of images in printed form used in the SAT method.

Table 2: Mental characteristic check test.

Scale	Contents	Score range (SAT criteria)
Self-esteem (Rosenberg 1965, Japanese version-Munakata et al., 1997) [27, 28]	The degree to which a person has a good or positive image for self. Higher self-esteem is more likely to be able to cope with stress and less likely to cause anxiety or depression	0–10 (0–6 lower/7, 8 mid/9, 10 higher)
State-trait anxiety inventory (STAI) (Spilberger 1970, Japanese version-Mizuguchi et al, 1982) [29]	The tendency to become anxious, not state anxiety that varies over time, but a vague degree of anxiety that reflects an individual's past experience	20–80 (20–31 lower/32–34 mid/35–41 higher/42–80 much higher)
Self-rating depression (SDS) (Zung 1965, Japanese version–Fukuda et al 1973) [30, 31]	The depressive symptoms in mood, appetite, and sleep	20–80 (20–35 non/36–48 lower/49–68 higher, 69–80 painful)
Health counseling needs (Munakata, 1999) [32]	Whether or not the response to stress manifested in the mind, body, or behavior, and to the extent.	0–20 (0–6 lower/7–10 mid/11–20 higher)
Self-repression behavioral trait (Munakata, 1996) [33]	The behavioral characteristics that suppress one's own feelings and thoughts	0–20 (0–6 lower/7–10 average/11–14 slightly higher/15–20 higher)
Difficulty in recognizing emotions (Munakata, 2001) [34]	The tendency to avoid feeling of one's own feelings, either subjectively or involuntarily Higher scores tend to accumulate stress and become chronic with physical symptoms even if they are not aware of them	0–20 (0–5 lower/6–8 higher/9–20 much higher)

the web page (Figure 4). When the user pressed the button with the URL link on the chat screen, the user moved to the test page and when the test was completed, the end button at the top of the screen was pressed to return to the chat screen.

5.4. Solution Part. The Solution part, along with the question procedure in Table 1, will provide the user with a series of questionnaires by a chatbot, and the user will be free-written or answered by choice (Figure 5). Following the user's response, the next question will be automatically presented, and a chatbot will induce progression. Images such as light image (Table 1, Q.4-2) and smile face image (Q.5-2) were viewed, and the selected image was displayed as large as possible on the screen in a scene where good image was obtained (Figure 6). Since the list of options that can be displayed on the chat screen is restricted to characters (Figure 5), the image selection scenes of Q.2-1 (aversive image selection), Q.2-2 (aversive image selection), Q.4-1 (light image selection), and Q.5-1 (smile face image selection) that need to be selected from the image list were moved from the chat screen (Figure 7) to the Web page (Figure 8).

6. Experiment

A comparative experiment was conducted to assess the stress reduction effect by using the Chatbot course with

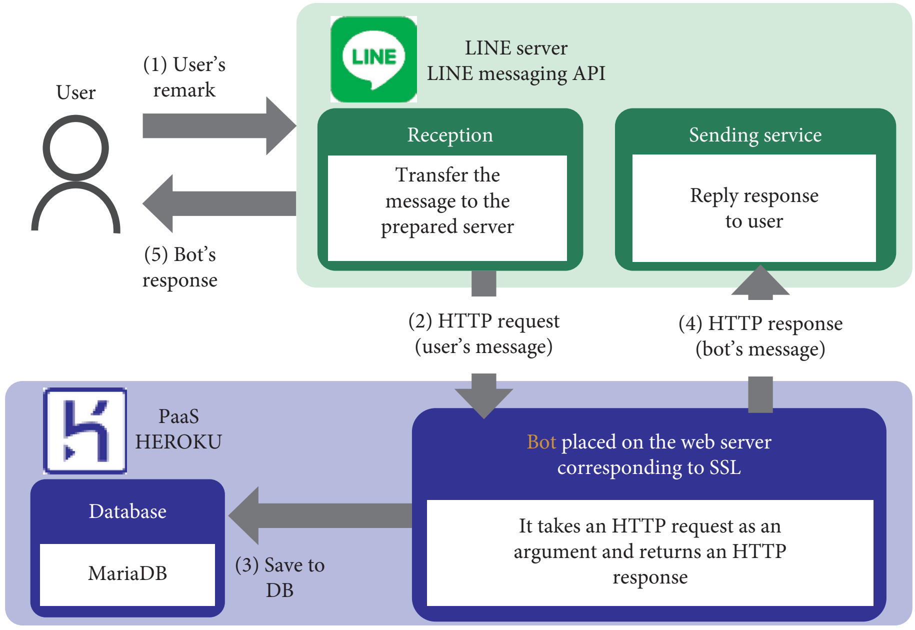

Figure 2: System architecture.

Figure 3: Start screen.

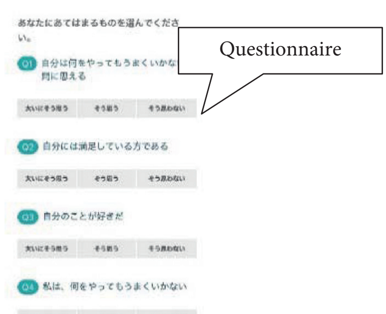

Figure 4: Page of check test.

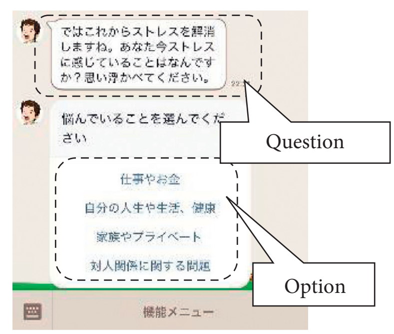

Figure 5: Scene of question and selection.

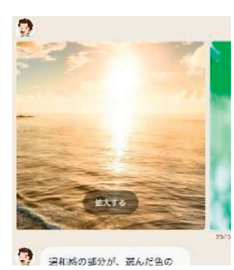

Figure 6: Scene of selected images viewing.

smartphones and the motivation to the courses and investigate the effectiveness of chatbot in the self-guided mental healthcare course. A control group will use another self-guided mental healthcare course built by web pages without a chatbot (Web course). The Web course was also conducted using smartphones to control experimental conditions.

This experiment was carried out with the approval of the ethics review committee in Faculty of Library Information and Media Science, University of Tsukuba (Notification No. 29-137).

6.1. Web Course. According to the digital-SAT method procedure (Table 1), the Web course was implemented on web pages to be the same as page configuration of the Chatbot course consisting of the scene of question and selection and the scene of selected images viewing. In implementing a Web course, the start page is displayed when the user starts the Web browser and logs in on the login page

Figure 7: Scene of image selection.

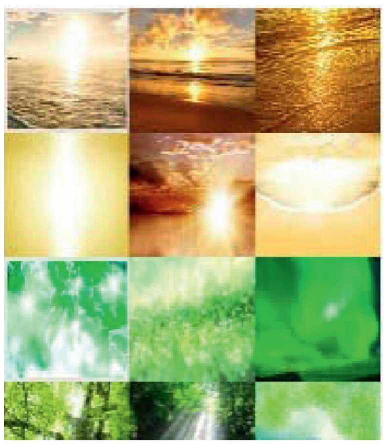

Figure 8: Page of image list.

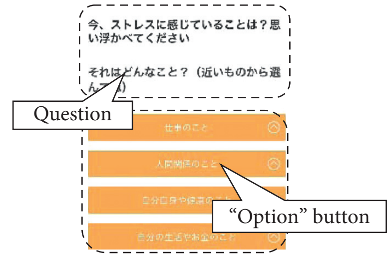

Figure 9: Scene of question and selection for Web course.

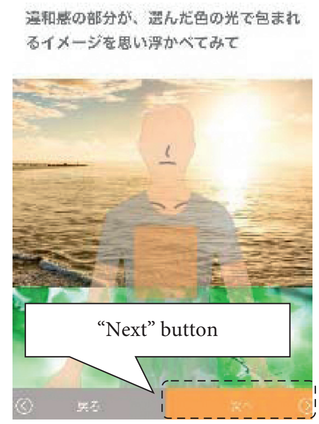

Figure 10: Scene of image viewing for Web course.

using the ID and password. Click Menu on this page to move to the Assessment or Solution part page. The Assessment part used the same check test page as the Chatbot Course (Figure 4). According to the digital-SAT procedure, the Solutions part implements and displays the situations of questions/choices (Figure 9, corresponding to Figure 5) and image viewing (Figure 10, corresponding to Figure 6) on each page.

The difference between the two courses is that when a user reads a question sentence presented by the blow out of the chat, responds and selects, the order is automatically displayed with the next blow and the development of the scene proceeds, while the Web course is developed by the user reading the question text at the top of the screen, depressing the option button (Figure 9), and then pressing the “Next” button at the bottom of the screen and sending the page (Figure 10).

6.2. Procedure. Twenty-seven college students were selected as participants and randomly assigned to two groups, the Chatbot course and the Web course (Chatbot course: $N = 15$, male 6, female 9, name, average age 24.80 years, SD = 1.57, Web course: $N = 12$, male 6, female 6, average age 25.33 years, SD = 3.37). The experiment was conducted in accordance with following procedure:

(1) Explanation of this study (10 min)

(2) Survey of stress condition by the mental characteristics test on web page (15 min)

(3) Explanation of the SAT methodology and the way of using the course (30 min)

(4) Implementation of the course (10 min)

(5) Survey of stress condition by the mental characteristics test and motivation to use the course by a questionnaire of TAM model (see Section 6.3) (20 min)

6.3. Measurement. The stress reduction effect was evaluated using the stress characteristic check test consisting of SAT psychological scales (Table 2), and the user’s motivation to use the course (the effect of improving the motivation to use) was evaluated using a questionnaire created based on the technology acceptance model (TAM) which is a human behavior model that predicts and explains the usage behavior of the information system (7 levels of the Likert scale) [39]. In this model, perceived usefulness (PU), perceived ease of use (PEOU), attitude toward using (AU), and behavioral intention to use (BI) as factor leading to user’s system use are measured for user’s motivation.

Regarding to the obtained data, the difference in the score of the mental characteristics check test before the course between the two groups was tested by the Mann–Whitney’s U test at 5% significance level. The difference in the score of the mental characteristics check test between before and after the course in each group was tested by Wilcoxon’s signed-rank test at 5% significance level. And then, the difference in the score of the Likert scale of the question included in each factor of questionnaire created based on TAM was tested by Mann–Whitney’s U test at 5%

significance level. Python's SciPy package was used for analysis. All tests used two-tailed measurements. Nonparametric tests were used to perform all tests with a small number of samples.

7. Result

First, we performed Mann–Whitney's U test to determine whether there were differences in stress condition before the course between the two groups (Table 3). No significant difference was found in any of the scale scores. It was found that there was a significant difference in the score changes of self-esteem, STAI, and SDS in the Chatbot course (self-esteem: $p = 0.024$, STAI: $p = 0.038$, SDS: $p = 0.043$).

Regarding the score of the questionnaire based on the TAM model, the average scores for all scores in the Chatbot course were higher than the Web course (Table 4). The result of the Mann–Whitney's U test on the scores showed that there was a significant difference in the score of PEOU ($p = 0.030$) and BI ($p = 0.027$) and a significant trend in the score of PU.

8. Discussion

First, it was confirmed that there was no significant difference between the Chatbot course group and the Web course group in the six scale scores before the course was implemented and that the group was not a group with different stress characteristics. The two groups are then compared.

According to the evaluation criteria of the SAT method (Table 2), the self-esteem score in the Chatbot course group before the course is in the "lower" level and STAI score is in the "much higher" level. In the interpretation of the SAT method, the low self-esteem and the inability to positively evaluate oneself predispose people to anxiety, even if problems arise in front of the eyes, because they are unable to tackle positively and are unable to make prospects. Continued high anxiety is associated with increased depression and higher SDS scores, but the SDS score of the group is in the "middle" level and does not lead to severe depression. In addition, the score for health counseling necessity, which indicates whether a stress response is manifested by physical illness or addictive behaviors, is also in the "middle" level and is not an increasingly serious condition. However, the self-repression behavioral trait of the index of stress personality tendency, which causes stress, is close to the "slightly higher" level and the difficulty in recognizing emotions is also in the "middle" level. Therefore, if the anxiety continues, it is a group in which the physical and mental distress caused by stress may become manifest. The Chatbot course significantly improved self-esteem, STAI, and SDS scores and improved self-esteem and STAI rating levels and confirmed the stress reduction effect. Improvements in these indicators are justified by the interpretation of the SAT method because of improved self-esteem, reduced anxiety, and decreased depression.

Self-esteem, STAI, and SDS scores are indicators of the state of stress and are relatively variable depending on the contemporary state. On the other hand, self-repression behavioral trait and difficulty in recognizing emotions are less variable than the above-mentioned three scales as representations of stress-producing personality traits. In the clinical setting of the SAT method, improvement of these indicators is one of the objectives of modifying the perception of stress, resolving problems, and increasing stress tolerance. Although the mean scores for self-repression behavioral trait and difficulty in recognizing emotions in the Chatbot course group decreased, no significant difference was found and no improvement was seen as the criteria changed. A latest survey using our VR course confirmed improvements to the deeper characteristics of stress traits such as self-repression behavioral trait and difficulty in recognizing emotions other than self-esteem, STAI, and SDS. In the Chatbot course, no significant difference in the effect on the stress personality trait could be confirmed, so it can be said that all improvements have been made. Alternatively, this could be a limitation of the Chatbot course performed on a small smartphone 2D screen.

Regarding the evaluation of the motivation to use the system by TAM, PEOU and BI were higher in the Chatbot course than in the Web course. In PEOU's "It's easy to learn to use this system," "I think it is easy to master this system," "I think it is easy to use this system" 3 total points and BI's "I will use this system in the near future," "I believe that the interest in this system will increase in the future," "Recommend to use this system for others" 3 total points, a significant difference was observed at the total points of the two question items. In addition, a significant trend was seen at the total point of the five question items of PU. These results suggest that Chatbot course may be more motivated than the Web course. In the Web course, although the same self-SAT procedure was implemented, no significant differences were found for any scale. Taken together, Chatbot's support suggests that motivation to use could be focused on the care process itself and exerted a stress-reducing effect. Given the importance of focusing on the care process itself, it may be substantiated that the intrusive view of the VR course produced higher levels of concentration and had a higher stress reduction effect.

Compared with VR, a smartphone-based Chatbot coarse offers considerable convenience and has the advantage of inducing Chatbot that allows users to guide self-care without being aware of it. This is a useful training tool. Some users who are familiar with this method may prefer to be able to perform it at their own pace, do not need Chatbot guidance, and may find it easier to use the Web course. In our other recent survey, a significant reduction in the STAI scale has been confirmed with the 2-week implementation of the Web course. It is possible to use VR to deepen the sense and understanding of its effectiveness, and then to repeat training in the Chatbot course and the Web course.

Future research firstly aims to develop tools that will be more effective by deepening research on how to use and combine tools. Further, the system, gathering data through

Table 3: Stress characteristic check scores before and after using the courses (Chatbot course: $N = 15$; Web course: $N = 12$).

Scale	Chatbot course average ± SD	Web course average ± SD	p value[1]
Self-esteem			
Before	6.93 ± 2.76	6.00 ± 3.07	0.208
After	8.00 ± 2.17	6.42 ± 3.50	
p value[2]	0.024*	0.314	
State-trait anxiety inventory (STAI)			
Before	45.33 ± 8.14	45.83 ± 12.68	0.480
After	40.80 ± 8.28	40.33 ± 12.81	
p value[2]	0.038*	0.245	
Self-rating depression scale (SDS)			
Before	41.07 ± 9.54	47.42 ± 13.27	0.106
After	37.73 ± 8.14	45.33 ± 16.76	
p value[2]	0.043*	0.193	
Health counseling necessity			
Before	7.00 ± 3.74	7.92 ± 4.36	0.304
After	5.80 ± 3.43	7.58 ± 4.32	
p value[2]	0.192	0.856	
Self-repression behavioral trait			
Before	10.40 ± 2.32	9.92 ± 3.87	0.199
After	10.27 ± 2.55	8.92 ± 3.87	
p value[2]	0.875	0.465	
Difficulty in recognizing emotions			
Before	8.60 ± 3.87	8.17 ± 4.26	0.432
After	7.40 ± 3.44	8.50 ± 3.99	
p value[2]	0.102	0.758	

[1]Mann–Whitney's U test for difference in score between groups ($^*p < 0.05$). [2]Wilcoxon's signed-rank test for score change in each group ($^*p < 0.05$).

Table 4: The score of the questionnaire based on the TAM model (Chatbot course: $N = 15$; Web course: $N = 12$).

Scale	Average ± SD	p
PU (perceived usefulness)		
Chatbot course	24.73 ± 6.09	0.078†
Web course	21.92 ± 4.89	
PEOU (perceived ease of use)		
Chatbot course	18.53 ± 2.92	0.030*
Web course	17.33 ± 1.44	
AU (attitude toward using)		
Chatbot course	21.27 ± 5.06	0.140
Web course	19.50 ± 3.75	
BI (behavioral intention to use)		
Chatbot course	16.00 ± 3.09	0.027*
Web course	13.25 ± 3.44	

Mann–Whitney's U test: $^{\dagger}p < 0.1$; $^*p < 0.05$.

using these tools and providing actual mental health condition of users to specialists, such as industrial doctors or counselors, for collaborative support, could be developed in the next stage. In addition, it should be mentioned that people who can use these courses are limited to users who can use SNS and smartphones.

As a limitation of the study, the number of participants in this study was small and further research with a bigger sample is needed on the effectiveness of the course in reducing stress. And, above all, the assessment was conducted once to determine motivation to use and continuity and not to verify whether or not the course was actually used continuously. Future studies should include an increase in the number of participants and a survey on the continued use of the course over a period of time.

9. Conclusion

In this study, the SAT method was converted to digital contents; a self-guided mental healthcare course and a system using a chatbot were developed, and a comparative evaluation experiment was conducted with a Web course without a chatbot as a control group. The results of the experiment show the possibility that the use of the chatbot enhances user's motivation and supports to reduce stress and is effective in the self-guided mental healthcare course. However, the sample of users in this study is small, and the user's motivation and stress reduction effect were evaluated based on one-time use of the course. Future studies should include an increase in the number of participants and a survey on the continued use of the course over a period of time.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Disclosure

This manuscript is an extended version of the paper presented at the 2018 International Workshop on Collaborative Technologies and Data Science in Smart City Applications.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Coordinating Real-Time Serial Cooperative Work by Cuing the Order in the Case of Theatrical Performance Practice

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Our goal is to facilitate real-time serial cooperative work. In real-time serial cooperative work, the order of subtasks is important because a failure of the order leads to a failure of the whole task. So, coordinating the order of workers' subtasks is necessary to smoothly accomplish the tasks. In this paper, we propose a method that uses vibration to present the action order and coordinate the orders. We conducted a user study to verify the effectiveness of the method in theatrical performance practice, which was an example of real-time serial cooperative work. As a result, order coordination reduced mistakes in the order of speech and action and in the contents of lines and action. This result suggests that order coordination can improve real-time serial cooperative work.

1. Introduction

Work is generally divided into several steps. For example, cooking includes processes such as cutting ingredients, stir-frying ingredients, and arranging ingredients. Assembling furniture includes steps like reading instructions, preparing the necessary tools, and combining parts according to instructions. In these examples, cooking and assembling furniture are called tasks, and each process is called subtask or process [1, 2]. A task is a unit of work that the worker has to achieve. Also, it seems natural to have a break after a task [3]. A task can be divided into several subtasks [3], and subtasks can be arranged hierarchically [4, 5]. Even in the context of cooperative work, a task is divided into subtasks that are assigned to workers, and workers complete their own assigned subtask [6, 7]. In this study, we focus on cooperative work where tasks are divided into several subtasks.

Some of the cooperative work has subtasks arranged serially, so the order in which subtasks are performed is essential. In order to accomplish this kind of work without mistakes, it is necessary to coordinate the order of subtasks and notify workers of the subtasks' order. In this paper, we propose a method to support cooperative work where the subtasks' order is important by coordinating the order. We deal with theatrical performance practice as an example of cooperative work in which the order of executing subtasks is essential.

In addition, some cooperative work subtasks are difficult for workers unfamiliar with the work, and they can disturb the task by making mistakes. Interruption of a task in co-operative work can necessitate restarting tasks, and it can increase the stress of other workers [8–10]. Therefore, this study aims to avoid task failures by supporting beginners, and we propose a method of order coordination for novice workers to facilitate cooperative work.

In this paper, we dealt with theatrical performance practice as an example of real-time serial cooperative work, which is equivalent to a school play. In theatrical performance practice, subtask refers to the utterances and actions of each actor. In theatrical performance practice, actors need to take actions in accordance with other actors' action. For that reason, actors must always consider other actors to grasp which one will take action next. Moreover, it is necessary for actors to pay attention to their own subtasks, such as posture and voice. Therefore, the need for much awareness burdens the actors. Theatrical performance practice is difficult work for novices, but we show that our proposed method can support them.

To coordinate the action order in theatrical performance practice, we used vibration to cue the order. Each actor attached a smartwatch to his or her arm to receive cues for the action order through vibrations. We conducted a theatrical performance practice experiment with 16 teams of 3 persons (totaling 48 persons) to verify the effect of notifying action order. In this experiment, we used a cuing system that vibrates the smartwatch of the actor who takes the next turn. As a result, giving actors two kinds of vibration patterns reduced the number of mistakes. Finally, we discuss the possibility of reducing mistakes during real-time cooperative work with serial subtasks.

2. Taxonomy in Cooperative Work

In order to define cooperative work in this study, we describe a taxonomy of cooperative work.

2.1. Real-Time or Non-Real-Time Work. Cooperative work has been classified as synchronous or asynchronous [11–13]. In this paper, we focus on synchronous, real-time work to verify the effectiveness of coordinating the order of subtasks. In this paper, we focus on theatrical performance practice. Theatrical performance practice is one task where the subtasks are performed in the same place, but the location of the subtask does not matter for the method of order coordination proposed in this paper.

2.2. Serial or Parallel Subtask Design. Cooperative work has a parallel subtask design or a serial subtask designs [14, 15]. For example, when all the classmates in a school class create a thousand Japanese paper cranes, each students' subtask of folding cranes is a subtask. So, making a thousand paper cranes can be considered a parallel task. In a relay race in physical education, however, each runner's run is considered as a subtask. If the baton is not passed, the next runner cannot start, so the subtasks of all runners are arranged serially. Therefore, a relay race can be regarded as a serial task. In this research, we focus on serial tasks in order to investigate whether workers' mistakes concerning the order of subtasks will decrease.

In the serial task in particular, the order of subtasks is important. In a music ensemble or team action, such as a dance or a march, once the order of subtasks collapses, the entire task will fail. Although support for completing these tasks has been reported [16, 17], we propose a coordination method for any real-time cooperative work with serial subtasks by presenting the order of subtasks to the workers in this study.

2.3. Deciding the Order of Subtasks in Advance. In some tasks, the order of subtasks is predetermined. In a group discussion, for instance, each speaker forms an argument and speaking can be considered a subtask. However, the order of appropriate speech in the discussion changes from moment to moment, so we cannot decide the order of remarks in advance. In this study, we discuss only cooperative work that can determine the order of subtasks before starting. For example, in an ensemble, the subtask is playing a sound with a musical instrument. Since a musical score shows when a certain kind of sound is needed, its order of subtasks is predetermined.

3. Related Work

3.1. Real-Time Cooperative Work and Serial Cooperative Work. Many studies argue that managing task sequences in serial cooperative work is necessary to facilitate tasks. In a serial crowdsourcing task, for example, subtasks may become stagnant [18] or it may be difficult to request complicated work [19] unless subtasks are presented in an appropriate order. Therefore, some studies have focused on the order or the content of the subtasks [20–22]. Other than crowdsourcing, some studies used a virtual conductor to inform performers of the order in an ensemble [23, 24], showing that it is useful to present the order of subtasks. In this study, we dealt with theatrical performance practice, but we propose a method that can be used for tasks other than theatrical performance practice.

In real-time cooperative work, it is necessary to do subtasks while paying attention to the actions of other workers. A conflict of workers talking or acting simultaneously with other workers is a known issue in such work [11, 25]. Although gaze information is used to avoid these collisions [26, 27], workers have to look at the circumstances of their surroundings, which can distract attention from their own subtasks. In this paper, we propose a method of using vibration to present the order of actions, to reduce mistakes while concentrating on individual subtasks, and to avoid burdening the worker.

Meanwhile, a presentation support system has been proposed as a method to support serial work done by one person. The system uses speech recognition technology to automatically show the script to a presenter who is not accustomed to giving a presentation. This study showed the importance of showing the order to a worker [28, 29], but our research extends these studies and shows the effectiveness of presenting the order for multiple workers.

3.2. Theatrical Performance Practice

3.2.1. Steps of the Theatrical Performance Practice Process. Theatrical performance practice steps include reading the script, practicing parts, running through practice, and rehearsal. While reading the script, each actor practices reading their lines aloud. While practicing parts, actors check the action and posture. While running through practice, actors play each role through the whole performance. While rehearsing, actors perform the whole production along with sound and lighting. In this research, we focus on practicing parts. In this step, actors must be conscious of their relationship with other actors' movements, which they do not have to consider while only reading the script. Therefore, actors must pay attention to more elements. Beginners especially may easily make mistakes in this step. Because mistakes interrupt practice and can prevent other actors from grasping the overall flow, we alleviate mistakes during the part practice step.

3.2.2. Supporting the Part Practice Step. Like a theatrical performance practice support method, some systems have been suggested that allow independent practice even when all the actors are not available [30] or offer support for remote performance instruction [31]. This study, on the other hand, supports a theatrical performance practice that progresses in real time with actors in the same place.

As a way to support the action by giving information to an actor in a theatrical performance, a cue card presentation system [32] and showing the script using Google Glass [33] have also been proposed. In this study, we notify actors of the subtask order, which is the action order of each actor, to coordinate the order of action in the collaborative work.

3.3. Memory. In a theatrical performance, actors must remember their own lines and actions. Baddeley's memory model [34] and Cowan's memory model [35] are known, but memory is generally divided into two kinds: a short-term memory held for about several tens of seconds in a limited storage area and long-term memories that can be stored for a long time. In order to transfer short-term memories to long-term memory, it is necessary to carry out iterative work, called rehearsal [35, 36]. Especially for beginners in a theatrical performance equivalent to a school play who try to memorize the whole script, the task can be incomplete, and it is hard for them to proceed with the repetitive work of memorizing the script. Presenting a part of the script's contents during practice can solve this problem by reducing the items that actors have to memorize.

4. Study of Cuing System for Theatrical Performance Practice as an Example of Cooperative Work

To accomplish our goal, we present a method of cuing the action order for novice workers. Workers who are unfamiliar with the task can make mistakes in the order and disturb the task. We present a method of order coordination that individually notifies each worker of the action order [37, 38].

We use the practice of theatrical performance as an example of real-time serial cooperative work and target novice actors. The actors who are unfamiliar with theatrical performance must pay attention to various contents such as the order of actions, their behavior, and the other actors' actions. Therefore, it is difficult for them to complete the work. Because theatrical performance practice has subtasks arranged serially, the task can be interrupted when actors have the wrong order. It is necessary to coordinate the order of action for individual actors. In this paper, we use a cuing system that instantly notifies each actor when they should take action.

Notifying the action order is expected to reduce the number of mistakes made by beginners during practice. However, because the actors do not always move as intended, even using the system, it is necessary to confirm that the number of mistakes in the speech/action order decreases by cuing the order.

In addition, we had to consider mistakes in the speech content and in the action content because theatrical performance practice includes mistakes in the order and mistakes in the content. By reducing the items that the actors must memorize, they can memorize the content-related items more easily. It is necessary to check whether the order cues can reduce the number of content-related mistakes. If we find that our method can reduce the number of content mistakes, a better quality of work is expected because the actors will not make mistakes in the content or in the order.

Therefore, we verified the following hypotheses about whether the order coordination is useful in theatrical performance practice:

(i) **H1**: notifying the actors of the action order in real time reduces the mistakes in the order of action in the theatrical performance practice.

(ii) **H2**: notifying the actors of the action order in real time reduces the content mistakes, such as the content of speech and action, in the theatrical performance practice.

5. Cuing System

We introduced a cuing system that notifies actors of the speech/action order [37, 38].

5.1. Scenario. An example scenario is shown in Figure 1. In this paper, one utterance or action by an actor is defined as a turn. This figure is an example of a script that is composed of three turns. The horizontal axis shows the time. The light blue lines in the figure show that the system gave a one-shot vibration, the dark blue lines indicate two-shot vibrations, the orange lines indicate the utterance section by the actor, and the green lines indicate the section of an actor's action. In this scenario, the system operated for actors A, B, and C are as follows:

(i) **[Turn 1]** Actor A: only speaks

  (1) The smartwatch of actor B vibrates twice, and the smartwatch of actor A simultaneously starts voice detection.
  (2) Actor A speaks.
  (3) The smartwatch finishes speech detection.
  (4) The system reads the next turn.

(ii) **[Turn 2]** Actor B: speaks and acts

  (1) The smartwatches of actor A and C vibrate once, and the smartwatch of actor B starts voice detection simultaneously.
  (2) Actor B speaks and acts.
  (3) The smartwatch finishes speech detection.
  (4) The system reads the next turn.

(iii) **[Turn 3]** Actor A and C: only speak

  (1) The smartwatches of actors A and C start voice detection.
  (2) Actors A and C speak.
  (3) The smartwatches finish speech detection.

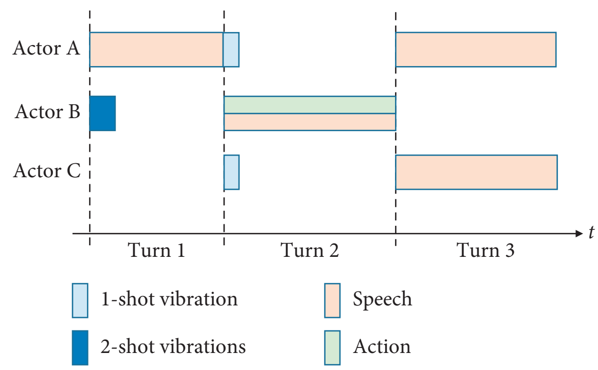

Figure 1: A timeline of a script.

Because the system used in this study was a prototype, if the actors made some mistake during the experiment, the experimenter operating the server temporarily interrupted the system and manually restarted the system.

5.2. Implementation. In this section, we explain our cuing system that notifies actors of the order.

5.2.1. Requirements. In this study, we used an experimentally constructed cuing system to notify actors of the order. This cuing system is a prototype system using existing technology. To begin, we note the requirements to be satisfied by this system.

First, in order to cue the order individually, a notification is sent to an individual actor's device. As described in Section 3.2.1, we assumed system usage in the part practice step, and we had to consider the possibility that the actor performs with props in both hands. Therefore, we chose a smartwatch as a wearable device that does not occupy both hands. Wearable devices can cue actors individually.

Second, this system can register scripts in advance. If the system records the script's information beforehand, it is possible to grasp the action order of the actors, and the system can correctly cue the appropriate actors.

This system can also detect the utterances of speakers. By detecting the speaker's utterance, it is possible to automatically notify the next actor of the order after the previous actor's turn. We used speech detection technology in the smartwatch worn by individual actors to observe who is speaking.

5.2.2. System Configuration. Figure 2 shows the outline of the system. Each actor wore a smartwatch (Samsung Gear Live) on each arm as a device to notify the action order through vibration. This smartwatch was connected to the server via Android tablets (Nexus 7) to synchronize all smartwatches. Smartwatches and tablets were connected one-to-one by Bluetooth, and all tablets and servers performed bidirectional connection using WebSocket. The tablet mediated the connection between each smartwatch

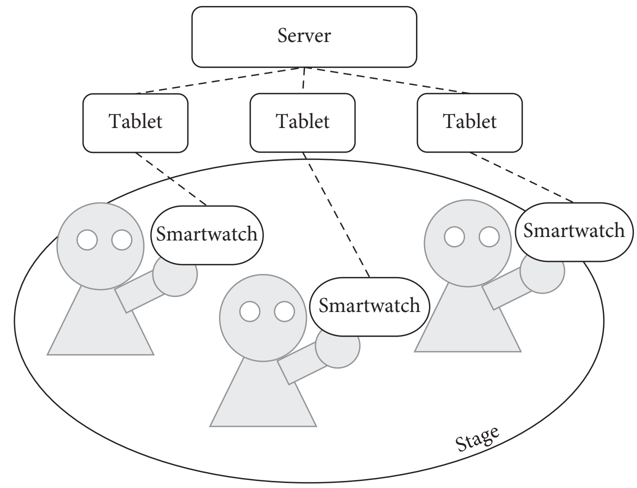

Figure 2: System configuration.

and the server, so it was unnecessary for the actor to carry the tablet as long as the tablet was in the range where the smartwatch, tablet, and server could be connected.

5.2.3. Storing Scripts. The scripts were stored as a CSV file on the server and read by the cuing system. CSV is a versatile file format that can be read and written by various text editors, including Microsoft Excel spreadsheet software. Considering that this system will be used in cooperative work other than theatrical performance practice in the future, we avoided using a unique file format like Opera Liber DTD [39] as the encoding model for the script. The system automatically read the script data and created the cue. The script CSV file included the following data: the order of speech, whether or not the action is included in the next turn, and the contents of the speech and the actions.

5.2.4. Cuing the Action Order to Actors. The action order cue was presented through the smartwatch's vibration. The cuing system gave two kinds of vibration patterns. When actors only utter their own lines, a one-shot vibration lasting 500 ms is given. If actors have to act, regardless of whether they utter lines or not, two vibrations lasting 500 ms and 700 ms were presented with a 200 ms interval between the two vibrations. The different length between the two patterns of vibrations is for the actor to easily distinguish the number of vibrations. These vibrations are given one turn before the actor should speak or act. Therefore, actors can know if their turn is next.

5.2.5. Detecting Actors' Utterances. The cuing system used the Android Speech Recognizer to detect actors' utterances. The smartwatches worn by the actor shifted to the utterance detection state when the actor's turn came, and it was possible to detect the utterance. Since Android's speech recognition does not always accurately detect the phrase, the smartwatches in this study's experiment detected only whether the speaker spoke so the system could follow the script and make cues in the right order. It took approximately 2 or 3 seconds to finish detecting actors' speaking (the processing time of the Android Speech Recognizer was measured using a script prepared for our experiment, and the average was 2.63 sec. SD was 0.47 sec ($N = 36$)). During an utterance, actors did not need to bring the smartwatch close to their mouth, and both arms could freely be brought to position according to the action at that time.

5.2.6. System Workflow. The workflow of this system is shown in Figure 3. First, the system checked if the actor's action was included in the next turn by reading the stored script. If an action was included, this system gave two vibrations via smartwatch to the actor who acts in the next turn. If an action was not included, the system offered a one-shot vibration to the next actor. If the actor performed the speech and/or action without making mistakes, the system read the next turn. This sequence was repeated until reaching the end of the script.

6. User Study of the System

In order to evaluate whether notifying the action order reduced the number of mistakes in the part practice step of theatrical performance practice, we carried out a user study in which the participants practice a theatrical performance using the cuing system [37, 38].

6.1. Participants. Forty-eight undergraduate and graduate students participated in this experiment. All of them were beginners in theatrical performance, which conformed to the target of this research.

6.2. The Scripts Used in the Study. In this experiment, two different scripts were prepared for each team. Each script had 12–14 speech lines and 5–7 actions for each actor, and there were about 40 turns total. Speech lines were limited to a single word or ones within ten seconds, considering the target users. On average, it took almost 3 seconds to complete a line. This included small movement actions, such as raising hands or hitting hands on the mouth. It also included whole body actions, such as standing up, crouching and stroking dogs, slowly looking back, falling down, and more. There was no action that participants could not physically perform. Because there was no turn where speech or action crossed between turns, no one acted when the system gave the vibration. Moreover, the scripts we prepared had actors perform utterances or actions alone in all the turns except for one, and two actors perform simultaneously in one turn. It took about three minutes to read each script.

6.3. Experimental Condition. We set up two experiments in this study. In one, the system cued only the order of the utterance (Speech-cue experiment). In the other, the system notified the order of both speech and action (Speech + action-cue experiment). In the Speech-cue experiment, the cuing system gave only a one-shot vibration for both speech and action. In the Speech + action-cue experiment, the system gave two patterns of vibrations. Two vibrations were given for action and one vibration for speech.

Forty-eight participants were divided into sixteen teams of three persons. Eight teams belonged to group A, and the other eight teams belonged to group B. The participants in group A took part in the Speech-cue experiment, and the ones in group B took part in the Speech + action-cue experiment (Table 1).

For each experiment, we set two experimental conditions. One was participating in the experiment using the cuing system (system condition), and another was participating without the system (control condition). All participants took part in both conditions. In both trials, they used different scripts. The eight teams in the two groups were divided into four small teams, and the experiments were conducted in the order shown in Table 2 for counterbalance.

6.4. Procedure. In conducting the user study, we focused on the part practice step of theatrical performance practice. Therefore, we had to carry out the experiments on the premise that the actors had already finished reading the script, which is the previous practice step. Therefore, participants needed to memorize their lines and actions before starting the experiment. In accordance with the opinion of the person with theatrical performance experience and to prepare a state in which the participants memorized lines and actions by roughly 80%, the experiments were carried out according to the following procedure:

(1) *Instruction of the Experiment and the System*. The experimenter told participants that this experiment was to practice using a cuing system that supports a theatrical performance practice. Participants were not informed of the purpose of the experiments other than what to do in this experiment. Next, the experimenter explained to the participants how the system works and let them wear a smartwatch to try the system. At this time, voice detection did not perform correctly when the voice was unclear or too quiet, so the experimenter instructed participants to make their voice clear. This instruction did not deviate from the assumed environment because a large and clear voice is necessary for the audience to hear actors' words in the actual theater.

(2) *Memorize the Script (1st Round)*. Each participant was given a role and a printed script. Then, they were instructed to memorize the script. They could memorize the script without restriction, but they were not allowed to memorize with other participants. In this step, participants were given five minutes to memorize the script.

(3) *Reading the Script*. Participants read the whole script aloud while holding their own printed script. At this step, participants understood how to utter lines and play a role.

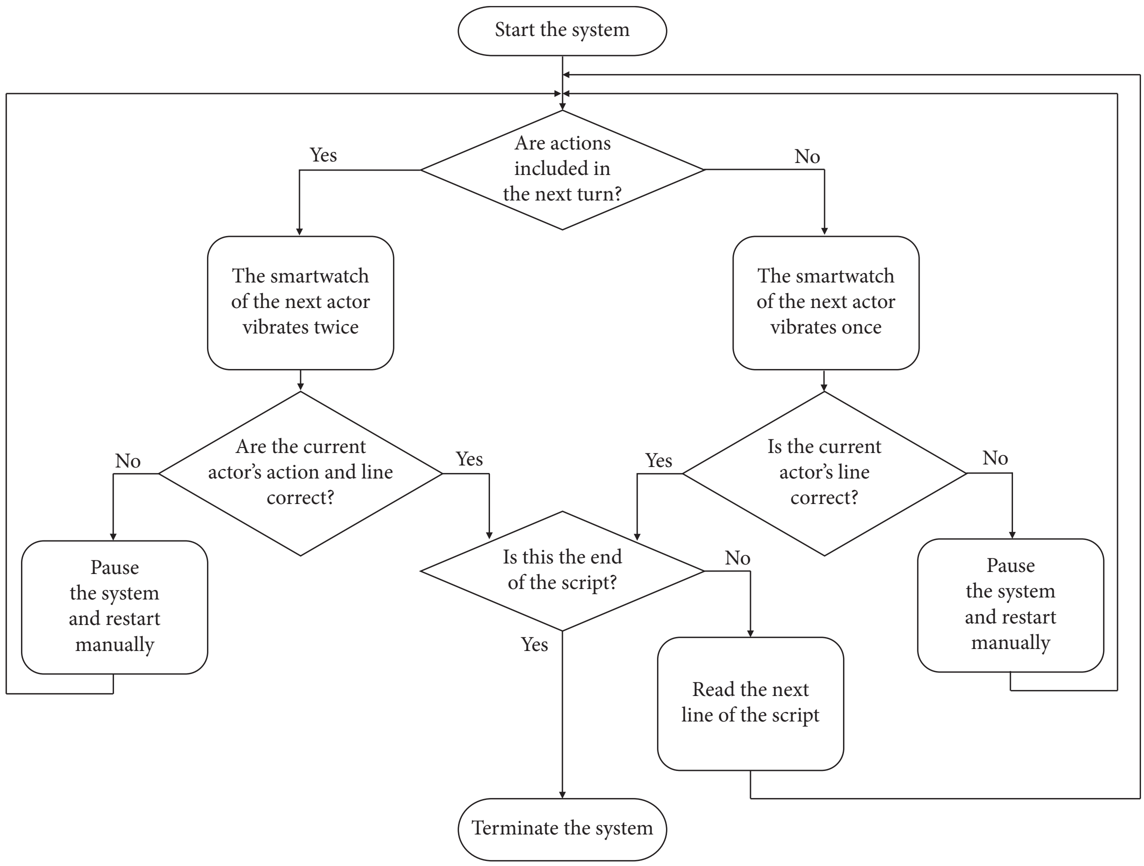

Figure 3: System workflow.

Table 1: Participants in the study.

	Team	Participants	Took part in
Group A	T1	P1, P2, P3	Speech-cue experiment
	T2	P4, P5, P6	
	⋮	⋮	
	T8	P22, P23, P24	
Group B	T9	P25, P26, P27	Speech + action-cue experiment
	T10	P28, P29, P30	
	⋮	⋮	
	T16	P46, P47, P48	

Table 2: Combination of the study conditions.

Team		1st trial	2nd trial
Group A	Group B		
T1, T2, T5, T6	T9, T10, T13, T14	System condition	Control condition
T3, T4, T7, T8	T11, T12, T15, T16	Control condition	System condition

(4) *Instruction of Action by the Experimenter*. The experimenter performed the actions written in the script to participants once.

(5) *Memorize the Script (2nd Round)*. Participants were instructed to memorize the script again. Just like the first round, they could memorize the script freely, but it was forbidden to memorize with other participants. Three minutes were given to memorize, which was shorter than in the first round.

(6) *Starting Practice*. The participants started performing all of the script. At this time, the experimenter counted the number of mistakes described in Section 6.5. In the case of a mistake, the experimenter stopped practice once and restarted from the turn that a mistake occurred.

(7) *Switch to the Next Script*. After the participants completed practicing the first script, they repeated the procedure from (2) to (6) with the next script.

6.5. Data Collection. In the Speech-cue experiment, the experimenter counted the number of mistakes in speech order and in speech content. In the Speech + action-cue experiment, the experimenter counted the number of mistakes in speech order and in speech content along with the mistakes in action order and in action content. It is not necessary for the speech content to be correct verbatim, and changing the expression somewhat without changing the speech's meaning was not counted as a mistake. For example, inverting the order of words and phrases or replacing part of a phrase with synonyms was not judged as a mistake.

7. Result of the User Study

In the user study, we carried out two experiments: a Speech-cue experiment and a Speech + action-cue experiment [37, 38]. The number of mistakes in speech order and speech content from 16 teams was obtained in the Speech-cue experiment. The number of mistakes in action order and action content from eight teams was obtained in the Speech + action-cue experiment.

The result of the user study is shown in Figure 4. Because different scripts were used in the two experiments, the ratios of the system condition to the control condition were calculated and compared. By putting the two experiments together, the mistakes in speech order and in speech content came from 16 teams (48 participants) and mistakes in action order and in action content came from 8 teams (24 participants), originally.

Table 3 shows the statistical differences in the measured items. A post hoc t-test followed by the Bonferroni correction was applied. Significant differences between the system condition and the control condition were found in the speech order and the speech content. Marginally significant differences between the system condition and the control condition were found in the action order and the action content.

Using the system surely reduced the number of mistakes during the theatrical performance practice. This result supported **H1**, the system reduces mistakes in speech and action order, and **H2**, the system reduces mistakes in speech and action content.

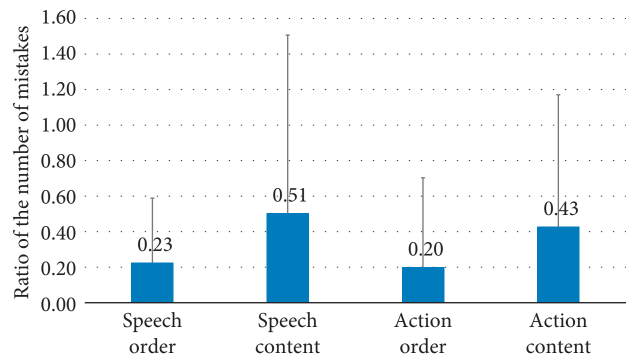

Figure 4: The result of the user study. The values are the ratios of the system condition to the control condition. Error bar shows the normalized standard deviation.

Table 3: Statistical differences in the measured items.

Number of mistakes	N	t value (unadjusted)	Bonferroni adjusted p value
Speech order	48	3.08	<0.05
Speech content	48	3.96	<0.05
Action order	24	2.18	<0.10
Action content	24	2.22	<0.10

8. Discussion

8.1. Effectiveness of Notifying the Action Order. In the user study, the system notified the order. As a result, it was shown that the number of mistakes in speech and action order decreased compared with the control condition. The speech and action order during a theatrical performance practice correspond to the order of subtasks in real-time serial cooperative work, which is dealt with in this study. The order of subtasks is essential because once workers make a mistake in order, it leads to the failure of the entire task. Therefore, we argue that the system is effective for the real-time serial cooperative work focused on in this study.

8.2. Effect of Difference in Two Types of Cuing Order. The experiments carried out in this study had two patterns of vibrations given by the system. To distinguish the one-shot vibration from the two-shot vibrations, the length of the two-shot vibrations was changed. By only changing the vibration length, the system notified the actors of the two kinds of order, including or not including action. As shown in Figure 4, the number of mistakes in speech order and in action order were reduced. This result shows a possibility to show the proper order of subtasks by different operations of vibrations.

8.3. Effect on Content-Related Subtasks. In theatrical performance practice, it is necessary for actors to memorize their actions in addition to relationships with other actors. In this study, the system only presented the order, but the results confirm that the number of mistakes related to the content of the speech and actions also decreased, as shown in Figure 4. It seems that the beginners of theatrical performance were able to concentrate on remembering speech and actions by automatically presenting the order, which reduced the number of items to memorize. This result suggested that notifying workers of the order of subtasks improves the quality of individual work.

8.4. Possible Effect on Learning Theatrical Performance. This study focuses on the school-play level of theater. After the practice, there will be an actual production of the performance. However, it may be possible to mitigate mistakes

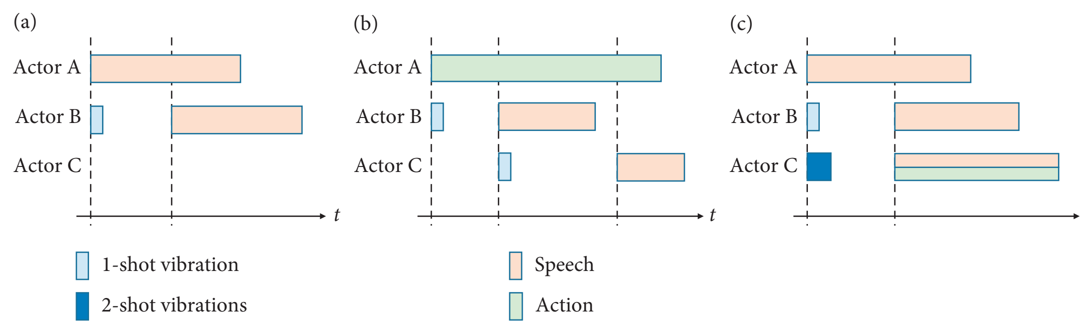

Figure 5: Examples of overlapping turns.

in the production without this system. This can be inferred from the concept of scaffolding, which enables efficient learning by establishing a foothold in learning [40–43]. Originally, scaffolding was used to enable children or novices to solve problems beyond their unassisted efforts [44, 45]. According to Vygotsky, learners also have a zone named "Zone of Proximal Development (ZPD)" that is the distance between what a learner can do with help and do without help [46, 47]. Scaffolding temporarily and dynamically supports learners in the ZPD [45]. However, the learners gain understanding and the scaffolding can fade over time as learners take more control over own learning [40, 42, 43, 45–48]. Therefore, learners can finally solve problems smoothly without scaffolding. Similarly, considering the theatrical performance practice as learning content, the cuing system in this study can become scaffolding. The actors practice efficiently using the system, and they might finally be able to perform an actual play without making mistakes.

8.5. System's Capability of Supporting Overlapping Turns. There was no overlapped utterance or overlapped action in the user study. However, we expect that our cuing system can support overlapping actions. Figure 5 shows examples of scripts including overlapping turns. Example (1) shows that actor B starts speaking while actor A is speaking. In this case, actor B's smartwatch vibrates when actor A starts to speak. Example (2) shows actor B and actor C start speaking while actor A is acting. In this case, actor B is notified when actor A starts acting, and actor C is cued when actor B starts speaking. In example (3), actor B and actor C start speaking and acting simultaneously during actor A's action. Both actors B and C are cued when actor A starts his/her turn. In any of the cases from (1) to (3), the system cues actors one turn before the actor(s) should start speaking or acting. Thus, the system can support various overlapping actions, including those shown in Figure 5.

8.6. Application to Other Real-Time Serial Cooperative Work. In this study, we considered three actors practicing a theatrical performance as an example of real-time serial collaborative work, and we verified the effectiveness of notifying action order. As a result, mistakes related to the order of speech and action decreased, along with mistakes related to the content of speech and action.

Considering the cooperative work covered by this study, it is believed that similar results can be obtained in similar real-time serial cooperative work. For example, dance performances and playing music with handbells are other examples of real-time serial cooperative work. These tasks also have some subtasks, and their order is essential to completing the entire task. Our method of cuing the order may be able to support these cooperative works.

However, it has been pointed out that when a worker is walking or running, vibrations can be difficult to sense [49]. In this study's experiment, every participant was able to sense the vibration because all participants were not moving when given the vibration. In other cooperative work, it remains a matter of research to present the cue in other ways while paying careful attention to the state of workers.

In this study, we discussed only tasks whose subtask order is determined in advance. As mentioned in Section 2.3, in a group discussion, for example, the order of each person's remarks cannot be determined in advance. However, some studies have already proposed how to decide the appropriate person in a discussion [50, 51], that is, to determine the order of subtasks in real time. By adding such knowledge to this method, the proposed method is applicable to tasks whose order of subtasks is not predetermined.

9. Conclusion

In this study, we focused on real-time serial cooperative work. In such cooperative work, the order of subtasks is important. Workers who are unfamiliar with the order of subtasks may make a mistake that interrupts the entire task, so we support novice workers by coordinating the order of actions. In this paper, we dealt with a theatrical performance practice as an example of the real-time serial cooperative work, and we presented a method of coordinating the order of subtasks to reduce the number of mistakes. We used a cuing system that gave vibrations to each actor through a smartwatch. The system notified actors of the action order. To verify whether order coordination by notifying action order leads to mitigation of mistakes, we conducted a user study in which participants practiced theatrical performances and confirmed the effectiveness of the method. As a result, notifying actors of the order reduced mistakes in the order and in the contents. It was also suggested that this system could improve the quality of subtasks by making the worker more focused.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

TDSRC: A Task-Distributing System of Crowdsourcing Based on Social Relation Cognition

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Crowdsourcing significantly augments the creativity of the public and has become an indispensable component of many problem-solving pipelines. The main challenge, however, is the effective identification of malicious participators while distributing crowdsourcing tasks. In this paper, we propose a novel task-distributing system named *T*ask-*D*istributing system of crowdsourcing based on *S*ocial *R*elation *C*ognition (TDSRC) to select qualified participators. First, we divided the tasks into categories according to task themes. Then, we constructed and calculated the Abilities Set (AS), Abilities Values (AVs), and the Friends' Abilities Matrix (FAM) by using the historical interactive texts between a given task publisher (requester) and its friends. When a requester distributes a task, TDSRC can generate the candidate participators' sequence based on the task needs and FAM. Finally, the best-matched friends in the sequence are selected as the task receivers (solvers), thus producing a personal FAM to disseminate the tasks. The experimental results indicate that (1) the proposed system can accurately and effectively discover the requester's friends' abilities and select appropriate solvers and (2) the natural trust relationship in the social network reduces fraudsters and enhances the quality of crowdsourcing services.

1. Introduction

Crowdsourcing systems [1] have become a powerful, scalable, cost-effective method for promptly completing tasks, enabling requesters to allocate large-scale tasks to a crowd and obtaining results by leveraging mass wisdom. A solver crowd is typically large, anonymous, transient, and unprofessional, so that it is challenging to establish a trust relationship between a requester and solvers [2]. Some solvers may not have required abilities for tasks or they may want to obtain the reward without carefully performing the tasks, which significantly influences the quality of the task outputs [3–6].

Many works have documented recently in order to improve the crowdsourcing quality. For example, Howe [1] proposed the *golden standard data* paradigm. Also, Eickhoff et al. [7] and Cao et al. [8] proposed another popular methodology, "*simple majority voting*." Jeffrey et al. [9, 10] leveraged the behavioral traces captured from online solvers to predict the crowdsourcing quality. The method of weighing results based on a solver's historical performance was well established by [5, 6, 11]. Some researchers leverage social relationship in crowdsourcing system [12–14]. However, most of these prior studies have assumed that a crowdsourcing platform has information of all the solvers, and these solvers can be considered as an entire large and stable resource set. The common processing flow is shown in Figure 1(a) where the platform matches the task needs with all the participants. There are two defects in the platform: (1) the tasks can only be distributed by the platform once, and

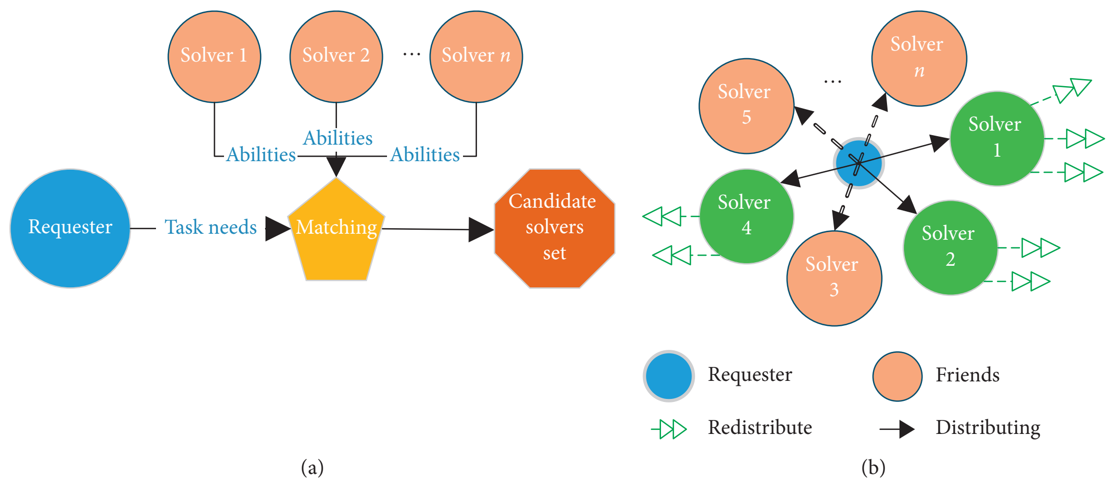

Figure 1: (a) Common node selection of crowdsourcing; (b) illustration of TDSRC.

the distribution process cannot be iterated by the individual solver and (2) all the potential participants can only be the registered users on the platform. In addition, the method of historical performance-based easily incurs a "cold start" because some new solvers have no any historical records.

Considering an alternative scenario in which any participant does not have to register in the crowdsourcing platform, we proposed a novel model called the Task-Distributing system of crowdsourcing based on Social Relation Cognition (TDSRC) where a requester can distribute the crowd tasks to some of his friends without obtaining information about all information of potential participants (e.g., friends' friend). The requester needs only to generate a task and distribute it to his relevant friends. Iteratively, the friends can play the role of the next requester and redistribute the task in their social networks without any extra burden (as shown in Figure 1(b)). By introducing social relation cognition (SRC) into crowdsourcing, we establish a trust relationship that is considered to be challenging in a common crowdsourcing platform [2].

This study has the following contributions:

(i) A method that enables a requester to efficiently distribute a task to more suitable solvers is proposed, and the accuracy of task distribution is promoted

(ii) The social relationship is used to create and distribute a crowdsourcing task in his friend circle directly without obtaining global information (e.g., the set of all candidate solvers) which is often difficult to get

(iii) The system can effectively avoid cold start problem which exists in performance-based methods

The remainder of this paper is organized as follows: The related studies are described in Section 2. Necessary definitions are described in Section 3. Feature discovery and candidate solver selection are discussed in Section 4. The process and simulation are described in Section 5. Section 6 summarizes this work and explores possibilities for future studies.

2. Related Works

Crowdsourcing has been attracted considerable attention since it was proposed approximately ten years ago. Lease et al. [15] indicated that quality control must be considered if the crowdsourcing quality needs to be improved. Eickhoff et al. [7] pointed out that (1) filtering low-quality solvers decreases malicious solvers but causes longer completion times and that (2) a solver's reliability cannot be efficiently ensured by the solver's acceptance ratio of the previous tasks. In general, the selection of crowdsourcing nodes and the guarantee of quality of service are always core issues. Many researchers have made great contributions to different aspects in this field. The following related studies are briefly reviewed as follows.

2.1. Quality Control. Howe [1] proposed the *golden standard data* paradigm. According to the paradigm, certain questions (named *golden standard data*), which are elaborately predesigned with definite baselines, are advocated by careful insertion into the tasks without being identified by solvers. By comparing the solvers' responses to these baselines, a requester can identify unqualified solvers and precisely aggregate all task results. The main flaw of this approach is that the design of golden data is generally challenging and costly. Another popular methodology, "*simple majority voting*" [7, 8], has been extensively discussed. This method classifies solvers' responses and aggregates the results according to the largest number of votes of the classification. Although this method is simple, it fails to identify a deceitful participant. The basic principle state of historical performance-based methods in [5, 6, 11] is that better historical performances are correlated with a greater impact on the aggregate results of the solvers. As a useful complementary technique, Jeffrey et al. [9, 10] leveraged the behavioral traces captured from online solvers to predict the crowdsourcing quality. The behavioral characteristics of the participants are highly correlated with the quality of the crowdsourcing. However, historical performance-based methods, for example, fail to consider the matched degree between the task requirements and the potential solvers' abilities. Some solvers may have better performance for a particular type of task than another [3]. In addition, they easily incur a "cold start" because they require sufficient historical data to build an effective model.

Moreover, some challenges are encountered when crowdsourcing complex tasks. Some tasks (e.g., picture editing) may generate a substantial amount of traffic in task distribution and results collection, which hinders the ability to attract participants due to the large cost of energy and money [16–18]. Therefore, the participants must collaborate with each other (e.g., applying the "*store-carry-forward*" routing pattern [18] to upload the results' data). Considering these facts, an alternative efficient manner for improving the task quality is to allocate the task to appropriate solvers rather than using complete random distribution.

Many researchers have employed social relationships in crowdsourcing. A social relation is considered as an essential and significant attribute of a human being; numerous methodologies are employed to establish social relationships [19–21]. The famous theory of *"six degrees of separation"* [22] maintains that people are six or fewer steps from each other and that a chain of "a friend of a friend" statements can be made to connect any two people using no more than six steps. The trust relationship in society is broadly applied to personalized recommendation systems [23, 24], software crowdsourcing [25], image annotation [26], and so on. Rahman et al. [12] proposed a framework that can create a large ad hoc social network and construct an incentive based on context-aware. This framework can solve many daily life problems such as finding lost individuals, handling emergency situations, helping pilgrims to perform ritual events based on location and time, and sharing geotagged multimedia resources within the crowd. Assem et al. [13] proposed a framework for summing up the crowd mobility patterns in cities using Location-Based Social Networks (LBSNs) data which is a spatial-temporal dataset crawled from Twitter based on nonnegative matrix factorization and Gaussian kernel density estimation. This framework utilizes a temporal functional to discover the correlation between the locations and crowd, and the framework can help in better allocating resources based on the expected crowd mobility. Gan et al. [14] proposed a novel game-based incentive mechanism for multiresource sharing based on social network, and a combination of task allocation process, profit transfer process, and reputation updating process is involved in the incentive to satisfy the truthfulness and individual rationality. Yang et al. [27] introduced a novel approach named the social incentive mechanism to incentivize the social friends of the participants who perform the sensing tasks. The incentive leveraged the social ties among participants to promote global cooperation.

However, the most prior studies focused on obtaining an optimal aggregate result by identifying and excluding frauds after analyzing the collected results of a crowd, which fails to partially remove the deceivers at the earliest time (e.g., the node selection stage). The researches of introducing social relations into crowdsourcing mainly focus on the coverage of sensing region based on the participants' location [12, 13, 28] and motivating participants by utilizing social relationships. They only use the mutual influence between friends [14, 27] and do not classify and quantify the ability of friends.

2.2. Solver Selection. The pioneering literature of solver selection in a social network was described in a study from Lappas et al. [29], in which the authors proposed a model to identify a group of individuals who can function as a team to minimize the communication cost. Zhao Dong et al. [30] designed two online mechanisms based on an online auction model. Under certain constraints (e.g., budget and time), the mechanisms can select proper solvers for different tasks and maximize the value of services. Considering the mobility of the mobile terminals, based on a time-sensitive task and a delay-tolerant task, Guo Bin et al. [31] proposed a framework named "ActiveCrowd" for multitask-oriented solver selection in large-scale mobile crowdsourcing scenarios, which applied the "greedy enhanced genetic algorithm" to achieve optimal or near-optimal solutions for minimizing the total distance and the burden, respectively, for tasks and solvers. According to the constraints of tasks, Zhang et al. [32] provided an incentive mechanism that enables a requester to actively assign most valuable tasks to the solvers. Bozzon et al. [33] proposed a model to select the *top-K* experts in a social network when a set of task needs is received. Considering both the profile information and the social activities, the model matches the expertise needs to candidate experts by formulating them as vectors. In contrast, with other team formation methods, Wang et al. [34] proposed an approach to build a collaborative team in a noncooperative social network, which assumed that individuals are selfish and pursue the maximization of their profits. Montelisciani et al. [35] highlighted some critical issues to structure a team formation with the aim of identifying suitable solvers in crowdsourcing natural language processing (NLP). Qing Liu et al. [36] devised four incentive mechanisms for selecting a team of solvers to accomplish some complex tasks. The authors addressed the team formation problems by formulating them as a task allocation and pricing mechanism design problem.

However, the majority of these authors assumed that the requester (or crowdsourcing platform) can obtain all potential solvers in advance, which is typically impossible and unnecessary in reality. The TDSRC proposed in this paper can accommodate the lack of information about the candidate solvers and needs only routine interactive information between the requester and friends. Based on the *"six degrees of separation"* [37, 38], the trust chain between the requester and solvers can be well established and iteratively transmitted. Relative to strangers, people always prefer to believe people with whom they are more familiar. Deception among friends is relatively lower, and the crowdsourcing results become more precise and reliable [39]. Therefore, using the social relationship, the TDSRC facilitates building a trust chain between the requesters and the solvers and then enhances the accuracy and credibility of task distribution.

3. Preliminary Definitions

We aim to apply the social relations of the requester in the crowdsourcing system. The first step is to discover and quantitate friend features. In this study, friends' abilities have the same meaning as friends' features and include interest, hobbies, personality, characteristics, and integrity.

3.1. Social Network. A social network is a social structure that consists of many nodes that typically refer to individuals or organizations. Such a network links various people or organizations regardless of whether they have a close relationship [37]. The interaction among individual members in the social network form relatively stable relations and influence people's social behaviors [38].

In the book "Networked: The New Social Operating System" [40], published in 2012, Lee Rainie and Barry Wellman described the social network revolution, mobile revolution, and Internet revolution as the three revolutions that influenced human society in the new period.

A social network is formed by nodes and the connections between these nodes. Commonly, nodes consist of different types of properties [22]. The social network in this study refers to any social network. A requester is the center of a network, and an edge is a one-way connection that indicates the friend features evaluated by the center node.

The participant node is denoted as $p = \langle A \rangle$, where $A = \{a_1, a_2, \ldots, a_n\}$ represents the attributes of the node. The social network is denoted as $G = \langle P, E \rangle$, where $P = \{p_1, p_2, \ldots, p_m\}$ denotes the friend nodes of the central node p and $E = \langle e_{i,j} \rangle$, where

$$e_{p,j(m\times n)} = \begin{cases} x \text{ with a direct connection between } p \text{ and } p_j, \\ 0 \text{ no direct communication between } p \text{ and } p_j, \end{cases} \tag{1}$$

where x represents the strength degree of communication between p and p_j and zero indicates that p_j has no communication.

3.2. Definitions Based on SRC. Each node has unique properties, such as hobbies and professional competence. A node typically evaluates the abilities of his friends, such as the specific interests of the friends and the friends that are suitable for specific tasks. p is a node in a social network, and p has m friends. Requesters and solvers are referred to as participants.

For the convenience of reading, the important and frequent notations used in this paper are illustrated in Table 1.

Definition 1 (ability). Ability denotes the qualities that are needed to complete a project or task. An ability is denoted as a in this study.

Definition 2 (abilities set (AS)). This set has all types of abilities to complete a crowdsourcing task. The AS is $A = \{a_1, a_2, \ldots, a_n\}$ in our system. AS is a global factor that should be shared in this system.

Table 1: Frequently used notations.

Notation	Description
a	An ability
p	A participant node
AS	Abilities set
ASS	Subset of AS
AV	Ability value
ACR	Abilities coverage rate
QF	Qualities factor
$F^{a_k}_{p,p_j}$	The communication times in a sampling time between node p and his friend p_j for the ability (topic) .
HI	Ho a_k nesty index
FAV	Friends' abilities vector, the ability values of a friend in different task classification
FAM	Friends' abilities matrix, the ability values of all friend in different task classification
e_{p,p_j}	The FAV that node p gives to his friend p_j
$C^{a_k}_{p,p_j}$	The communication times between p and his friend p_j for ability a_k.

Definition 3 (abilities subset (ASS)). This subset consists of the elements from the AS.

Definition 4 (abilities value (AV)). This digital denotation corresponds to the AS. We denote it as C. For example, $C_p = \{C_p^{a1}, C_p^{a2}, \ldots, C_p^{a_n}\}$ denotes the abilities of node p. The original value is set between zero and one by p, and the default value is zero.

Definition 5 (abilities coverage rate (ACR)). The ACR is the proportion of the actual AS of the solvers to the demanded AS of the requester. We use δ to denote it as follows:

$$\delta = \frac{AS_{\text{so}} \cap AS_{\text{se}}}{AS_{\text{se}}}, \tag{2}$$

where AS_{so} denotes the AS of the solvers and AS_{se} represents the demanded AS of the solvers.

The ACR indicates the match degree between the solvers and the task. For example, if the government wishes to conduct a public poll, certain characteristics of the informants, such as knowledge, background, location, job category, sexuality, income, and party category, may substantially influence the results. The larger the ACR, the more typical are the results.

Definition 6 (qualities factor (QF)). The QF is the comprehensive valuation given by all friends of a solver after the solver finishes a crowdsourcing task. The QF can be denoted as Q. Hypothesis s_j is the total number of tasks that the friend p_j invited p to perform. After the tasks are completed, p_j gives p a valuation according to the performance of every task. The valuation is represented as y_z, $(z = 1, 2, s_j)$ and $y_z \in [0, 1]$, and QF is denoted as Q_p^j:

$$Q_p^j = \frac{\sum_{z=1}^{s_j} w_z^j * y_z^j}{s_j}, \quad j = 1, 2, \ldots, m, \tag{3}$$

where w_z^j indicates the weight of the task Z of the friend j and $w_z^j \in [0, 1]$.

Definition 7 (communication). Communication represents the interaction times between a node and its friends in the social network. A short message, telephone, and information receiving and sending on social software can be counted in communication. We use F_{p,p_j} to denote the total communication times in a sampling time between node p and his friend p_j.

Definition 8 (honesty index (HI)). This index is a weighted average of the *QF* evaluated by all a solver's friends. We denoted it as h, and it is a global variable. For example, h_p denotes the total evaluation that all friends of node p give to p:

$$h_p = \frac{\sum_{j=1}^{m}\left(W_p^j * Q_p^j\right)}{m}, \tag{4}$$

where W_p^j denotes the weight of the friend j to node p, which is generally set to one.

Definition 9 (friends' abilities vector (FAV)). A solver, as the central node in his social network, gives the *AVs* to one of his friends based on the *AS* according to their communications. For example, the *FAV* that node p gives to his friend p_j is denoted as e_{p,p_j}:

$$e_{p,p_j} = \left[x_{p,p_j}^1, x_{p,p_j}^2, \ldots x_{p,p_j}^n\right]. \tag{5}$$

Definition 10 (friends' abilities matrix (FAM)). The *FAM* of a node is a matrix that consists of all the node's *FAVs*. For example, the *FAM* of node p is denoted as E_p:

$$E_p = \begin{bmatrix} e_{p,1} \\ e_{p,2} \\ \vdots \\ e_{p,m} \end{bmatrix}. \tag{6}$$

4. Feature Discovery and Candidate Solver Selection

As previously discussed, we redefine the node p in the social network as a triple:

$$p = \langle h_p, C_p, E_p \rangle, \tag{7}$$

where h_p indicates the *HI*, C_p denotes the *AVs*, and E_p represents the *FAM*.

4.1. Computing and Updating the AVs. where d represents the total sampling times, and $C_{p,p_j}^{a_k}$ denotes the communication times between p and his friend p_j for ability a_k. The *AVs* update once in every sampling period, and $C_p^{a_k} \in [0, 1]$.

4.2. Computing and Updating the FAM. where F_{p,p_j} denotes the total communication times between node p and his friend p_j, and $F_{p,p_j}^{a_k}$ represents the times for the ability (topic) a_k.

Based on formula (4) and algorithms 1 and 2, node p can reconstruct itself as the following form:

$$p = \left\langle h_p, \left\{C_p^{a1}, C_p^{a2}, \ldots, C_p^{a_n}\right\}, \begin{bmatrix} x_{p,1}^1 & x_{p,1}^2 & \cdots & x_{p,1}^n \\ x_{p,2}^1 & x_{p,2}^2 & \cdots & x_{p,2}^n \\ \vdots & \vdots & \cdots & \vdots \\ x_{p,m}^1 & x_{p,m}^2 & \cdots & x_{p,m}^n \end{bmatrix} \right\rangle. \tag{8}$$

4.3. Candidate Nodes Selection for Task Distribution

4.3.1. Definition 11 (candidate nodes (CNs)). The *CNs* comprise a friend subset (*FSS*) whose *AVs* match the task's demands.

When p wants to distribute a task, all he needs to do is select the task topics and set the weight for each topic. If the task is associated with a location, his friends are filtered based on the location. Then, the TDSRC generates the *CNs* by algorithm 3.

The topics (abilities) of the task should be set by node p; two main parameters must be set: *ASS* and the weight of this subset. Assuming that $ASS = \{a_{u1}, a_{u2}, \ldots, a_{up}\}$, the corresponding weight is $\{w_{u1}, w_{u2}, \ldots, w_{up}\}$, the node number in *CN* is α, and $u1, u2, u3 \in \{1, 2, \ldots, n\}$.

4.4. Quick Task-Distribution Mode Based on Abilities Coverage. According to algorithm 3, the *CNs* of p can be determined, and then p can push the task forward to the *CNs*. As shown in Figure 2, the social network of p is surrounded by a red dotted line. The *CNs* of p may be $\{p_1, \ldots, p_m\}$, and p does not push the task to $\{p_3, p_4, p_5\}$, whose backgrounds are gray. The friend who receives the task can complete the task or redistribute the task in his social network in the same manner. The processes can be repeated until the task is completed.

According to the concept of "*six degrees of separation*", a task can be sent to anybody in the world by transferring six times [23–26]. Every time, we let a participant push the task to α friends in his social network (the value of α can be changed according to the demand). As a result, the distribution accuracy of the TDSRC is higher than that of a random distribution, and friends can avoid interference by irrelevant information.

5. Frameworks and Simulation

5.1. Framework and Process of the System. The modules and flow of the distribution system are illustrated in Figure 3. Assumption: *P4* is the requester who wants to distribute a task. The main processing flow may be expounded in the following steps:

Step 1. Requester *P4* extracts the historical contents and records between his friends and himself.

Step 2. *P4* statistically analyzes the contents and records, selects suitable abilities from the *AS*, and sets relevant weights to generate the task requirements.

Input: *communication times of p and his friends for different keywords;*
Output: *ability value for node p;*
n: *number of ability types;*
m: *number of p's friends;*
(1) **For** $k = 1, 2, \ldots, n$
(2) $C_p^{a_k} = (C_p^{a_k} / \sum_{k=1}^{n} C_p^{a_k})$; //*Normalization of the initial AVs for node p.*
(3) **End for;**
(4) $k = 1$; $j = 1$;
(5) **Do while** $k \leq n$
(6) **Do while** $j \leq m$
(7) $C_p^{a_k} = (C_p^{a_k} + (\sum_{j=1}^{m} C_{p,p_j}^{a_k} / \sum_{j=1}^{m} \sum_{k=1}^{n} C_{p,p_j}^{a_k})/d)$; //*Dynamic updating of AVs of p.*
(8) $j = j + 1$;
(9) **End Do;**
(10) $k = k + 1$;
(11) **End Do;**

Algorithm 1: Dynamic updating of the AVs.

Input: *communication times of p and his friends for different keywords;*
Output: *the ability value for p's friends;*
(1) $k = 1$; $j = 1$;
(2) **Do while** $k \leq n$
(3) **Do while** $j \leq m$
(4) $x_{p,p_j}^{k} = h_p * (x_{p,p_j}^{k} + (F_{p,p_j}^{a_k} / \sum_{j=1}^{m} F_{p,p_j})/d)$;
(5) $j = j + 1$;
(6) **End Do;**
(7) $k = k + 1$;
(8) **End Do;**

Algorithm 2: Dynamic updating of the FAM.

Input: *FAM of p and task demand;*
Output: *the candidate sequence for p to distribute the task;*
(1) **For** $i = 1$ *to* m;
(2) $WA_i = \sum_{i=1}^{up} w_{ui} * x_{p,ui}^{ui}$
(3) **End For;**
(4) Sorting WA_i *from large to small, assuming the first* α *numbers are* $\{WA_{p1}, WA_{p2}, \ldots, WA_{p\alpha}\}$, *where* $p1, p2, \ldots, p\alpha \in \{1, 2, \ldots, m\}$
(5) $CNs = \{p_{p1}, p_{p2}, \ldots, p_{p\alpha}\}$;

Algorithm 3: Discovering the CNs.

Step 3. As the center, *P*4 reconstructs his social network and generates the triple, as shown in formula 7.

Step 4. *P*4 generates *CNs* using algorithm 3, and some best-matched friends in *CNs* are chosen as the solvers.

Step 5. The solvers iteratively undertake or redistribute the task.

Step 6. *P*4 evaluates the responses of the friends.

Step 7. *P*4 updates relevant data in his tables.

Step 8. Friends are regarded as the next requesters if they redistribute the task in their social network. These steps are repeated (as shown in Figure 2, second distribution).

5.2. Simulation. In recent years, WeChat has become the most popular social network in China. In 2017, the number of monthly active users reached 963 million, which is 20% more than the previous year [41]. By the end of 2016, the WeChat public platforms published an average of 518 articles, each of which was read approximately 3603 times and won 17 praises [42]. Thus, WeChat has excellent transmission capacity. Regarding privacy protection, any individual in WeChat is restricted to viewing his contents and records through the WeChat system, which is suitable to our system. TDSRC simulates the process of information diffusion in a friends circle in WeChat.

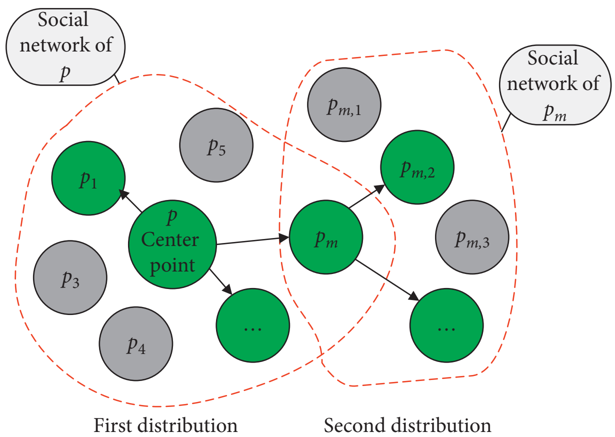

Figure 2: Task releasing mode based on social relationship.

5.2.1. Data Preparing. A dataset for our scheme does not exist, and conducting a comparable and real experiment to examine our scheme is challenging. The study by Bozzon et al. [33] employed a perspective that is similar to our perspective. The authors selected the *top-K* experts in a social network who fulfilled the task needs, and all potential experts were regarded as a stable and whole resource set. However, the set of candidate experts cannot be built in our system, which prevents the outcome of the two methodologies from being directly comparable. Therefore, to validate the feasibility of our scheme, we leverage web crawler technology to grab the data, e.g., task categories, time, and other data for about 8 weeks on ZhuBaJie [43], which is an actual and well-known crowdsourcing platform in China. Then we simulate data according to those data. Similar to [33], in which the experts' needs were classified into seven domains (namely, *computer engineering, location, movies and TV, music, science, sport, technology, and video games*), we approximately categorize the tasks into ten types by investigating ZhuBaJie. The tasks are designated $A = \{1, 2, \dots, 10\}$. Several keywords are extracted in every type, as shown in Table 2.

Assumption: Node p has 100 friends numbered from 1 to 100. The data are sampled once every three months. Ten topics (abilities) exist, as shown in Table 1. The communication times between p and his friends range from 0 to 300. The abilities' interactive times follow a Poisson distribution. Several topics are randomly selected from the ten topics, and the *FAM* of p is calculated and shown in Table 3. Only 20 friends are included in the table due to length restrictions. The numbers in the table indicate the communication times with different friends for different topics in a sampling cycle. This table can also be denoted as E_p (formula 6).

5.2.2. Abilities Discovery of Friends. The data in Table 3 cover only one sampling period. We also count the communication times in five sampling periods. The *AVs* of p can be calculated by algorithm 1, and the results after the data are normalized by formula 7 are shown in Table 4. From Table 4, we can easily determine the largest value. Column 1 and column 10 contain the largest amount of data, which indicates that p is good at (i.e., interested in) abilities 1 and 10.

The differences between one sampling and five samplings are shown in Figure 4. Only Nos. 14, 28, 42, 85, and 100 are randomly selected as the examples.

As shown in Figure 4–7, Figure 4 is similar to Figure 5, and Figure 6 is similar to Figure 7. We can conclude that the number of times for topic 1 is large, whereas the number of times for topic 2 and topic 3 is small, which implies that the *AVs* of p is relatively stable and that p likes topic 1 and he probably is interested or skilled in topic 1.

5.2.3. CN Selection. Because a requester intends to distribute a crowdsourcing task, he should select *ASS* and the weight of *ASS*. Using algorithm 3, for every ability, p can select the highest priority of ten (or other number according to the demands) friends to perform or redistribute a task. In the experiment, the *CNs* obtained by algorithm 3 are listed in Table 5. If p needs to release a crowdsourcing task of topic 1, he should send the task to his 92nd, 78th, 2nd, 46th friends, and so on.

The experimental results with multiple topics/abilities are shown in Table 6.

The simulations reveal that the TDSRC can successfully count the communication times according to the *AS* and calculate the *AVs* and *FAM*. These parameters can be simultaneously updated according to the sampling period. For any task, the TDSRC can correctly determine the most appropriate *CNs* by matching the abilities' demands and the friends. A *CN* can complete and redistribute the task in his social network, and all procedures can be iterated until the task constraints (e.g., time constraints) are violated.

5.2.4. Time Efficiency of Task Distribution. The time efficiency of task distribution is very significant mainly for delay-sensitive tasks. Therefore, we randomly selected three different types of tasks: Sports, Business, Public welfare, and Manufacturing (Nos. 1, 2, 9, and 10 in Table 2). We applied three simulation experiments, i.e., random distribution method, full distribution method, and TDSRC distribution method. In the experiment, we have 2,000 friends. We assume that the success of the task distribution is that we receive valid task execution results from 50 friends. We, respectively, selected 200 friends for the random method and TDSRC method, and full distribution means that the task is distributed to all friends. In the experiment, we also assumed that when the task ability requirement falls in the top 50% of the friend's ability matrix (FAM), it means that the friend will perform the task. The time spent on the task means the average time spent of the 50 friends. The experiment results for different methods are shown in Figure 8.

As can be seen from Figure 8, the random strategy takes the longest time because it cannot accurately find the most appropriate participants. The results of the full strategy are almost the same as the TDSRC strategy, which shows that TDSRC can accurately find the suitable task workers almost as much as the full strategy. However, the number of samples selected by TDSRC is only one-fifth of the full strategy, which means TDSRC brings much less interference to unrelated friends than full strategy. In addition, most task

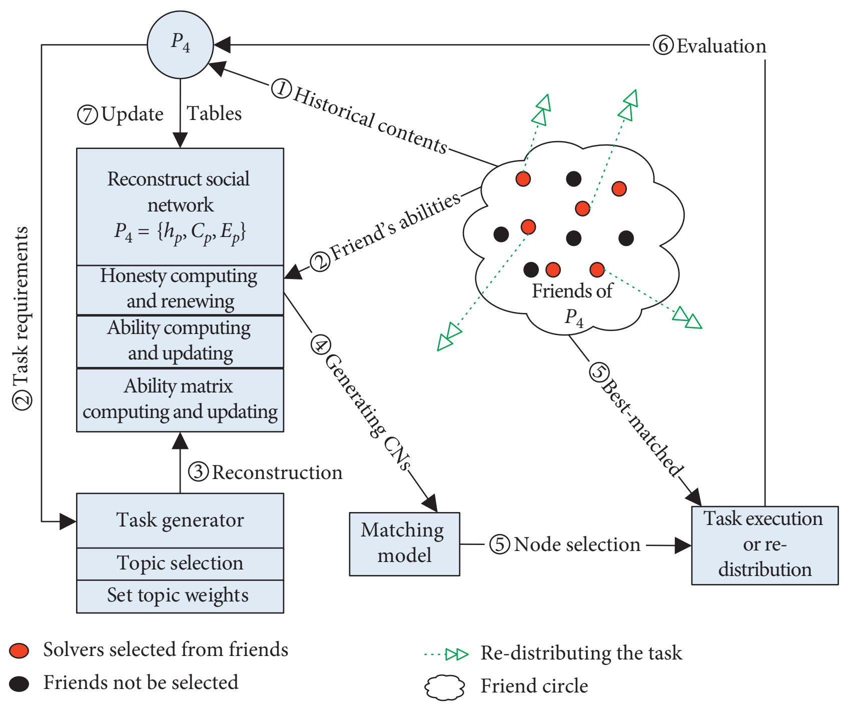

Figure 3: Crowdsourcing flow based on SRC in the social network.

Table 2: Task topics and relevant keywords.

Ability no.	Topic/ability (AS)	Keywords
1	Sports	Basketball, football, badminton, table tennis, running. . .
2	Business administration	Finance, law, register, HR, patent, taxation. . .
3	Part-time jobs	Part-time, promotion, typewriting, shopping, sharing. . .
4	Brand ideas	Logo, packaging, AD, VI, cartoon, video production. . .
5	Health and medicine	Ill, sickness, disease, cold, infect, food, drink, contagion, health. . .
6	Software	APP, test, website, H5, UI, develop, 3D VR. . .
7	Scientific research	Poll, mark, questionnaire, survey, research investigating, science, lab, experiment. . .
8	Personal lives	Translation, shoot, camera, travel, name, photo. . .
9	Public welfare	Donation, pollute, opinion, jam, safe, reward, old, young. . .
10	Manufacturing	Hardware, industry, machine, intelligent. . .

Table 3: FAM of p (20 friends, one sampling cycle).

Friends	Abilities									
	1	2	3	4	5	6	7	8	9	10
1	157	19	25	57	103	126	98	78	149	134
2	51	36	12	45	21	31	22	27	27	74
3	62	18	65	77	27	108	57	21	77	56
4	61	22	65	96	63	68	58	75	58	73
5	178	40	110	94	86	164	53	88	109	161
6	196	129	48	65	91	57	121	158	101	120
7	5	3	3	3	2	5	1	2	1	5
8	52	35	29	20	56	69	17	27	20	31
9	106	15	71	55	13	60	65	71	92	57
10	44	11	22	48	50	59	3	18	43	46
11	108	87	46	61	105	103	62	51	89	160
12	10	7	1	9	2	7	3	7	8	9
13	48	44	19	77	72	93	44	25	47	69
14	143	23	122	144	32	68	51	81	105	95
15	112	96	15	76	18	98	88	107	98	94
16	54	63	59	82	54	69	29	64	98	64
17	11	2	6	3	5	6	3	3	4	7
18	117	114	123	70	47	114	127	125	73	202
19	71	58	50	73	26	46	5	59	50	29
20	31	0	22	24	28	18	27	11	10	19

distribution is accompanied with some incentives, and the TDSRC strategy can save more costs than full distribution strategy.

6. Conclusion and Future Work

Adequate qualified participation is one of the most crucial factors that determine whether a crowdsourcing system can achieve perfection. We expand participants' coverage to location, attributes, background knowledge, social relations, and credibility. The TDSRC can dynamically and automatically discover participants' abilities according to the routine communication between requesters and friends and then reconstruct their social networks to facilitate task distribution. This study is the first investigation of tasks distribution by leveraging the trust chain and transmission capabilities implied in a friends circle. The TDSRC not only

Table 4: Statistics of AVs for various sampling times (normalized).

Sampling times	AVs (ability from 1 to 10)
1	(0.1274, 0.0751, 0.0703, 0.1183, 0.0853,0.1204, 0.0840, 0.0906, 0.0996, 0.1289)
5	(0.1422, 0.0789, 0.0781, 0.0787, 0.0943,0.1245, 0.0902, 0.0800, 0.1096, 0.1236)

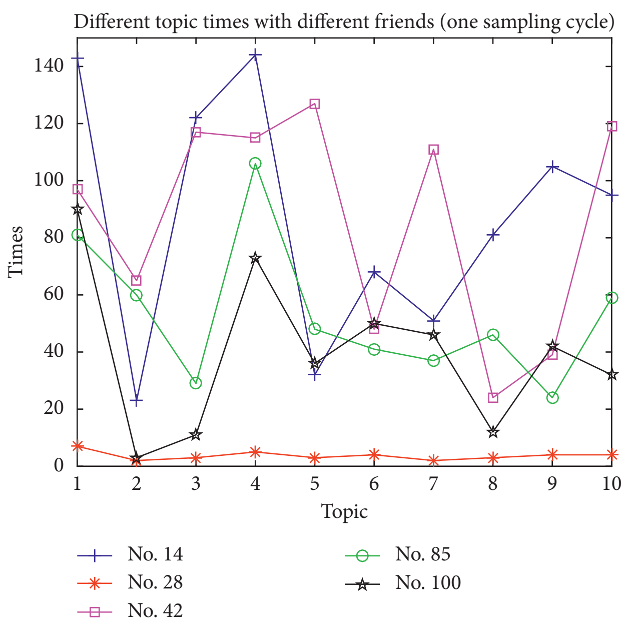

Figure 4: One sampling period.

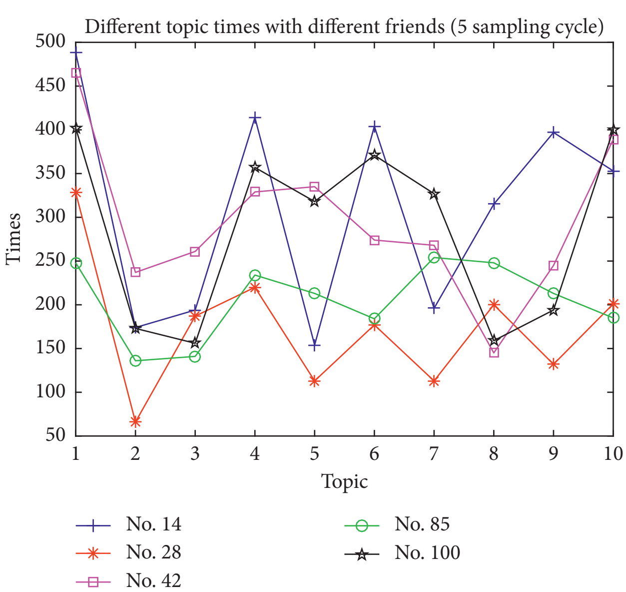

Figure 5: Five sampling periods.

improves the rapidity, precision, and extensity of task distribution but also protects privacy and avoids building a set of all candidates. The simulation results verify the effectiveness of the TDSRC. However, several issues warrant future investigation.

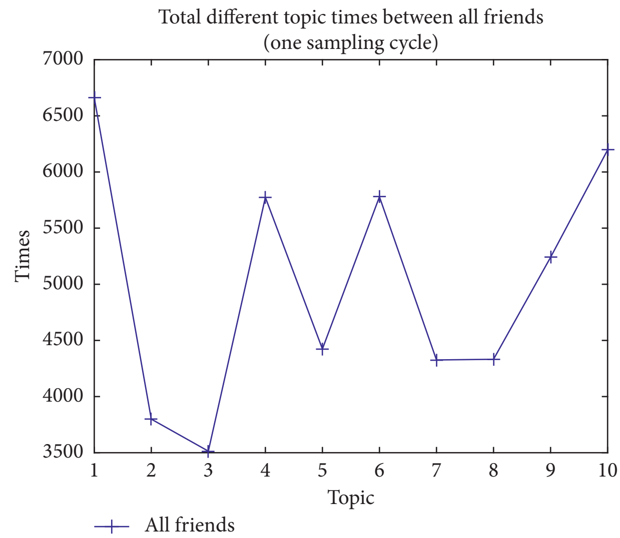

Figure 6: One sampling period.

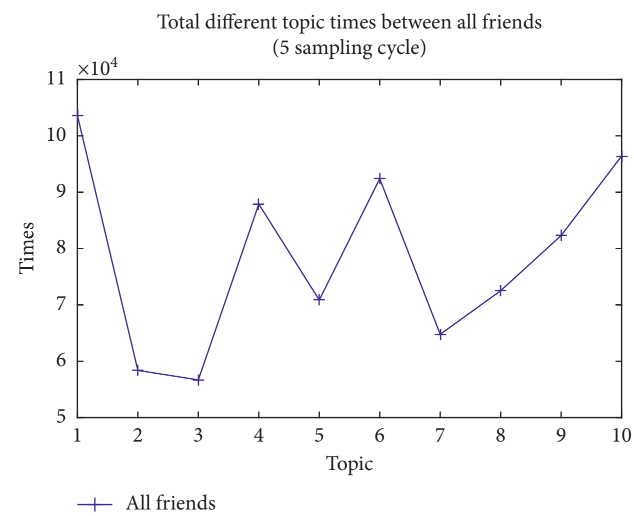

Figure 7: Five sampling periods.

6.1. Time Factor of Keywords. In this study, we employ communication content without considering the time factor, which is significant (e.g., a keyword that appeared one month ago is more important than a keyword that appeared six months ago). The TDSRC becomes more complex if the time factor is considered. We can compromise by setting different weights for different sampling periods. The nearer the time, the more important the content.

6.2. Weight Values of Friend Evaluation. Many weights should be set in the TDSRC (e.g., formulas 3 and 4). Different weights produce different results. Setting the weights is a topic worthy of further discussion. In our system, we use default values, which can typically be manually set by the central node. In the future, we will attempt to employ machine-learning methods to automatically set these weight values.

Table 5: Selection results of CNs with single ability.

Topic/ability no.	Candidate sequence nodes (CNs)									
1	92	78	2	46	94	30	73	49	1	8
2	24	46	83	52	92	1	59	6	95	15
3	31	75	98	83	52	46	78	11	80	92
4	52	30	31	57	66	83	53	42	69	51
5	69	68	46	30	75	2	78	25	51	96
6	78	30	83	66	31	88	92	97	10	52
7	30	50	92	3	80	51	68	83	10	46
8	78	83	46	52	69	66	75	30	97	6
9	30	52	97	75	80	66	12	42	83	92
10	2	46	80	32	57	43	94	12	52	83

Table 6: CN selection results with multiple abilities.

Topic/ ability no.	Weight respective	Candidate sequence nodes (CNs)									
1, 4	0.4, 0.6;	92	30	52	2	31	78	94	46	83	68
5, 9	0.8, 0.2;	69	30	75	46	2	68	57	24	42	31
3, 8	0.3, 0.7;	78	83	46	52	75	11	34	10	69	92
2, 6	0.9, 0.1;	83	46	24	52	92	1	59	30	43	6
7, 10	0.6, 0.4;	80	46	30	92	83	2	68	12	25	57
6, 9	0.5, 0.5	30	52	66	83	97	92	75	80	31	2

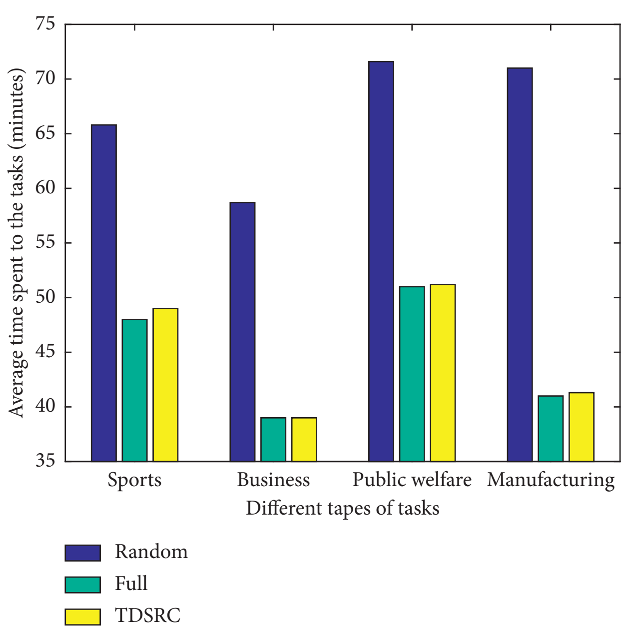

Figure 8: Time efficiency under different distribution strategies.

6.3. Varied Interactive Data. In this study, we considered only the contextual information. In reality, extratextual elements, such as voice, pictures, and emoji, are also popular in WeChat. Such elements play an increasingly important role in expressing emotions among friends. To take advantage of all information, AI technologies, e.g., speech recognition and image understanding, should be incorporated to enhance the complexity of the TDSRC. We plan to conduct extensive research in this area in the future.

Data Availability

The data used in the study come from ZhuBaJie (a crowdsourcing network in China; https://www.zbj.com/).

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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Research Article

Spatial Crowdsourcing Quality Control Model Based on K-Anonymity Location Privacy Protection and ELM Spammer Detection

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The spatial crowdsourcing task places workers at a risk of privacy leakage. If positional information is not required to submit, it will result in an increased error rate and number of spammers, which together affects the quality of spatial crowdsourcing. In this paper, a spatial crowdsourcing quality control model is proposed, called SCQCM. In the model, the spatial k-anonymity algorithm is used to protect the position privacy of the general spatial crowdsourcing workers. Next, an ELM (extreme learning machine) algorithm is used to detect spammers, while an EM (expectation maximization) algorithm is used to estimate the error rate. Finally, different parameters are selected, and the efficiency of the model is simulated. The results showed that the spatial crowdsourcing model proposed in this paper guaranteed the quality of crowdsourcing projects on the premise of protecting the privacy of workers.

1. Introduction

Computer-supported collaborative work is an exciting research field [1], wherein "crowdsourcing" is an important topic. Crowdsourcing was first proposed in June 2006 by Jeff Howe, a journalist from the United States Magazine Connection, which he defined as a type of a working model where a company or agency outsources the work of a hired employee or a full-time outsourced person to a nonfull-time group via an open network platform. Crowdsourcing tasks are usually done voluntarily by individuals or groups of people. The key of crowdsourcing is to make full use of the labor resources of the open network platform to accomplish simple or complex tasks [2]. As a successful model that makes full use of group intelligence, crowdsourcing has been widely used for tasks such as picture tagging, natural language comprehension, market prediction, and view mining. In recent years, crowdsourcing has received extensive attention in the fields of translation, logistics, transportation, and lodging and has gradually become a new research hotspot. However, the future of crowdsourcing faces many theoretical and practical challenges.

With the improvement of mobile internet technology and the computing and sensing abilities of mobile devices, a crowdsourcing form of these technologies based on user location information has become popular. Kazemi and Cyrus [3] calls this kind of crowdsourcing as "spatial crowdsourcing" (SC), whose tasks are mainly related to space and location. As a special form of crowdsourcing, SC has become a new research topic in academic circles (What TaskRabbit Offers [EB/OL] (2017-08-25) [2017-08-28]; https://support.taskrabbit.com/hc/en-us/articles/204411410-What-TaskRabbit-Offers) and industry [4]. Typical SC is achieved via a crowdsourcing platform that assigns tasks to nearby workers, who in turn move to the designated locations to complete the assigned spatial tasks. Through this kind of crowdsourcing, people can make better use of swarm intelligence to accomplish simple or complex spatial tasks. Although spatial crowdsourcing makes full use of swarm intelligence and brings great benefits, the construction and promotion of crowdsourcing platforms are not easy. A crowdsourcing platform releases and allocates spatial tasks according to the location information submitted by the user, which will include sensitive information [5], such as the identity of the user, their home address, their health status, and living habits.

In recent years, smart mobile phones have been used as multimode sensors that collect and share various types of data, including pictures, video, location, moving speed, direction, and acceleration. Therefore, crowdsourcing platforms can obtain considerable amounts of user location data through smart mobile phones, which may lead to a leakage of sensitive information and seriously threaten the users' privacy. For example, in July 2018, the poor management of the website http://datatang.com resulted in a tremendous infringement of personal information privacy. In eight months, the http://datatang.com website used spatial crowdsourcing to transmit personal information at an average of 130 million items per day and a total cumulative transmission of compressed data of about 4000 GB, including highly private data. The problem of user information security in terms of spatial crowdsourcing has become an urgent problem in theory and practice.

Crowdsourcing information sharing is a double-edged sword. On the one hand, crowdsourcing information sharing can ensure the smooth development of work and prevent dishonest cheating workers [6] and spammers from making money. On the other hand, crowdsourcing information sharing requires location information of the workers, which not only threatens the privacy of the workers but also affects their enthusiasm for work, especially if they are worried about the leakage of their private information. How to effectively achieve a balance between privacy protection and quality control has become a difficult problem in spatial crowdsourcing, and it is a blind spot in the existing literature.

At present, scholars have done a lot of research on the prevention of privacy leakage. In 2002, Sweeney [7] put forward the K-anonymity privacy protection technology to solve the problem of personal and sensitive data leakage. On this basis, additional researchers further proposed a number of improved algorithms, such as the L-diversity method [8], the t-closeness method [9, 10], (α, k) anonymity algorithms [11], and the ε−cloning [12] method, which can better prevent privacy disclosure when publishing data sets. However, the above methods are often targeted as static data sets; that is, all data are published only once, and no data updates are made after publication. The location information in spatial crowdsourcing scenarios change with any change in the platform tasks, which demonstrate the dynamic characteristics of continuous publication. Hu et al. [13] studied the spatial crowdsourcing location privacy protection in a P2P communication environment and implemented spatial crowdsourcing worker location privacy protection using a peer-to-peer spatial k-anonymity algorithm [14]. Their method solved the problem that it is not considering the spatial domain attributes of each crowdsourcing worker in the differential privacy space decomposition method studied in [15]. Vu et al. [16] proposes a privacy protection mechanism based on a locally sensitive hash [17], which protected the user's identity and location information in participatory perception scenarios. The location privacy protection based on differential k-anonymity proposed by Wang et al. [18] can resist persistent and background-based attacks. A definition of spatial crowdsourcing location k-anonymity was given by An et al. [19]. All the above studies have proved that K-anonymity algorithms can solve the privacy leakage problem in spatial crowdsourcing scenarios. However, the focus of the above research was only on privacy leakage, and the quality control of crowdsourcing was not considered.

Varshney et al. [20, 21] use two different schemes based on the random noise method to prevent publishers' privacy from being attacked by multiple workers. Hiroshi et al. [22] proposed a privacy protection protocol based on decentralized computing to ensure workers' privacy under the premise of quality control. The above literature only considered the balance between privacy protection and quality control, while the issue of publisher privacy protection is considered in the current study. What we aim to find is a balance between privacy protection and the quality control of workers in SC.

To sum up, in practical application scenarios of SC, workers need to submit their own location information to the crowdsourcing service platform, which has the risk of privacy leakages. However, the existence of errors arising from the normal crowdsourcing workers and any deceptive workers/spammers has led to a quality problem in crowdsourcing services. Our aim was to protect the location privacy of crowdsourcing workers, identify and exclude spammers, and reduce the error rate to ensure crowdsourcing quality control.

This article is structured as follows. In Section 2, we give the complete definition of our proposed SC anonymity technology and privacy protection models based on spatial anonymity technology and introduce the process of spammer identification with an ELM algorithm. In Section 3, we introduce our experiments, and in Section 4, we analyze the results. Finally, in Section 5, we summarize our study.

2. Problem Solving Ideas

First, a description of the crowdsourcing quality control problem in the SC scenario is given, and a solution to the balance between location privacy protection and crowdsourcing quality control is given. Then, a complete definition of the used privacy protection model based on spatial anonymity technology and the principle of spammer recognition via ELM [23] are given.

2.1. Problem Description. Consider a typical crowdsourcing scenario: one-task publishers (requester) publish m tasks $T_i\,(1 \le i \le m)$, where n workers (worker) $W_j\,(1 \le j \le n)$ are involved in the task completion. Each task is completed by n workers, and each worker completes m tasks; however, a single task is completed by only one worker. The matrix $V_{m\times n} = \{v_{ij}\}$ represents all the task results submitted by the workers, and $V_{m\times 1} = \{v_i\}$ represents the correct result of each task. To simplify the problem, we assume that T_i is a two-tuple problem, and W_j only needs to answer "yes" ($v_{ij} = 1$) or "no" ($v_{ij} = 0$). The conclusion of the two-tuple model is not difficult to expand and apply to other task types [22]. The quality control problem of crowdsourcing is how requesters can deduce the correct result, $V_{m\times 1}$, of all tasks according to the result, $V_{m\times n}$, submitted by the workers. In the process of crowdsourcing quality control, there are at least two types of crowdsourcing quality disturbance factors: deceptive workers, called spammers, and the worker error rate, η. In order to maximize the benefits per unit time, spammers will not seriously submit low quality task results, and even diligent and conscientious workers may submit incorrect results at a certain error rate. Therefore, to carry out crowdsourcing quality control, we need to exclude spammers and reduce the error rate.

2.2. Solutions. For the privacy protection of spatial crowdsourcing, in this paper, we give a complete definition and workflow of a privacy protection model of spatial anonymity technology based on the method presented in [23]. In order to gain greater pay, spammer-type workers will submit the most amount of information in the shortest space of time. However, the number of submissions, time changes, and other parameters of ordinary workers will show different characteristics. According to these characteristics, machine-learning algorithms can achieve the purpose of identifying spammers. An extreme learning machine (ELM) is a fast, single, hidden layer feedforward neural network training algorithm, which is faster than the traditional neural networks under the premise of ensuring good accuracy [24]. Traditional neural network learning algorithms (such as the BP (back propagation) algorithm) need to set a large number of network training parameters artificially, and they easily fall into local optima. The ELM algorithm only needs to set the number of hidden layer nodes of the network, and it does not need to adjust the input weights of the network and the biases of the hidden layer units in the process of algorithm execution; these conspire to produce a unique optimal solution. Therefore, the ELM algorithm has the advantages of fast learning speed and good generalization performance, and it is used in this paper to identify spammers.

For the problem of the worker error rate, the EM (expectation maximization) algorithm [25, 26] is used to estimate worker errors. Firstly, the correct rate (correct rate + error rate = 1) is used as the correct weight estimation for each task, and the specific implementation is to assign the same task to multiple workers who complete the task independently. Then, we take the majority of the results as the correct result and update the error rate estimation of each worker with it. Next, the error rate of multiple workers is estimated with a maximum likelihood method, and the two steps of E-step (Expectation step) and M-step (maximization step) are repeated until the result converges.

Based on the above ideas, this paper proposes a Spatial Crowdsourcing Quality Control Model (SCQCM) to solve the balance between location privacy protection and cheating-worker screening and error rate estimation.

2.3. Privacy Protection Model Based on Spatial Anonymity Technology. First, the basic concept of the spatial anonymity technology is introduced, and the workflow of our SC platform is given. Then, the k-anonymity and privacy of spatial crowdsourcing location are defined. Finally, a privacy protection model based on the spatial anonymity technology is given.

2.3.1. Basic Concepts. The following steps and terms are defined here:

(1) *The task requester* [27], in short, is called as "requester."

A requester first registers on the crowdsourcing platform, whereby it performs a series of tasks related to designing and releasing of spatial tasks, refusing or receiving the results from the workers, and collating the results. A requester is often defined as $R = \langle L_R, T_R\rangle$, where L_R represents the location information of the requester and T_R represents the task that the requester releases.

(2) *Spatial tasks* [2, 27]. A spatial task is usually a special task that has geographical location and time attributes. It is generally defined as a four tuple: $T = \langle L_T, t_{\text{begin}}, t_{\text{end}}, P_T\rangle$, where L_T represents the location of the spatial task, t_{begin} represents the release time of the spatial task, t_{end} represents the cutoff time of the spatial task, and P_T represents the reward for the completion of the task.

(3) *Spatial crowdsourcing worker*, in short, is called as "worker" [2, 27]. The workers are the mobile device users who perform the spatial task(s). They can select a spatial task, accept the task, submit positional information, and submit the result by registering on the crowdsourcing platform. A worker is usually defined as a three-tuple: $W = \langle L_W, R_W, T_{\max}\rangle$, where L_W represents the current location information of the worker, R_W indicates the spatial domain that the worker can accept, and $T_{\max}$ represents the maximum number of tasks that the worker can accept in the spatial domain, R_W.

(4) *Spatial crowdsourcing.* The complete SC includes task requesters, SC tasks, SC platforms, and SC workers. Spatial crowdsourcing usually refers to the process where a requester designs a SC task and publishes it to the SC platform. In turn, the SC platform realizes the task assignment, and the workers accept and complete the spatial task at a designated place. The basic spatial crowdsourcing model is shown in Figure 1.

2.3.2. Work Flow. As the core of SC, the SC platform establishes a cooperative relationship between the requester and the worker based on the spatial task, which is

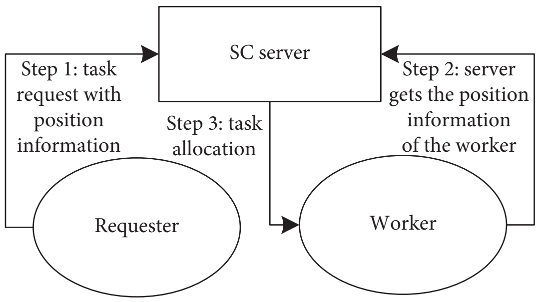

Figure 1: Basic model of spatial crowdsourcing (SC).

responsible for comprehensively processing the task and/or individual position information submitted by the requester and the worker. Figure 2 shows the SC workflow. In general, the SC platform first collects the task information from the requester and the location information from the worker. The information is preprocessed by the data processing module who then submits a request to the task allocation module, which then completes the task allocation. Finally, the spatial tasks are completed by the worker, and the results are submitted to the quality control module.

According to the allocation of spatial tasks, SC can be divided into two operating modes: WSTs (Worker Selected Tasks; worker selection modes) and SATs (Server Assigned Tasks; server assignment task modes). First, let us consider the WST mode workflow: crowdsourcing workers take the initiative to find tasks released on the platform according to their own spatial location information and choose the appropriate spatial tasks to perform. Next, in the SAT mode workflow, workers first submit their spatial location information to the platform. The data process module matches the position information of the worker with the task, and if it is matched, it allocates a task to the worker. Then, the workers decide whether to accept the assigned task. As the task selection in the WST mode is done by the crowdsourcing workers themselves, they do not need to upload their location information: hence, this mode is not considered in this paper. Instead, in this article, we only analyze SAT patterns.

2.3.3. Spatial Crowdsourcing Location K-Anonymity. In SC, the location attribute of a worker is a quasi-identifier. In an anonymous spatial area, the location of any worker cannot be distinguished from the location of at least $k-1$ workers. Among them, the quasi-identifier is the minimum attribute set [28], which combines other external information and identifies the target's location with a high probability. As shown in Figure 3, the real location of a spatial crowdsourcing worker is L, and then the location point L is extended to a hidden area R to replace the exact location information of the worker. In this anonymous spatial area, every worker is hidden in at least $k-1$ workers, which mean any attacker can only judge the number of workers in the hidden area, but they cannot determine their exact locations. This approach gives a certain degree of privacy protection to the workers.

2.3.4. θ Privacy of Location L. $P(L_t)$ represents the probability that a user is at position L at time t, $L_{\overleftarrow{t}}$ represents the location data that the attacker has collected before t, and θ is the maximum attack effect expended by an attacker:

$$P\left(L_t \mid L_{\overleftarrow{t}}\right) - P(L_t) \le \theta. \quad (1)$$

2.3.5. Privacy Protection Model Based on Spatial Anonymity Technology. Our privacy-preserving model based on spatial anonymity is illustrated in Figure 4. The crowdsourcing platform is a trusted third party. First, the location privacy policy of a worker (activity 3 in Figure 4) is formulated according to the task released by the requester. Then, the platform blurs (i.e., "fuzzifies") the submitted position using k-anonymity (activity 5) and transfers the protected location information to the requester (activity 6). Figure 5 shows a spatial crowdsourcing task map. The m task location $L_i\,(1 \le i \le m)$ is distributed in different locations (L_i is the correct execution location of task T_i). Using a Voronoi graph as the initial point set of the task point, the map is divided into m regions, $R_i\,(1 \le i \le m)$, which satisfy the condition that, for any point, L, within the region, R_i, L_i, is the nearest task point, that is,

$$|L - L_i| \le |L - L_l|, \quad \forall L \,\varepsilon\, R_i,\ l = 1, 2, \ldots, m. \quad (2)$$

Suppose a worker completes the P_i point task and submits the results before leaving A_i. Using the information entropy to measure the degree of crowdsourcing system privacy protection, the greater the information entropy is, the greater the uncertainty of the position of the worker is, and the higher their degree of protection is. The position information entropy W_j at t time is as follows:

$$I_t\left(W_j\right) = -\sum_{i=1}^{m} L\left\{W_j \text{ lies in } \mathrm{R}_i\right\} \log L\left\{W_j \text{ lies in } \mathrm{R}_i\right\}. \quad (3)$$

2.4. Using the ELM to Discriminate Spammers. The ELM learning process consists of two steps: first, (1) random feature mapping. Here, the ELM generates input weights randomly and initializes implicit layer unit biases and maps input vectors to the feature space using nonlinear mapping functions; and (2) a solution of linear parameters, where the ELM model is used to solve the output.

For a data set with N number of examples, (x_i, t_i) satisfies $x_i = [x_{i1}, x_{i2}, \ldots, x_{iN}]^T \in R^N$ and $t_i = [t_{i1}, t_{i2}, \ldots, t_{iM}]^T \in R^M$. There are L number of hidden layer nodes, and the activation function is $g(x)$. The single hidden layer neural network then can be described as

$$\sum_{i=1}^{L} \beta_i g\left(w_i \cdot X_j + b_i\right) = o_j, \quad j = 1, \ldots, N, \quad (4)$$

where $w_i = [w_{i1}, w_{i2}, \ldots, w_{iN}]^T$ is the input weight vector, $\beta = [\beta_1, \beta_2, \ldots, \beta_L]^T$ is the output weight vector between the hidden layer nodes and output nodes, $b = [b_1, b_2, \ldots, b_L]^T$ is the bias vector of the hidden layer, b_i is the bias of the hidden layer unit i, and $w_i \cdot X_j$ is the inner product of w_i and X_j.

The structure of the ELM algorithm is shown in Figure 6.

The matrix expression of equation (4) is

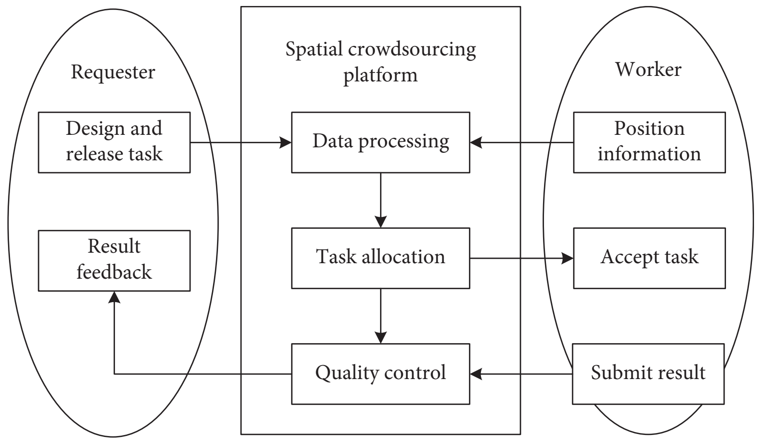

Figure 2: SC workflow.

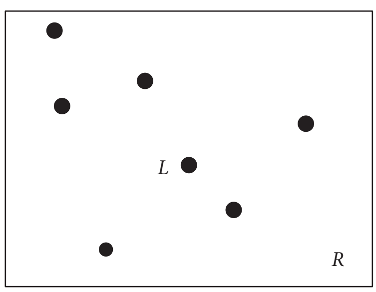

Figure 3: Spatial K-anonymity scheme.

$$H\beta = T,$$
$$H = \begin{bmatrix} g(w_1 \cdot X_1 + b_1) & \cdots & g(w_L \cdot X_1 + b_L) \\ \vdots & \ddots & \vdots \\ g(w_1 \cdot X_N + b_1) & \cdots & g(w_L \cdot X_N + b_L) \end{bmatrix},$$
$$\beta = \begin{bmatrix} \beta_1^T \\ \vdots \\ \beta_L^T \end{bmatrix}_{L\times m}, \tag{5}$$
$$T = \begin{bmatrix} T_1^T \\ \vdots \\ T_N^T \end{bmatrix}_{N\times m},$$

where H is the output of the hidden layer nodes, β is the output weight, and T is the expected output.

The training objective of ELM is to minimize the output error, that is,

$$\sum_{j=1}^{N} \left\| o_j - t_j \right\| = 0. \tag{6}$$

t_j is a sample of T. For β_i, w_i, and b_i,

$$\sum_{i=1}^{L} \beta_i g\left(w_i \cdot X_j + b_i\right) = t_j, \quad j = 1, \ldots, N. \tag{7}$$

Solving $\widehat{\beta}_i$, $\widehat{w}_i$, and $\widehat{b}_i$, we find

$$\left\| H\left(\widehat{w}_i, \widehat{b}_i\right)\widehat{\beta}_i - T \right\| = \min_{w,b,\beta} \left\| H\left(w_i, b_i\right)\beta_i - T \right\|, \quad i = 1, 2, \ldots, L, \tag{8}$$

which is equivalent to the optimal loss function:

$$E = \sum_{j=1}^{N} \left(\sum_{i=1}^{L} \beta_i g\left(w_i \cdot X_j + b_i\right) - t_j \right)^2. \tag{9}$$

In the ELM algorithm, the input weight w_i and the hidden layer bias b_i are selected randomly during training. When the activation function is infinitely differentiable and the number of hidden layer nodes is large enough, the ELM can approximate any continuous function. According to the values of W_i and b_i, only the determined output matrix H is calculated. The training single hidden layer neural network is converted to a least squares solution that is solved as a linear system, $H\beta = T$, whose solution is

$$\widehat{\beta} = H^{+}T = \left(H^T H\right)^{-1} H^T H. \tag{10}$$

In equation (10), H^{+} is the generalized inverse matrix of the output matrix H.

The ELM learning algorithm is mainly implemented by the following steps:

(1) Determine the number of hidden layer units and then randomly generate the input weight w_i and hidden layer offset b_i

(2) Select an infinitely differentiable function as the activation function of the hidden layer element and then the output matrix H is obtained

(3) Calculate the output weight β_i according to the output matrix H

(4) The output t_j is obtained according to equation (7)

In addition, ELM is widely used in cluster [29], feature selection [30], and other fields.

3. Experiments

We collected approximately 100,000 data points provided by a crowdsourcing platform, each of which include the task

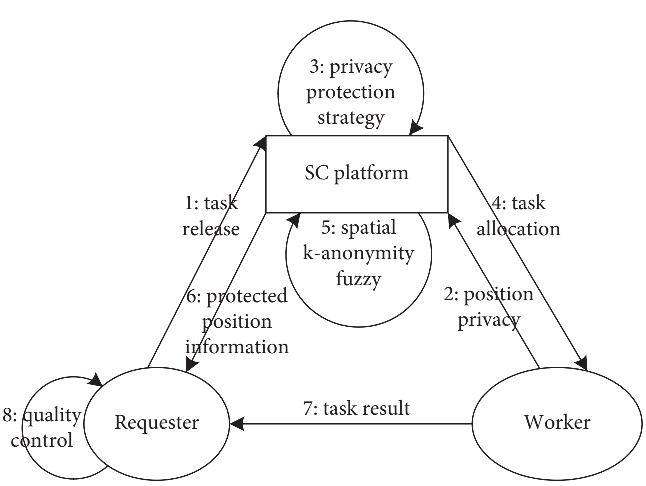

Figure 4: Model of SC based on spatial anonymity privacy protection.

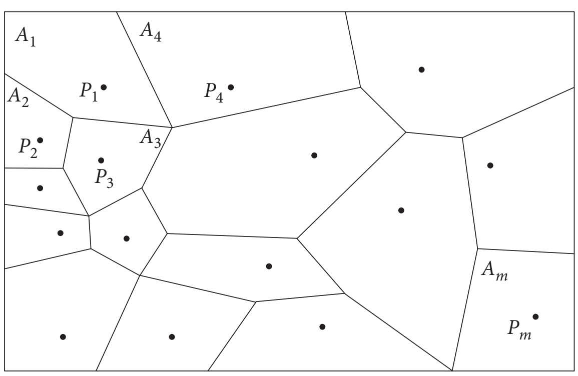

Figure 5: Task map.

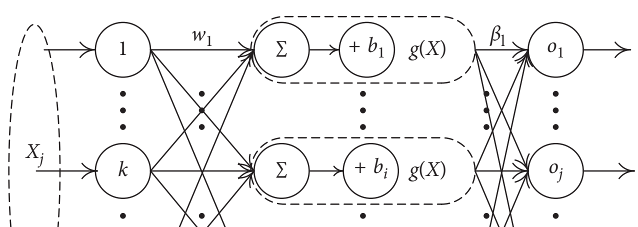

Figure 6: ELM algorithm structure.

number, task name, task position, release time, payment amount, dispatch time, worker's name, worker's position, position of periodicity reported by the worker, time of submission, and so on. For spammer-type workers, because of their desire to quickly end a task and earn a reward, their position changes in the entire order cycle are different from those of ordinary workers. In this paper, these features are used as input to the ELM, which were trained with neural networks to achieve the purpose of identifying spammers.

In this method, a neural network model activation function $g(x)$ selected the "sigmoid" function. The specific steps of the neural network training are as follows: (1) the data of the workers are grouped according to an hour, 24 hours a day as the observation unit, and the user's day behavior is divided into 24 groups. (2) We calculated the reappearance frequency of each group's behavior. Then, (3) according to the distribution of the reappearance frequency in the time series and the duration of the worker's task of establishing the characteristic description of the workers, we formed a temporal behavior matrix, which can be described as

$$\text{Log} = \begin{bmatrix} (t_1, f(a_{11})) & \cdots & (t_N, f(a_{1N})) \\ \vdots & \ddots & \vdots \\ (t_1, f(a_{K1})) & \cdots & (t_N, f(a_{KN})) \end{bmatrix}, \tag{11}$$

where t_i is the duration of a worker's task, $f(a_{ij})$ is the reappearance frequency of worker behavior i in time j, $N = 24$, and K is the number of behavior categories. The reappearance frequency is defined as the ratio of the total number of actions in a certain period to the total number of acts in a day as $f(\cdot) = c_a/c_{\text{all}}$.

Next, we selected all elements about $f(a_{ij})$ from the rows of matrix log and mapped them into a N dimension vector: $TT^{\text{LINE}} = [(t_1, f(a_{X_1 1})), \ldots, (t_i, f(a_{X_i i})), \ldots, (t_N, f(a_{X_N N}))]$, where $f(a_{ij})$ is the maximum of $\{f(a_{1i}), \ldots, f(a_{ki})\}$ and $X_i \in \{1, \ldots, K\}$. This method detects the highest recurrence frequency of specific behavior.

In the ELM algorithm, we used the N dimension vector TT^{LINE} or the $K \times N$ dimension vector TT^{ALL} as the input vector, which was recorded as TT. The question of spammer detection in then inverted into a two-classification problem:

$$\sum_{i=1}^{L} \beta_i g(w_i \cdot L_j + b_i) = o_j, \quad j = 1, \ldots, N. \tag{12}$$

Among them,

$$g_i(x) = G(a_i, b_i, x), \quad a_i \in R^d, b_i \in R, o_j = [o_{i1}, o_{i2}]^T, \tag{13}$$

where the vector set $\{(W_i, TT_j)\}$ is the training data and $W_j = [W_{j1}, W_{j2}]^T$. $W_{ji} \in \{0, 1\}$ indicates the ordinary worker and spammer $TT_j = TT_j^{\text{LINE}}$ or $TT_j = TT_j^{\text{ALL}}$.

The ELM process of detecting spammers is as follows: (1) analyze the data, group the worker behavior sequence in time, and calculate the appearance frequency of each group. Then, (2) serialize the worker behavior and task length of time and position into the worker information matrix. Next, (3) determine the parameters of the ELM model and use the worker information matrix to train the single hidden layer feedback neural network. Finally, (4) distinguish general workers and spammers.

3.1. The Impact of a Small Number of Error Results on the Overall Results. For a two-element spatial crowdsourcing task, as n workers submit their results, their average rate error is η, It is stipulated as $\eta < 0.5$ here. The requesters use the majority voting method [31] to estimate the correct results, where the correct result is 1, estimated at 0, or the correct result is 0, estimated at 1. The posteriori probability of error estimation is as follows:

$$P_e = \sum_{i=(n+1)/2}^{n} C_n^i \eta^i (1-\eta)^{n-i}. \tag{14}$$

The posteriori probability of error estimation P_e exponentially declines with the number of workers n. So, when there are more workers to complete a task, P_e tends to 0, where P_e indicates the error probability of a worker submitting a result directly to the requester without using the crowdsourcing platform. Adding Δn wrong results into the n task results ($\Delta n \ll n$), the posterior probability of $n + \Delta n$ task results are estimated to be

$$P_e' = \sum_{i=(n-\Delta n+1)/2}^{n} C_n^i \eta^i (1-\eta)^{n-i}. \tag{15}$$

If we subtract equation (14) from equation (15), we find

$$\begin{aligned}\Delta P_e = P_e' - P_e &= \sum_{i=(n-\Delta n+1)/2}^{(n-1)/2} C_n^i \eta^i (1-\eta)^{n-i} \\ &\le \left(\frac{\Delta n}{2} - 1\right) C_n^{(n-1)/2} \eta^{(n-\Delta n+1)/2} (1-\eta)^{n+1/2}.\end{aligned} \tag{16}$$

As n increases, the right-hand side of equation (16) tends to zero. The above analysis shows that if a small number of error results are mixed with a high-quality result set, this does not significantly interfere with the final judgment, and it does not significantly affect the accuracy of the estimated result.

3.2. Error Rate and Correct Result Estimation. In this paper, the error rate of workers is taken as a potential variable to estimate the correct result of crowdsourcing tasks via maximum likelihood estimation. The n–dimensional vector $\eta_{n\times 1} = \{\eta_j\}$ is the error rate of all workers. A worker W_j completes a task according to a certain error rate η_j, $\eta_j = (\eta_j^1, \eta_j^2)$, where η_j^1 and η_j^2 are independent of each other, which indicates the error rate of W_j when the correct results are "1" and "0," respectively, as follows:

$$\begin{aligned}\eta_j^1 &= P(V_{ij} = 0 \mid \tilde{v}_i = 1), \\ \eta_j^2 &= P(V_{ij} = 1 \mid \tilde{v}_i = 0).\end{aligned} \tag{17}$$

The expectation maximization algorithm is used to estimate the error rate of the EM algorithm. The specific steps are as follows:

(1) *E-step*: we define the m dimension vector μ, $\mu_i (1 \le i \le m)$, which indicates the posteriori probability of the task T_i' correct result is 1, that is,

$$\mu_i = P(\tilde{v}_i = 1 \mid V_{m\times n}, \eta). \tag{18}$$

Using the correct rate as the weight to the initial value of μ,

$$\mu_i^{(t)} = \frac{pa_i}{pa_i + (1-p)b_i}. \tag{19}$$

Among them, t indicates the tth iteration, p is the expectation probability of task's correct result (which is 1): $a_i = \prod_{j=1}^{n} (1-\eta_j^1)^{V_{ij}} (\eta_j^1)^{1-V_{ij}}$ and $b_i = \prod_{j=1}^{n} (1-\eta_j^2)^{1-V_{ij}} (\eta_j^2)^{V_{ij}}$.

(2) *M-step*: according the expectation value of μ in the E-step, we can estimate the value of p as

$$p = \frac{1}{m} \sum_{i=1}^{m} \mu_i. \tag{20}$$

The maximum likelihood estimation is then calculated, and the estimation of the error rate variable is obtained:

$$\begin{aligned}\eta_j^1 &= 1 - \frac{\sum_{i=1}^{m} \mu_i V_{ij}}{\sum_{i=1}^{m} \mu_i}, \\ \eta_j^2 &= 1 - \frac{\sum_{i=1}^{m} (1-\mu_i)(1-V_{ij})}{\sum_{i=1}^{m} (1-\mu_i)}.\end{aligned} \tag{21}$$

Next, the Q function is

$$Q(p, \eta_j) = \sum_{i=1}^{m} [\mu_i \log pa_i + (1-\mu_i) \log (1-p) b_i]. \tag{22}$$

To judge the model is convergent, we use ε, which is the convergence threshold. ε is an artificial very small value, such as 10^{-6}:

$$\frac{\left|Q\left(p^{(t+1)}, \eta_j^{(t+1)}\right) - Q\left(p^{(t)}, \eta_j^{(t)}\right)\right|}{\left|Q\left(p^{(t)}, \eta_j^{(t)}\right)\right|} < \varepsilon. \tag{23}$$

In every iteration, we calculate Q function, if it makes the inequality (23) true; we think the model is convergent and then return the estimation result μ and end the calculation. Otherwise, we return to the E-step and begin the next iteration.

4. Analysis of the Experimental Results

A series of data sets were generated by changing the task parameters, such as the task number, m, worker number, n, worker error rate, η, spammer ratio, r, and other experimental parameters. The data generation steps included the following: (1) generate the correct result vector $\tilde{v}_{m\times 1}$ of all tasks, where each correct result $\tilde{v}_i$ obeys the Bernoulli distribution of $p = 0.5$, and p is the probability that the correct result of the task is "1." Next, (2) generate the task results of all workers, $W_j (1 \le j \le n)$. If W_j is a spammer, the result $v_{ij} (1 \le i \le m)$ obeys the Bernoulli distribution $B(1, 0.5)$; otherwise, for the task of $\tilde{v}_i = 1$ and $\tilde{v}_i = 0$, v_{ij} obey the Bernoulli distribution $B(1, 1-\eta_j^1)$ and $B(1, 1-\eta_j^2)$ respectively about error rate (η_j^1, η_j^2). Finally, (3) generate the location of each worker. If W_j is a spammer, we select an area randomly from the m region of Figure 5 as the result submission position. Otherwise, we submit the location area R_i that corresponds to task T_i.

4.1. The Influence of the Fuzzy Coefficient K on Information Entropy and Accuracy. The quality control level of crowdsourcing systems was measured with an accuracy index, where the so-called accuracy rate is the consistency rate between the correct results estimated via statistical methods and the real results. We assumed $\tilde{v}_i = 1$ when the posterior probability of the correct result of task T_i is $\mu_i > 0.5$; otherwise, it is $\tilde{v}_i = 0$. First, the positional information is "fuzzily processed" with the fuzzy coefficient, k. According to equation (3), the average information entropy of the fuzzy coefficient, k, shown in Table 1 can be obtained at different locations. When $k = 1$, it represents a model that does not carry out k-anonymous handling in the spatial crowdsourcing location. A change of k indicates a change of the fuzzy degree. It is not difficult to find that the model proposed in this paper can produce an obvious protection effect if the position information is slightly fuzzy ($k = 6$), and the uncertainty degree of the worker's position is close to half of the case without submitting the position information ($k = \mathrm{m}$). The data in Table 1 also show that although the three task publishers obtain different amounts of location information, they produce the same quality control results. The results show that location information may not be helpful for quality control in some real situations. The effect of the error rate and spammers on the results is not considered at this time. The error rate and spammer ratio parameters are considered in the subsequent discussion.

4.2. The Influence of Task Scale, Number of Workers, Error Rate, and Spammer Ratio on the Accuracy Rate. In accordance with the test data set for different parameters, we compared the relationship between the accuracy and other parameters in Figures 7–10 with fuzzy coefficients of $k = 1, 6$, and m. There is a lower error rate $\eta = (0.2, 0.2)$ and spammer ratio $r = 0.2$ in Figures 7 and 8. Regardless of the change in the number of tasks and workers, the quality of the three models is always close. The difference in the two figures is that changing the number of tasks does not affect the model quality. With an increase in the number of workers, the quality of the model has increased. Figures 9 and 10 show that, when η and r are low, the accuracies of the three models are still close. However, with an increase in η and r, the quality control level of the $k = m$ model begins to be significantly worse than the other two models. Moreover, the quality control level of the case when $k = 6$ is always close when $k = 1$. That is, when the error rate and spammer ratio are high, the quality control results are completely different from those without considering spammer and error rate. The experimental results of Figures 7–10 prove that the spatial crowdsourcing privacy protection model with a fuzzy coefficient of $k = 6$ effectively protects the workers' location privacy under the premise of effectively controlling the quality of the crowdsourcing.

Table 1: The influence of the fuzzy coefficient k on the information entropy and accuracy rate.

	$k = 1$	$k = 6$	$k = m$
Average information entropy	0	5.12	10.89
Accuracy rate	0.941	0.942	0.942

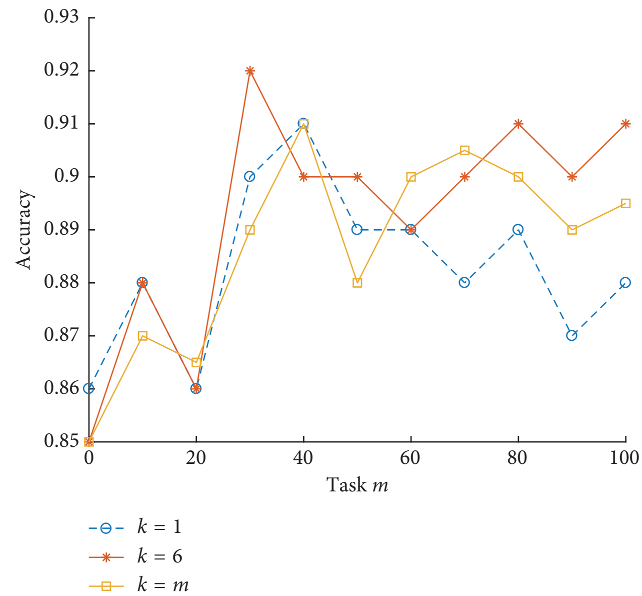

Figure 7: Task number versus accuracy.

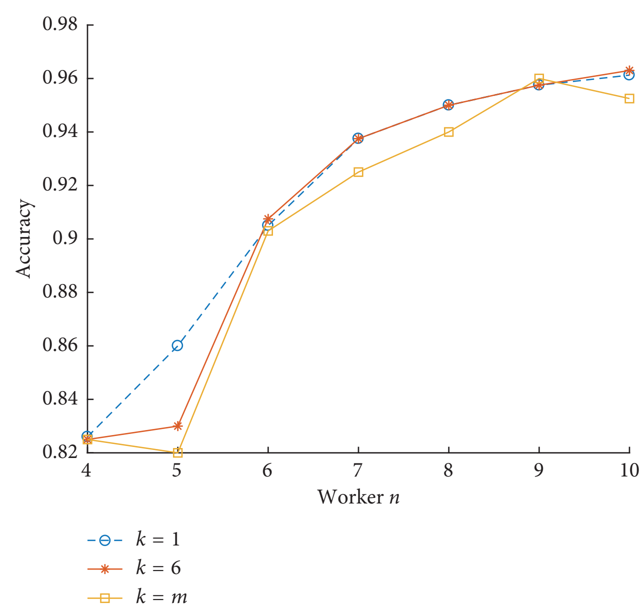

Figure 8: Worker number versus accuracy.

5. Conclusions

The spatial crowdsourcing task results in the leakage risk of the workers' locations privacy. If location information is not required to ensure privacy, this will have the side effect of an increase in the error rate and an increase in the number of

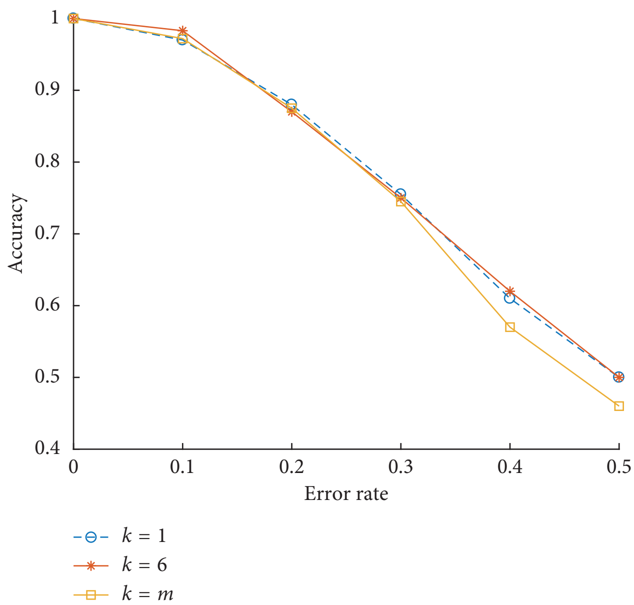

Figure 9: Error rate versus accuracy.

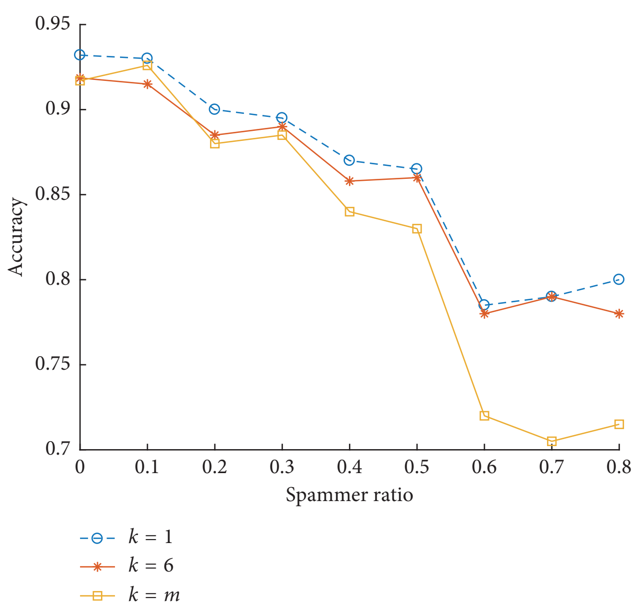

Figure 10: Spammer ratio versus accuracy.

spammers, both of which would affect the quality of the crowdsourcing. In this paper, a SC model is proposed. A spatial k-anonymity algorithm is used to protect the location privacy of the public spatial crowdsourcing workers. Next, an ELM algorithm is used to detect spammers, and an EM algorithm is used to estimate the error rate. Finally, different parameters were selected, and the efficiency of the model was simulated. The results show that the SC model proposed in this paper can guarantee the quality of the crowdsourcing project on the premise of protecting the privacy of the workers.

Aiming at achieving a balance between location privacy protection and crowdsourcing quality control, we proposed a SC quality control model based on spatial k-anonymity and the ELM algorithm for location privacy protection and deception worker screening. The main contributions of this paper are as follows:

(1) On the basis of Wang et al. [18], we provided a definition of SC anonymity technology, a workflow of spatial crowdsourcing platform based on spatial anonymity technology, a definition of spatial crowdsourcing location k-anonymity, and formulae for privacy protection.

(2) We used the ELM algorithm to realize the automatic identification of spammers and used the EM algorithm to estimate the error rate.

(3) By considering different test data sets, the proposed model was verified. The simulated results show that the proposed SC model can protect the workers' location privacy on the premise of ensuring the quality of crowdsourcing projects.

Next, we will further study how to apply the model to actual crowdsourcing platform systems, and we will further explore whether the privacy protection and quality control requirements of different types of crowdsourcing tasks have relevant characteristics, and whether we can establish a model to study them. If the said model can be constructed using an adaptive algorithm, perhaps in the case where the k value used for different crowdsourcing tasks no longer has the same fixed value, we may be able to calculate the k value according to the type of task, so as to achieve the best privacy protection and quality control effect.

Data Availability

The data used in this study are owned by a third party.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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Research Article

Batching Location Cloaking Techniques for Location Privacy and Safety Protection

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Location-based services (LBSs) have become a profitable market because they offer real-time and local information to their users. Although several benefits are obtained from the usage of LBSs, they have opened up many privacy and safety challenges because a user needs to release his/her location. To tackle these challenges, many location-cloaking techniques have been proposed. Even though these solutions are effective in protecting either location privacy or location safety, they do not provide unified protection. Furthermore, most of them do not address the potential bottleneck in the anonymity server as a high demand of location and safety protection is requested. Finally, they do not take into account the potential impact of processing a large amount of location-cloaked queries. This paper deals with the efficient construction of location-cloaking areas for many users, who have both privacy and safety requirements. To achieve this goal, the construction of location-cloaking areas is carried out in batches. The LBSs' batch processing takes advantage of users who are close to each other and who have similar requirements. Two batching techniques to build cloaking regions are analyzed using simulations. Empirical results show our techniques are able to balance the anonymizer workload, quality of location privacy and safety protection, and LBS workload.

1. Introduction

This paper is an extension of a work in progress published at CODASSCA [1] in the context of location-based services (LBSs). An LBS is a geographic information system connected to the Internet, whose main goal is to track the location of their users within a wireless network. These users report their exact position when a service is required, by using their location-enabled mobile devices. Having received users' location, the LBS offers them real-time information about other users who are close; for example, a user who suffered a serious car accident should submit his/her current position as soon as possible to get prompt medical support.

On the other hand, when LBS users reveal their locations, they could endanger their safety and privacy integrity. An adversary, listening to this information, could not only determine their identities but also track them to any place they go to. Moreover, the same LBS providers should keep the data confidential and should not release this information to unknown third parties. All of these issues have motivated a series of research on location-cloaking techniques.

The key idea is to limit location resolution to achieve a desired level of protection. When requesting for an LBS, users report a cloaking region instead of their exact positions. A cloaking region needs to contain a user's current position and also encloses other locations in which the user could be located. Most of the approaches [2–11] are based on a trusted third party, called *the anonymizer*, which is responsible for selecting these additional locations depending on what type of protection a user is demanding. Other techniques such as [12–16] assume that the same users, collaborating with other peers, can compute their own cloaking regions. In addition, a few articles have proposed a hybrid approach, in which an anonymizer and users collaborate to create cloaking regions [17–19].

The approaches proposed in [2–4, 6, 12] support anonymous use of an LBS. An adversary will not know the identity of the user located at each location even if he/she manages to identify all these users by matching the cloaking region with public information available in white and yellow pages. In contrast, the techniques in [1, 7, 8, 14, 15] ensure that each cloaking region contains locations that have been visited by at least K different users. Because these users visited the region at different periods of time, it prevents an adversary from identifying the user who was in that region at the moment the LBS was requested. Thus, the user's location privacy is protected from the time dimension.

Other techniques [20, 21] have been proposed to protect location safety. Their goal is also to build a cloaking region containing a user's position, but they want to prevent an adversary from combing the entire region to locate and destroy a target user and every other user located within that region. The idea behind this concept is that the target user and the other users located nearby could have some common purpose. For example, let us consider a set of wireless sensors deployed in some area and working together to detect or track specific objects, like a tank. In this case, the adversary is not concerned about finding the identity of each sensor but simply wants to locate and destroy each one of them.

Reducing location resolution limits privacy and safety risks but adds more workload on the LBS server and the anonymizer. First, on the LBS server, a precise location is more convenient because a query result is only computed with respect to a specific position. However, when a user location is cloaked, (i.e., the user's real location is mixed with other possible locations) the LBS server also needs to compute the responses for these other locations. We will refer to a query in which the location has been cloaked as a *Location-Cloaked Query* (LCQ). In a system with a large number of users, the processing of LCQs can be overwhelming to the LBS server and could bring it down. This is especially problematic (in terms of runtimes) when the server has to deal with large cloaking regions, which happens when users request a high level of protection (e.g., high values of K are requested by users).

Secondly, the anonymizer can also be problematic. If the anonymizer has high demand with the aim of finding an optimal (size) cloaking region for a large amount of clients, the anonymizer becomes a bottleneck and therefore clients experience high response times. This is undesirable if the LBS wants to support real-time applications. A solution for this issue is to build the smallest amount of cloaking regions that satisfy the privacy and safety requirements of every user. However, this approach can end up returning cloaking regions larger than those needed. Thus, an approach that balances the LBS and anonymizer workloads is needed.

Thirdly, in [1], we consider the problem of building cloaking regions for users demanding only location privacy protection. However, in this paper, we aim to satisfy both location privacy and location safety requirements, which is more challenging. A cloaking region for location privacy must prevent an adversary from distinguishing between a subject demanding protection and others located within this region. The more users present within that area, the better it is for the subject. However, location safety is the opposite; if this region is highly dense, it can become quite attractive for an adversary to comb such a region, localize all users within that area, and destroy them. In this paper, we address the problem of building a set of cloaking regions (CRs) for a large number of users having both location privacy and location safety requirements. Our idea is to build CRs in a large-scale system as long as the anonymizer has processing resources available. In such a real-time processing model, a CR is computed upon its request arrival without any latency when the anonymizer is underloaded. However, when the anonymizer is overloaded, the incoming requests for CRs are queued. These requests are processed in a batch as soon as the anonymizer has hardware resources available. Our research focuses first on how to build a cloaking region satisfying both location privacy and safety requirements. Then, we address the scalability dilemma between the anonymizer and the LBS.

The paper makes the following contributions: we propose a unified approach for building CRs demanding both location privacy and safety requirements. To achieve this goal, we propose two algorithms to batch build a set of cloaking regions. To the best of the authors' knowledge, this problem has not been addressed before in any literature. By using our algorithms we tackle the problem of improving scalability on the anonymizer without potentially compromising the LBS workload, which also, to our knowledge, has not been properly addressed. To measure the effectiveness of these solutions, we have simulated different scenarios (not addressed in [1]) in which users have similar and different location privacy and safety requirements and are disseminated nonuniformly in different places of the service area.

The remainder of this paper is organized as follows: in the section *Related Work*, an extensive review of articles related to the problem of building cloaking regions is presented. Then, we explain the background and basic concepts in the section *System Overview*, and our scalable location privacy and safety protection techniques are presented in the section *Proposed Batching Techniques*. The empirical results are reported in the section *Results and Discussion*. Then, this paper concludes in the section *Conclusions*.

2. Related Work

A wide range of approaches deals with location cloaking techniques. Some of these techniques can be categorized in different ways. In [22], the techniques can be classified as spatial anonymization, obfuscation, and private retrieval methods. Another classification is proposed in [23], where the different methods are categorized as dummy-based, K-anonymity, differential privacy, and cryptography. Unlike the previous classifications, we present the related work according to performance for a single user and a batch of users.

Several approaches present their performances for a single user. Among them, in [24], a scalable fog server architecture with a bus-based edge device was implemented. It is based on the topology of roads: the authors optimize the allocation of roadside *cloudlets* to better offload the computation tasks in the moving fog servers. The data set reflects the actual movement of the buses with time. A genetic algorithm is used to address the problem. Two metrics are used: the total cost of the roadside cloudlet over the number of buses and the performance comparison between service offloading and non-offloading. The data set used corresponds with collected traces of the fleet of city buses in Seattle. A sample of the data set was chosen under uniform distribution. The authors do not consider privacy issues, rather assuming that the LBS servers themselves are trusted 3rd parties.

In [25], the authors present three dynamic grid-based spatial cloaking algorithms to provide location k-anonymity and location l-diversity in a mobile environment. These algorithms rely on a semitrusted third party to give spatiotemporal cloaking. In the worst case, their method has to consider the entire search space through iteration to create a covering for each user. The metrics considered in this work centre on the algorithm's effectiveness in terms of privacy, quality, time complexity, and scalability. The PrivacyGrid framework and Zipf distribution with parameter 0.6 were used to provide the K values. The authors point out that their algorithms are highly efficient in terms of both time complexity and update cost.

In [26], the automatic generation of cost-effective dummy locations in the clients is presented with the aim to obfuscate the user's real location without a trusted third party. The main metric used here is the number of dummies. According to the authors, three distributions of users are used; however, these are not detailed. The empirical results show that the cost rapidly escalates if a high value of dummies is required: all of them are recalculated individually, on each query. Therefore, response efficiency is necessarily limited by the computing power of the clients.

The cloaking algorithm presented in [3] enables the user to specify the level of anonymity, by specifying restrictions such as the geographical size of the covering. The algorithm takes into consideration the distribution of all users on the map along with their previous cloaking requests. The experiments show the performance under several conditions by using realistic workloads synthetically generated from real road maps and traffic volume data. The empirical results are expressed in terms of success rate, relative anonymity level, and relative spatial/temporal resolution, where Zipf distribution is used to spread out users. Another component studied was the scalability of the extreme cases in terms of the runtime performance. This method works well when the distribution of users is uniform across the entire space but may fail to anonymize effectively when small covering regions are used in low density spots.

Niu et al. [14] consider the decentralized creation of well-crafted dummy locations, intended to maximize both entropy and the covered spatial region. The authors propose a novel Caching-aware Dummy Selection Algorithm (CaDSA). The main evaluated metric incorporates the effect of caching on privacy, which describes the quantitative relation between cache hit ratio and the achieved privacy area on the map of New York City. In the simulations, users follow the Levy walk mobility model. Two caching-aware dummy selection algorithms to improve user's location privacy are proposed. The first algorithm, CaDSA, achieves K-anonymity effectively by selecting some candidate cells with similar query probabilities. The second algorithm, enhanced-CaDSA, considers distance normalization and data freshness. Enhanced-CaDSA improves caching hit ratio along with the overall privacy. However, the authors do not consider efficiency; calculations are performed redundantly in the clients, without analyzing how this might affect communication and storage costs, and it is assumed that users have complete and trustworthy information of other users.

In [27], the authors further improve the work in [14] by caching the dummy locations that contribute to maximizing entropy. In this work, two privacy metrics to measure location privacy are defined. One of these metrics measures the privacy degree achieved for a user when he/she sends a query to the LBS server. The other metric considers the effect of caching and measures the overall privacy achieved for the system. This work uses dummy locations to achieve K-anonymity even when the LBS server has side information. Aiming to evaluate the performance of proposed algorithms, several simulations are carried out, where every 1 minute, 10 users issue a request for LBS service. The query probability of the cell is considered to assess the user probability in order to be chosen. However, contrary to our work, their gains cannot guarantee a response time below some constant φ, which is desired to ensure quality of service (QoS).

The authors in [28] present an algorithm that preserves both query and location privacy, by creating a set of dummy locations that maximize entropy in cells with similar query probability. The entropy-based metric is used to quantify location privacy. Two dummy schemes are considered, optimal and random. Simulation is used to obtain experimental results on a New York map. The Levy walk model is used to generate synthetic data. Final results improve privacy; however, contrary to our method, all calculations have to be performed for each incoming request.

In a recent work, the authors in [29] use a *function generator* of service, which is based on Hilbert curves. It allows anonymization of both the queries and their respective responses. The function generator encodes users' queries into an alternate representation, which is sent to a third-party anonymization service without danger of identification. The anonymizer passes the queries through to the LBS, encoding its responses in the same code given by the function generator. This enables the clients to decode the response themselves upon return, protecting them in case the anonymization server gets compromised. Their experiments used (randomly generated) uniform data sets. The metrics evaluated here correspond to the computational cost on the user side with the aim of building the areas. This method increases the overall computation costs by requiring additional coding/decoding operations around the anonymization procedure. In this sense, it will be as effective as the one used by the anonymization server, with the addition of the codification overhead.

A mixed approach is presented in [30]. In this work, both a semitrusted third party with caching capabilities and client-based anonymization are addressed. The user sends an encrypted query through the semitrusted third party—ignorant of the contents itself—which, in turn, passes them through to the LBS server as an enlarged region, obfuscating the point of origin. The results are returned to the clients through the semitrusted third party, so that they can locally select their points of interest themselves. To assess the approach, a set of moving objects on the real road map of Hennepin County, Minnesota (USA), are generated. Randomly, a vertex of the road map as the location is picked out. The mainly used metric corresponds to computation cost.

To summarize, from an experimental point of view, approaches that address the processing for a single user obtain the user data from a real map or a simulation framework. When a real map is used, all experiments are carried out considering only it. However, other real maps are not considered by which intuitively other results should be reported according to the initial distribution of users on these maps. In most cases, only Levy walk mobility distribution takes place in the experiments. On the other hand, when a simulation framework is used, only Zipf distribution with just one parameter is instantiated (generally, this parameter has a low value). Differing from this approach, in this paper, we use several probability distributions (Zipf, exponential, and uniform) in order to cover a wide range of possible results. Besides, several metrics are evaluated to assess the construction impact of location-cloaking areas on the anonymity server when it has high demand. It should be noted that our techniques deal with batch processing.

Other approaches use batch processing. In [31], a cloaking algorithm over a hierarchy-based representation of a road distribution is presented. The authors' procedure takes into account the spatial restrictions imposed by road systems in order to enhance privacy, both for a single user and batches of users. The proposed framework is evaluated from the aspects of privacy-preserving ability, quality of service, and system performance. A network-based generator of moving objects on the road map of Oldenburg was used to carry out the experiments (a sample of the road map was chosen randomly). Some empirical results to obtain the local privacy were processed in batches. According to the authors, the amount of needed calculation decreases when the batch processing takes place. Contrary to their method, our techniques always consider users in batches, rather than choosing to memorize previous batch responses for future queries.

In [16], the authors present an incentive-based batch algorithm to build a K-anonymity covering with $K-1$ willing participants. In this work, a probability threshold is suggested to indicate a user's reputation on a framework based on fuzzy logic. Batch processing is used to verify the certificates. The main metrics used here are the cost in order to build the areas and number of certificates. Final results show a reduction in processing time and energy consumption. Moreover, their solution needs to continuously calculate new covering regions, at least one per session. However, the distribution of users by space is not mentioned in this paper.

In summary, approaches that deal with batch processing acquire the user data from a real map or from a uniform data set. Similar to the approaches based on the processing for a single user, all experiments are carried out considering the same real map. For this case, we believe that other different data to the same map should be considered. On the other hand, the approach that uses uniform data does not use other distributions. Different to our approach, several probability distributions are used to expand the results, considering other metrics as the entropy at the same time.

Finally, to our knowledge, none of the aforementioned works and those presented in the introduction have properly addressed the efficient building of a large number of cloaking regions for users having heterogeneous privacy and location safety requirements.

3. System Overview

Without loss of generality, we assume that a single anonymity server is used to manage all users, as shown in Figure 1. In order to efficiently process each request for a CR, the entire network area is partitioned into a set of $n \times n$ disjoint cells of equal size as shown in Figure 2. Each user u submits a protection request including his/her current location represented as a 2D point $(X_u; Y_u)$, location-based query, and location privacy (K_u) and location safety (θ_u) requirements. We also assume that our system receives a large set of queries and requirements for location privacy and safety protection, which are queued in a waiting list, denoted by U. Finally, our system returns for each user u in a cloaking region, denoted by CR_u, which conforms to the requirements of privacy and safety given by users.

To protect location privacy, we follow a similar approach as shown in [1, 14]. Our system chooses at least K_u cells to maximize the entropy. To do so, when users report their current locations, the anonymizer maintains a count of how frequently a request comes from a given cell. Based on this information, we define the *query probability* as

$$q_i = \frac{\text{Number of requests originated from cell } i}{\text{Number of requests coming from the network area}}, \tag{1}$$

where $\sum_{i=1}^{n^2} q_i = 1$, for all $i = 1, \ldots, n^2$. Besides, the entropy of a given region CR, denoted as $H(\mathrm{CR})$, is computed as:

$$H(\mathrm{CR}) = -\sum_{K}^{j=1} p_j \log_2(p_j), \tag{2}$$

where p_j represents the normalized request probability of cell c_j. This latter probability is computed as $p_j = q_j / \sum_{l=1}^{K} q_l$. The higher the entropy of a CR, the better the location privacy protection offers.

To protect location safety, we follow a similar approach as shown by Xu and Cai [20]. These authors define the *safety level* of a cloaking region CR as $\mathrm{SL}(\mathrm{CR}) = A(\mathrm{CR})/N(\mathrm{CR})$, where $A(\mathrm{CR})$ denotes the area of a CR and $N(\mathrm{CR})$ denotes the population of CR (i.e., the number of wireless users moving within a CR).

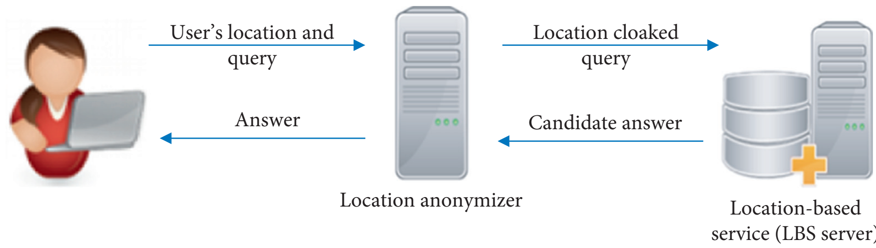

Figure 1: Traditional architecture of an LBS.

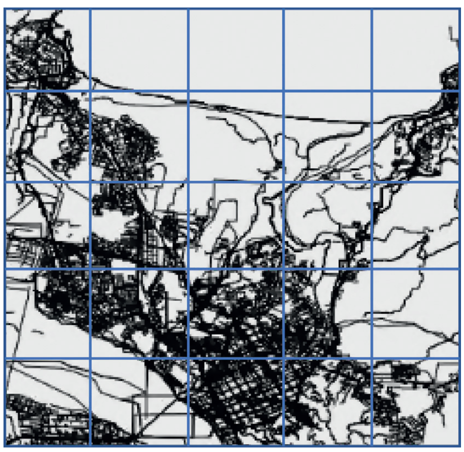

Figure 2: Partitioning of the network area.

Thus, given a user u located within a CR and demanding a location safety requirement θ_u, then CR protects the location safety of the user u if $\mathrm{SL}(\mathrm{CR}) \geq \theta_u$.

Also, Xu and Cai [8] assume that a CR is a convex region, which is not our case, since a CR is a set of fragmented areas or cells. Now, let us consider a cloaking region, CR, as a set of K-disjoint cells (c_i) of the network area, and we propose to compute a safety level of CR as follows:

$$\mathrm{SL}(\mathrm{CR}) = \frac{\sum_{i=1}^{K} A_i}{\sum_{i=1}^{K} \#\text{ of wireless users moving within } c_i}. \tag{3}$$

Since all cells have the same area (A), we can simplify equation (3) as $(A/((1/K)\sum_{i=1}^{K}\#\text{ of users in } c_i))$. The higher the safety level of a CR, the better its location safety protection.

4. Proposed Batching Techniques

First, we define the following notation to describe our location cloaking techniques:

(i) Let C_N be the set of all cells in the network area sorted in ascending order of their request probability.

(ii) Let U be the current set of users requesting location privacy and safety protection. Given a user u in U, we say c_u is the current cell containing u's exact location and CR_u is the user u's cloaking region.

(iii) Given a user u, we say K_u is the location privacy protection demanded by user u, and similarly, θ_u is the location safety protection demanded by user u.

(iv) Let $\#(\mathrm{CR})$ be the cardinality of a cloaking region CR as the number of cells c_j making up this region.

(v) Let $C(u, r)$ be a subset of C_N, which consists of those "r" neighbor cells at the right and at the left of c_u in C_N. These cells are the ones whose request probability is close to c_u's probability. Thus $\#(C(r)) = 2 * r + 1$.

(vi) Given two cells c_i and c_j in C_N, the distance between these two cells is $|i - j|$.

(vii) Given a cell c_i, we say the occupancy of c_i is the number of mobile users currently located within c_i.

(viii) Let $\theta_{\max}$ is the maximum location safety requirement a user can demand.

We developed two batching techniques to compute cloaking regions at once. The first one, denoted as BU, follows a bottom-up approach because it first finds out a small candidate cloaking region satisfying a given location privacy requirement. Then, it tries to enlarge this region until the location safety requirement is satisfied. The second technique, denoted as TD, follows a top-down approach and works on the contrary. It assumes the entire network is an initial candidate for a cloaking region, and then it attempts to reduce its size while the location safety and location privacy requirements are both satisfied. In both techniques, users having similar location privacy and safety requirements may share a computed cloaking region.

4.1. Bottom-Up Technique. Our bottom-up approach is based on two algorithms denoted by Algorithms 1 and 2. The goal of the first algorithm is to build a candidate cloaking region satisfying the location privacy requirement demanded by a user u. To achieve this goal, this algorithm first finds a candidate set of size $2\dot{K}_u$ cells with the highest entropy (lines 4–6). Finally (line 8), it chooses a set of K_u cells from the previous candidate set at random with a probability inversely proportional to that of the occupancy of a cell. This is done in order to prioritize cells having smaller density of nodes.

Algorithm 2 is a proper batching procedure, whose goal is to build several cloaking regions at once for all pending users in U. The idea is to first build a candidate CR for the user having the largest location privacy requirement (u_l).

Data: user u, m
Result: A Cloaking Region (CR_u) for user u satisfying K_u
$i \longleftarrow 0$;
$C_{\max} \longleftarrow \varnothing$;
for $i < m$ **do**
  $C \longleftarrow 2K_u$ cells at random with equal probability from $C(u, 2K_u)$;
  $C_{\max} \longleftarrow C$ only if C has the highest entropy;
  $i \longleftarrow i + 1$;
end
$\mathrm{CR}_u \longleftarrow$ Select K_u cells from $C_{\max}$ with a probability $\propto$ (1/cell' soccupancy);
Return CR_u;

Algorithm 1: Computing Cloaking Region for a user u.

Data: set U
Result: A set of cloaking regions for every user u in U satisfying its respective K_u and θ_u
(1) $l \longleftarrow$ chooses a user with the highest K from U (denoted as K_l). If there are many of them, chooses one with the highest θ in U;
(2) $\mathrm{CR}_l \longleftarrow$ call Algorithm 1 (l, $2K_l + 1$);
(3) **repeat**
(4)   **if** $\mathrm{SL}(\mathrm{CR}_l) \geq \theta_l$ **then**
(5)   **for** any user u located in CR_l **do**
(6) $\mathrm{CR}_u \longleftarrow \mathrm{CR}_l$ if $K_l - \Delta \leq K_u \leq K_l$ and $\theta_u \leq \theta_l$;
(7)   Remove u from U only if CR_u was set as CR_l;
(8)   **end**
(9)   **end**
(10) $c \longleftarrow$ from $C_N \backslash \mathrm{CR}_l$ with a probability inversely $\propto$ distance $(c_l, c_u) \times C_u$'s occupancy;
(11) $\mathrm{CR}_l \longleftarrow \mathrm{CR}_l \cup \{c\}$;
(12) **until** $U = \varnothing$ or $\mathrm{CR}_l = C_N$;

Algorithm 2: Bottom-up cloaking batching algorithm (BU).

This CR is then checked whether it needs to be extended to satisfy user u_l's location safety requirement.

Specifically, Algorithm 2 chooses first, the user l, with the highest location privacy requirement (K_l, line 1). Then, it calls the bottom-up technique algorithm to obtain a candidate CR for this chosen user. Now, it verifies whether this CR_l satisfies the safety level (location safety) demanded by *user l* (line 4). If this is the case, then it finds out what other users may share in this cloaking region (lines 5-6). Otherwise, it randomly chooses a cell having a low occupancy but a high request probability (line 10) and adds it to CR_l (line 11). Again, it verifies whether this new CR (line 11) satisfies θ_l (line 4), otherwise, another cell is chosen randomly (line 10) until $\mathrm{SL}(\mathrm{CR}_l)$ is greater or equal to θ_l (line 4). This algorithm finishes when either U becomes empty or $\mathrm{CR}_l = C_N$ (line 12).

4.2. Top-Down Technique. Our top-down technique is described by Algorithm 3. The idea of this procedure is to compute an initial CR for a chosen u and see if other users can share it. To do so, it chooses any user l in U (line 4) having the largest θ, denoted as θ_l, and sets C_N as a candidate CR_l (line 5). From now on (lines 9 to 21), it tries to reduce the size of C_l (lines 10–12) as long as the cardinality of $\mathrm{CR}_l \geq K_l$ and $\mathrm{SL}(\mathrm{CR}_l) \geq \theta_l$ (lines 6–21). For doing that, it finds out whether the removal of a randomly chosen cell c (line 11) from CR_l could achieve the lowest reduction of the entropy of CR_l (line 12). After "m attempts" (line 9), only one cell is definitely chosen and removed from CR_l (lines 18 y 19). Note that the state variable $E_{\max}$ becomes no zero (line 18) only when lines 11 and 12 are satisfied. This means there exists a candidate cell c_i to be removed (line 14). In lines 22 and 23, this technique verifies whether other users can share the same cloaking region CR_l. Finally, the algorithm stops when the first repeat-end statement finishes (lines 6 and 24). The latter happens when all pending requests have been attended successfully.

5. Results and Discussion

We evaluated the performance of our batching techniques using simulations. Four performance metrics are used, including

(i) *Computational Cost*. The average total amount of work (complexity time) incurred on building a set of cloaking regions.

(ii) *Size of a Cloaking Region*. The average number of cells conforming to a cloaking region. This size can be equal to or higher than the degree of location privacy protection (K) demanded by a user.

Data: set U
Result: A set of cloaking regions for every user in U
$C_N \longleftarrow$ all cells in the network area;
if $\mathrm{SF}(C_N) \geq \theta_{\max}$ **then**
  repeat
    $l \longleftarrow$ a user from U with the largest θ. If many, chooses the one with the largest K, (K_l);
    $\mathrm{CR}_l \longleftarrow C_N$;
    repeat
      $E_{\max} \longleftarrow 0$;
      $i \longleftarrow 0$;
      for $i < m$ **do**
        $c \longleftarrow$ from $CR_l \backslash \{c_l\}$ with a probability $\propto$ cell's occupancy;
        if $\mathrm{SL}(\mathrm{CR}_l - \{c\}) > \theta_l$ **then**
          if $E(\mathrm{CR}_l) > E_{\max}$ **then**
            $E_{\max} \longleftarrow E(\mathrm{CR}_l - \{c\})$;
            $\mathrm{CR}_t \longleftarrow \mathrm{CR}_l - \{c\}$;
          end
        end
      end
      if $E_{\max} \neq 0$ **then**
        $\mathrm{CR}_l \longleftarrow \mathrm{CR}_t$
      end
    until $(\#(\mathrm{CR}_l) = K_l)$ or $(E_{\max} = 0)$;
    Set CR_l for user l and for every other user u in CR_l having $K_l - \Delta \leq K_u \leq K_l$ and $\theta_u \leq \theta_l$;
    Update set U removing those users whose cloaking region is CR_l;
  until $U == \varnothing$;
end

Algorithm 3: Top-down cloaking batching algorithm (TD).

(iii) *Number of Cloaking Regions Built*. The number of CR built by the anonymizer. The minimum value is one, because only CR can be built to protect all users at once. The maximum value corresponds to the number of users deployed in the network area, because for each of them a CR can specifically be built.

(iv) *Entropy of a Cloaking Region*. We apply equation (2) to compute the entropy of a CR and then to obtain the average entropy of many computed CRs. With this metric we want to evaluate the quality of the location privacy protection offered by a CR. The higher the entropy, the better the quality.

We developed a C-based simulation, in which you can set the location cloaking technique and the network area. As a network area, we consider a medium-size city, as shown in Figure 1. We generate a network domain of 21×21 which is equally partitioned in cells of size 3×3. We disseminate a fixed number of users in this area in a range of $[200, 800]$. These users are disseminated based on three probability distributions: uniform (UNI) and two other nonuniform distributions as the exponential (EXP, 0.5) and the Zipf (ZIP, 2.0). With these two latter distributions, we want to simulate a scenario in which there are a large proportion of users and requests coming from some specific zones of the network area.

We also generate a frequency of requests for cloaking regions per cell based on the aforementioned distributions. To simplify our experiments, we use the same distribution and parameters to set both the location of the users in the network area and the frequency of requests per cell.

The value of K ranges from 2 to 12, and the value of θ ranges from 0.018 to 0.882 ($\theta_{\max}$). We are mainly interested in comparing how the anonymizer performance is impacted with the quality of the computed cloaking regions when we run our two batching techniques (denoted as BU and TD) independently and two baseline techniques that compute all CRs one by one (IND-BU and IND-TD). The first baseline approach, IND-BU, is our bottom-up approach used to compute a CR for every user from scratch, and it does not verify whether this computed CR can be assigned to other users as well. Similarly, the second baseline approach, IND-TD, is our top-down approach used to compute a CR for each user independently from scratch as well. Finally, we set $\Delta = 0$ and $m = 2 * K_u + 1$ when we run all techniques.

5.1. Effect of the Number of Users. We vary the number of users in the range of 100 to 800 users. We fixed K to 7 and θ to 0.45.

Figure 3(a) shows the computational costs incurred by all techniques. We observe that all techniques based on our TD approach show larger costs; because these techniques are set as an initial CR for the entire network region, they conservatively check whether it is possible to remove a cell from this region without affecting the required θ and K. We

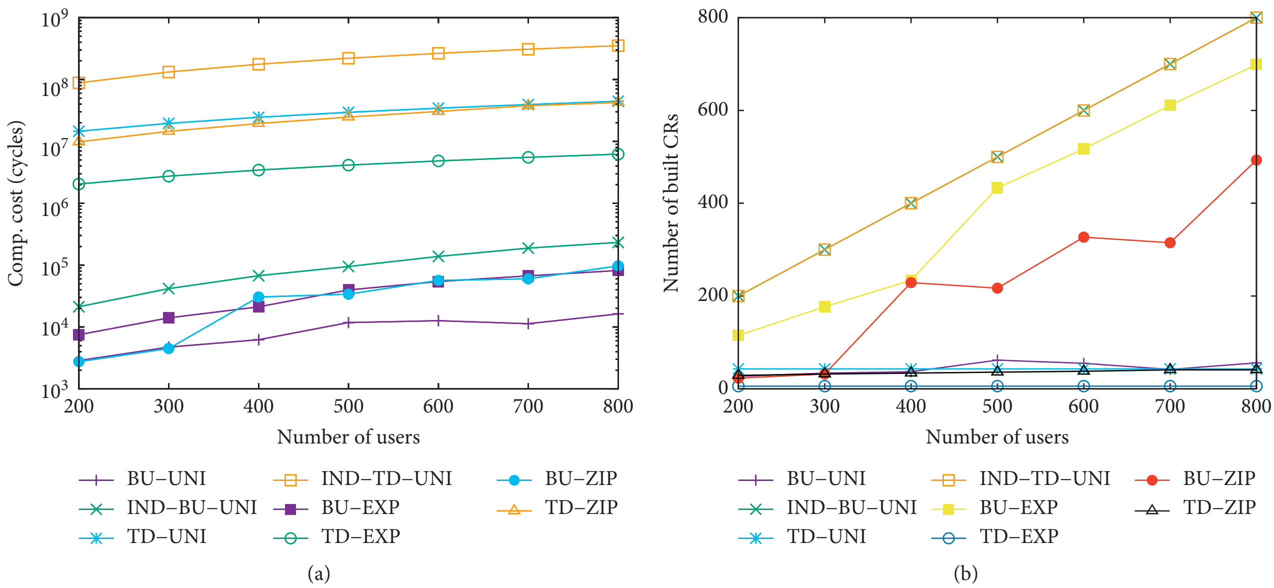

FIGURE 3: Effect of the number of users.

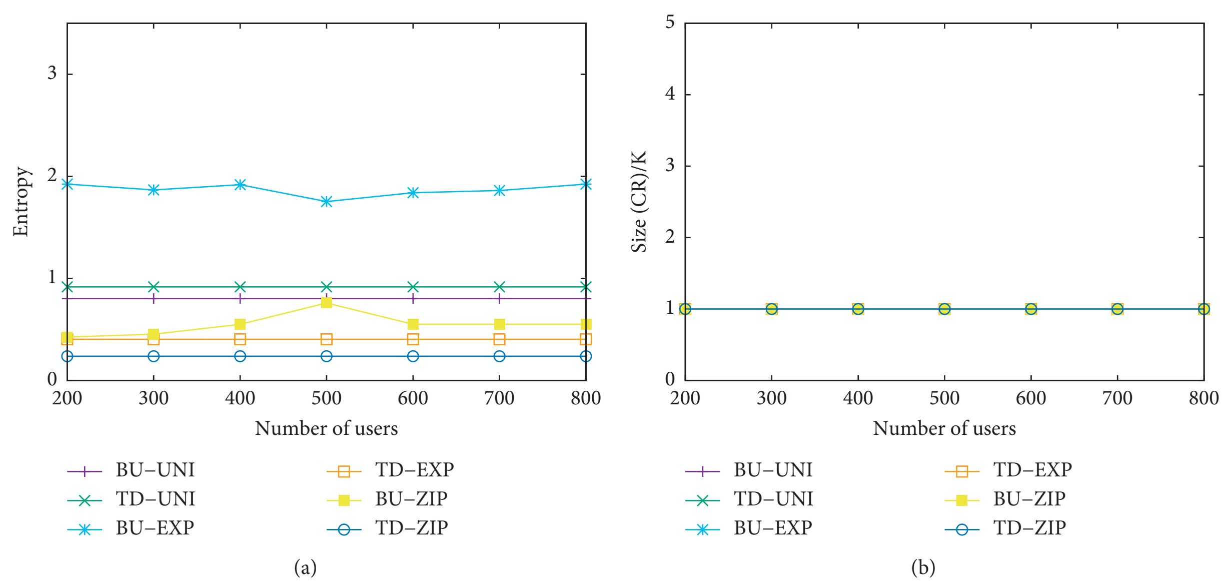

FIGURE 4: Effect of the number of users.

also observe that our approaches take advantage of the locality of the requests when users are preferably located in certain zones (EXP and ZIP) because they exhibit smaller costs than their similar versions running on a uniform distribution of users and requests.

Figure 3(b) shows the number of built cloaking regions by all techniques. We can observe that techniques based on TD, except IND – TD, build a smaller amount of cloaking regions. This is not surprising because TD-based approaches begin with a large cloaking region (network area) and refine this solution until it is not possible to satisfy the demanded location privacy and safety requirements.

Figure 4(a) shows the average entropy of all techniques for several distribution of users. We observe that the quality (entropy) of the cloaking regions provided by TD- and BU-based approaches is similar when the same user distribution is applied.

Figure 4(b) shows the ratio between the size of cloaking region (number of chosen cells) and the value K demanded. We observe that all techniques show similar and the best performance, which is close to 1. This is because when we consider BU-based approaches, we observe that the candidate cloaking regions returned by the bottom-up technique algorithm also satisfy the demanded location safety requirement. For TD-based approaches, the size of the initial candidate cloaking region (the entire network area) is reduced to a size equal to the location privacy requirement demanded and also satisfying the location safety required.

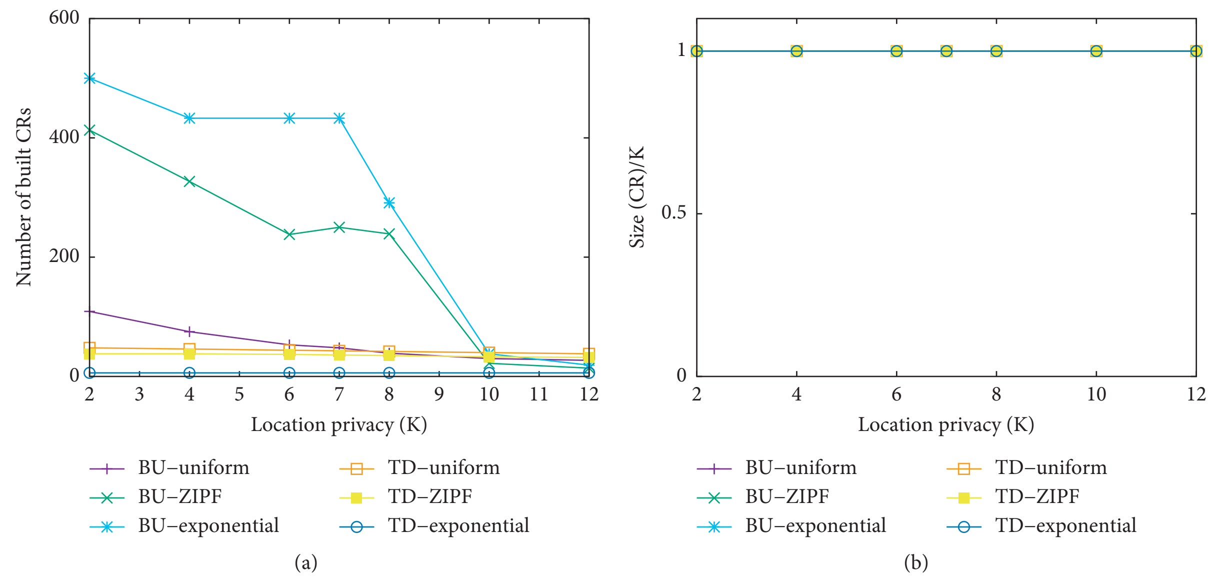

Figure 5: Effect of the location privacy (K).

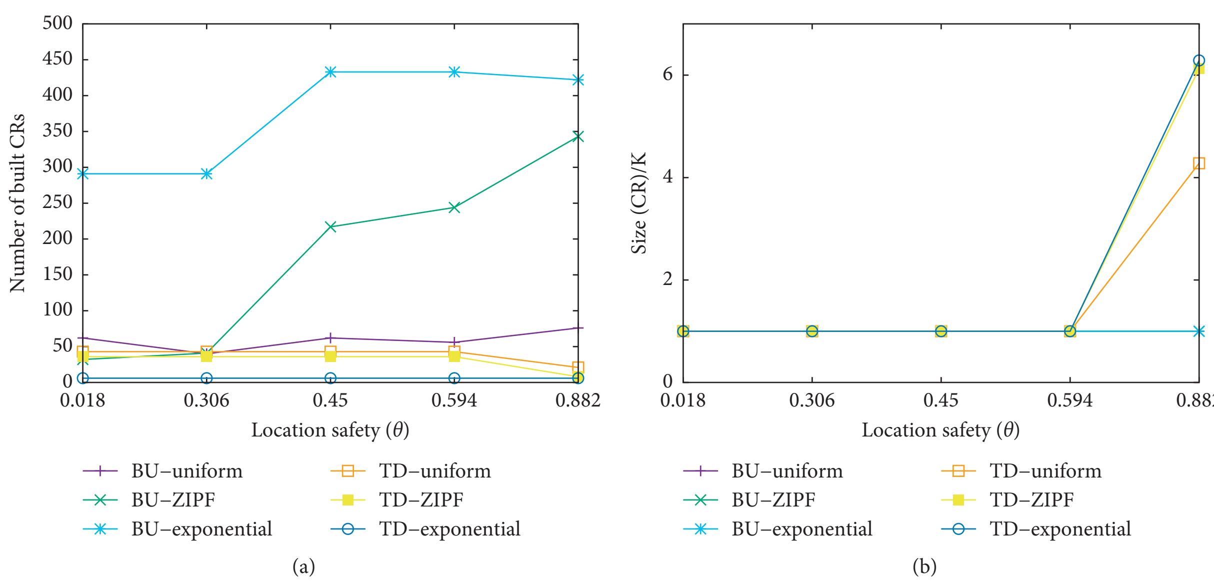

Figure 6: Effect of the location safety (θ).

5.2. Effect of the Location Privacy (K). We vary the value for K between 2 and 12. The (X, Y) coordinates of users and the frequency of the cloaking requests per cell are set according to either uniform (UNI), exponential (EXP,0.5) or Zipf (ZIP, 2.0). We fixed the location safety requirement (θ) at a value of 0.45, and the number of users is set to 500.

Figure 5(a) shows the average number of built cloaking regions. We observe that when K becomes higher, more cells are demanded, and therefore it is highly probable that the cloaking region might have a large proportion of area overlapping. As a consequence, we observe a reduced number of cloaking regions being built. Specifically, TD-based approaches exhibit the smaller amounts of cloaking regions since they initially propose the entire network area as a candidate cloaking region and they attempt to reduce its size.

Figure 5(b) shows the ratio between the size of a cloaking region and K. All techniques exhibit the best result, i.e., 1.0, which means the size the of a CR is equal to the demanded location privacy requirement (K).

5.3. Effect of the Location Safety (θ). We vary the value for θ between $0.018 = 3 \times 3/500$ and $0.882 = 21 \times 21/500$. The (X, Y)-coordinates of users and the frequency of the cloaking requests per cell are set according to either uniform (UNI), exponential (EXP, 0.5) or Zipf (ZIP, 2.0). We fixed the location privacy requirement (K) at a value of 7, and the number of users is set to 500.

Figure 6(a) shows most of the techniques based on BU build more cloaking regions when θ is increased. On the contrary, techniques based on TD build a number of cloaking regions almost independently of θ.

Figure 6(b) shows the ratio between the size of the cloaking region and K. All techniques exhibit a value equal to one, except when θ achieves a larger value (0.882). This is because a higher θ value demands larger areas with low user occupancy.

6. Conclusions

This paper introduced two novel batching techniques to build cloaking regions for a large number of users having diverse location privacy and location safety requirements. Our proposed techniques attempt to balance computational cost of the anonymizer and the location-based service. Our techniques take advantage of building efficient cloaking regions of users having similar location privacy and safety requirements and who are located close to each other.

From the results, our techniques offer cost-effective solutions for the anonymizer side to build location privacy and safety protections. Our bottom-up approach shows a good balance between quality of a cloaking region, its size (which measures the impact at the LBS), and its computational cost for the anonymizer. Our top-down approach shows good results for the quality and the number of built cloaking regions at the expense of computational cost. This is because the latter approach is quite conservative, and there is space to make it more efficient.

Our results are preliminary yet promising. We are planning to test more diverse scenarios and to find optimal values for some system parameters such as m and Δ. In addition, we would like to extend our techniques to support continuous LBS. In this service, users periodically request location privacy and safety protection and either an LBS server or a third party adversary can attempt to correlate these cloaking regions to narrow down the location of one or many target users. Thus, the anonymizer must take into account the cloaking regions released to a user before returning a new one.

Data Availability

The data used and the simulator from which this data was obtained to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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