Building a Crowdsensing Platform Based on Spatio-Temporal Fencing

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Abstract. In this research, we propose the concept of spatio-temporal fencing, which restricts the time and area of sensing, and construct crowdsensing platform based on this concept. We have focused on convenience and sense of security to address the issue of improving and maintaining collaborator motivation. For requesters who want to implement crowdsensing, defining the contents of a request is a time-consuming task with many items that must be defined. This platform simplifies the definition of the request and makes it easy to use, because the request can be basically defined only by setting the spatio-temporal fencing and the sensor to be used. Spatio-temporal fencing can make it clear to collaborators when and where sensing will take place, and provide sense of security by reducing privacy barriers caused by concerns about data provision and sensing. In this paper, we have designed, implemented, and verified the operation of this platform.

Keywords: Mobile computing · Ubiquitous computing · Sensing · Smartphone

1 Introduction

In recent years, the number of smartphones equipped with sophisticated sensors has been increasing, and a wide variety of sensors are becoming available. Therefore, there are a number of research that use smartphone sensors [1,2]. Crowdsensing is an attempt to utilize the sensing capability of smartphones [3–5]. Crowdsensing is currently being employed in research and surveys [6–8]. The implementation of crowdsensing requires the development of a dedicated system, which is expected to incur significant initial and running costs. In addition, in order to encourage many collaborators to cooperate in crowdsensing, there are issues such as reducing the time and effort required for collaborators and eliminating their anxiety. As for the time and effort required for collaborators, the burden of operating and communicating with smartphones can be mentioned.

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The concerns of the collaborators include worries about providing data due to privacy barriers of the collaborators and distrust of sensing. Furthermore, since crowdsensing handles a lot of sensitive data such as sensing-data, security and privacy protection measures are essential.

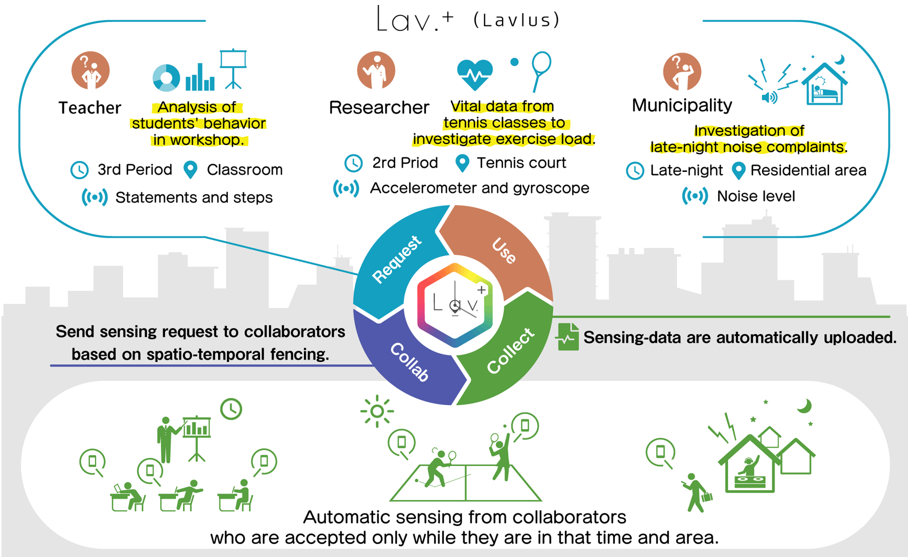

Fig. 1. Overview of this crowdsensing platform

In this research, we propose the concept of spatio-temporal fencing that limits the time and area of sensing, and build crowdsensing platform Lav.$^+$(Lavlus) in Figure 1 based on it. The purpose of this research is to realize a significant reduction of initial and running costs in research and surveys by simple use of crowdsensing and various data collection. As conventional research, crowdsensing platforms have been proposed to enable crowdsensing in various situations [9–14]. However, crowdsensing platform cannot realize diverse data collection without securing a larger number of collaborators. Therefore, it is necessary to improve and maintain the motivation of collaborators.

Therefore, Lavlus provides collaborators with convenience and sense of security to promote crowdsensing implementation and cooperation. For a requester who wants to implement crowdsensing, defining the contents of the request is time-consuming because there are so many items that need to be defined. However, Lavlus can basically define the request by only setting up the spatio-temporal fencing and the sensors to be used. Therefore, spatio-temporal fencing simplifies the definition of the request by the requester and makes it easier. For the collaborator, since it is clear when and where sensing will take place, it reduces privacy barriers due to concerns about data provision and sensing, and provides a sense of security. This makes it easier to cooperate with crowdsensing requests made through Lavlus, since they are all based on spatio-temporal fencing. In addition, to reduce the time and effort required for collaborators, sensing is performed automatically with minimal smartphone operation. This removes the sense of obligation for the collaborators to cooperate, and allows for continuous cooperation.

The contribution of this paper is the proposal, design and implementation of a system that aims to stimulate research and surveys using crowdsensing as a type of crowdsourcing. Although widely used smartphones are the best mobile devices for crowdsensing, their methods have not been generalized. This is because many conventional studies require the construction of a dedicated system. However, since the essence of these studies and investigations is the analysis and investigation of the collected sensing data, the construction of a dedicated system has a large initial cost and cannot be the essence of the studies and investigations. Even if a dedicated system is built, the next challenge is to get as many collaborators as possible.

2 Related Research

There are several research that use crowdsensing to collect data from a large number of people for estimation and analysis. For example, crowdsensing using mobile devices is used to collect and share ambient sounds to conduct noise surveys [6,7], and motion sensors such as accelerometers are used to collect data from car users to estimate road conditions such as icy and paved roads, and road geometry such as flat and hollow surfaces [8]. In these research, the development of a crowdsensing system is expected to incur significant costs. To implement crowdsensing, it is necessary to develop a sensing smartphone application exclusively for the collaborator and a server to manage the collected data.

Therefore, a crowdsensing platform would be very useful if the requester wishes to use crowdsensing to collect data. For the requester, it is no longer necessary to create and distribute a dedicated smartphone application for sensing for each research, thus eliminating the time and effort spent on these tasks. As for the collaborators, there is no need to install a separate smartphone application for each research, and there is no need to use separate applications for each research. In addition, the use of a common smartphone application can lead collaborators to other crowdsensing applications, which can lead to the acquisition of many collaborators.

Next, we discuss related research on crowdsensing platforms. There are already some that operate as simple platforms mainly for the purpose of reducing system development costs [9,10]. However, securing collaborators is very important for crowdsensing platforms. Related researches include those to improve and maintain the motivation of collaborators and to secure collaborators.

This includes research using monetary incentives [11] and research that uses gamification to provide non-monetary incentives [12]. There are also research that offer a flexible choice between monetary and non-monetary incentives. In this research, our approach is to remove disincentives for collaborators through spatio-temporal fencing, and we are considering introducing a mechanism that can provide incentives in the future.

3 Crowdsensing Platform Based on Spatio-Temporal Fencing

This chapter describes the details of Lav.$^{+}$(Lavlus), a crowdsensing platform based on spatio-temporal fencing. Each section is organized in the following order: Definition of spatio-temporal fencing, Implementation of Lavlus, and Verification of Lavlus operation.

3.1 Definition of Spatio-Temporal Fencing

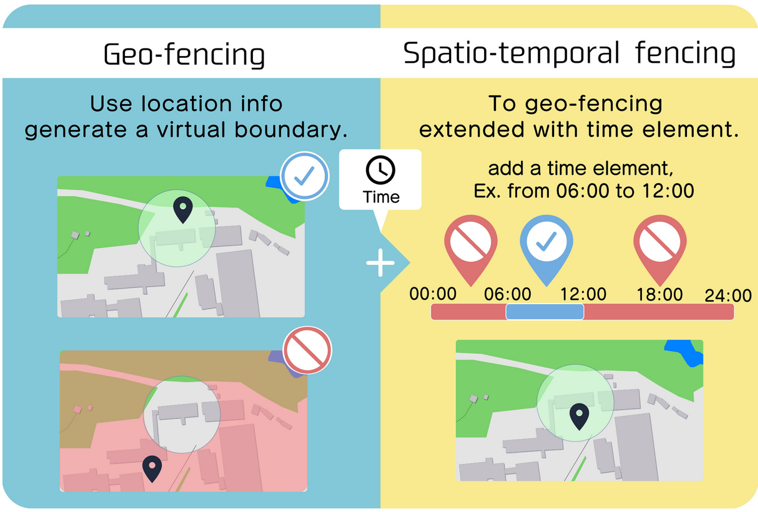

Fig. 2. Geofencing and spatio-temporal fencing

Spatio-temporal fencing is defined as a unique fencing method that extends geofencing by adding a time element in Fig. 2. In the figure, the pin marks are considered to be fencing targets. Geo-fencing is the process of creating a virtual boundary on a map, as shown by the circle in the figure, and using location estimation technologies such as GPS, Wi-Fi, and BLE beacons to provide specific services when a user enters or exits the boundary. In other words, spatio-temporal fencing is a fencing method that generates a virtual boundary by specifying the time and area. The specific service in Lavlus is sensing.

When the boundaries are delimited by time and area using spatio-temporal fencing, the requester can specify a variety of situations. For example, a park from 3:00 to 5:00 p.m., a specific classroom on a university campus during third period, or a cafeteria during the daytime. On the other hand, it is not suitable for data collection that does not depend on time or area. For example, such as sensing all day long or traveling by train. This is because such long-time sensing or sensing that is not certain when it will end places a heavy burden on the collaborator in terms of power consumption and anxiety about sensing. For this reason, Lavlus does not support all possible types of crowdsensing that a requester may expect.

Lavlus uses spatio-temporal fencing to make it easier for collaborators who have no contact with the requester to make decisions about cooperation. For example, when a collaborator who does not have any contact with the requester cooperates with the requester's crowdsensing, if the time of day or area where the sensing is to be performed is unclear, the collaborator will feel uneasy and will be less likely to cooperate. Therefore, we believe that time zone and area restrictions based on spatio-temporal fencing can provide a sense of security to collaborators and promote sensing cooperation.

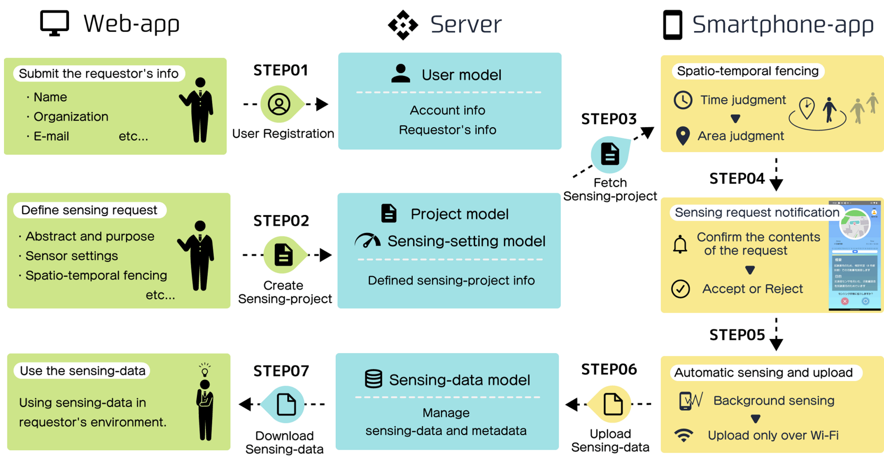

Fig. 3. Overall system flow of Lavlus

3.2 Implementation of Lavlus

Lavlus is composed of three components: server, web-app, and smartphone-app. In addition, the requester's crowdsensing requests are managed in units called projects (hereafter referred to as projects). The server is designed to manage projects and sensing-data, the web-app is a console for managing projects for the requester, and the smartphone-app is a sensing smartphone-app for the collaborator. In this section, we describe Overall system flow of Lavlus, Implementation of each component, and Security measures.

Overall System Flow of Lavlus. The overall system flow of Lavlus is shown in Fig. 3. We assume that the requester uses a PC and the collaborator uses a smartphone as the device used. In STEP01 of the figure, the user is asked to prepare in advance for using Lavlus. To use it as a requester, requestor registration through the web-app is required. To use it as a collaborator, installation of the smartphone-app is required.

As shown in STEP02, the requester first creates a project through a web application. The project defines time and area to be sensed, the purpose and outline of the sensing, the type of sensor to be used for sensing, and the sampling rate. This is the setting of the sensing and spatio-temporal fencing required for the smartphone-app, and also serves as the basis for presenting the project to collaborators and deciding whether or not to cooperate. The created project can be managed by the server.

Next, we ask the collaborators to cooperate with each project using the smartphone-app. As shown in STEP03, the smartphone-app first gets the project from the server. Then, for each acquired project, the operations are performed in the following order: spatio-temporal fencing, sensing request notification, sensing, and uploading. In STEP04, spatio-temporal fencing is performed to reference the spatio-temporal space specified for each project, and a sensing request notification is sent when the collaborator is in the spatio-temporal. The collaborator confirms the contents of the project from the sensing request notification, and decides whether to accept or reject it. The sensing request notification is sent as a heads-up notification, and the detailed screen is displayed by tapping the heads-up notification. In the detailed screen, you can check the contents of the project, such as the time period, sensing area, purpose and outline of the sensing, and the requester information. In STEP05, sensing is started only when the collaborator is satisfied with the project and is willing to cooperate. After sensing is completed, the sensing data is automatically uploaded to the server only when Wi-Fi is connected, as shown in STEP06.

The operation flow of the smartphone-app in the figure is the cooperation procedure of the collaborators. In order to minimize the amount of time and effort required, the only part of the cooperative procedure that requires the operation of the collaborator's smartphone is basically the acceptance or rejection of the sensing request notification. This is because all the processing in the spatio-temporal fencing, sensing, and uploading procedures is done in the background. Therefore, there are no operations such as opening the smartphone-app or having the collaborator start and stop sensing, which makes sensing cooperation easy. In addition, once a project is accepted, it is saved, and when the collaborator enters the same project's spatio-temporal again, sensing will start without sending a sensing request notification.

In STEP07, the requester uses the sensing data provided by the collaborator through a web application. The sensing-data can be downloaded in CSV or JSON format, which are provided in a uniform format. The requester downloads the sensing data from the web application and analyzes it using his or her own environment, and uses it for research and surveys. Currently, Lavlus needs to provide support to the requester, such as analysis and visualization of the sensing-data, but has not yet been able to implement such support. Therefore, we are investigating the filtering of bad data that may occur due to the nature of crowdsensing. Bad data is data that has been sensed contrary to the intent of the project. For example, in a project aimed at measuring locomotion, data sensed by a collaborator while the smartphone is placed on a table, or data sensed when the smartphone's sensor does not work properly, can be considered. In other words, we are considering implementing a function that filters out bad data and supports how reliable the sensing data is.

Implementation of Each Component. The server was designed as a JSON-based REST API that is highly compatible with both the web-app and the smartphone-app so that they can be linked smoothly. The web-app was implemented using a Single Page Application in Fig. 4. First, the requester registers as a requester using the web-app. The registered requester information is managed according to the User model defined on the server. At this time, the requester is asked to register real name, organization, e-mail address, and other requester information. This information is required because if the requester is anonymous or unclear, it may cause anxiety to the collaborators, making it difficult to obtain their cooperation. Although the requester information is personal data, the terms of use of Lavlus require the requester to disclose identity. The next step is to define the project based on the outline and purpose of the sensing request, sensor settings, spatio-temporal fencing, and other information. The defined project is managed according to the Project model and the SensingSetting model. The sensing-data provided by the collaborators is then managed according to the SensingData model, and the sensing data is acquired through a web-app.

The smartphone-app was implemented as an Android application. The smartphone-app works with the server to receive projects and upload sensing-data along with metadata. Projects are retrieved from the server as necessary and registered in the database in the smartphone-app. The smartphone-app searches for the nearest specified start time from the current time in the database, and sets the specified start time and specified end time to spatio-temporal fencing. Spatio-temporal fencing first determines the time in order to minimize location information acquisition, and then determines the area at the start time specified by the project.

The area determination determines whether the collaborator has entered or exited the sensing area defined in the project. However, if the collaborator is active near the boundary of the sensing area, the area judgment becomes unstable as it repeatedly makes entry/exit judgments. Therefore, we introduced the area margin in Fig. 5 to stabilize the area judgment determines. The area mar-

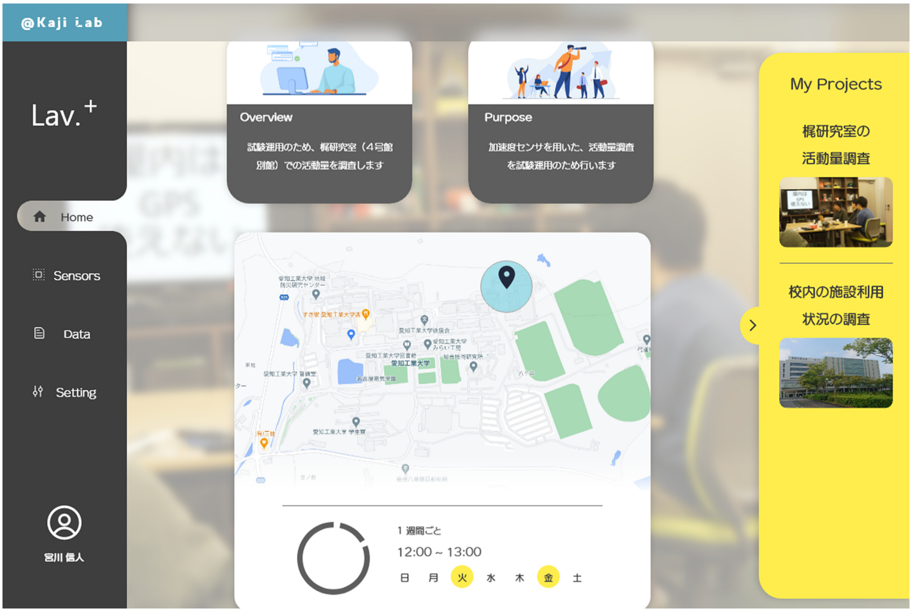

Fig. 4. Dashboard of the web-app

gin defines two types of areas, considering the inner and outer margins. The two areas are the inner area, which has been reduced in size relative to the sensing area, and the outer area, which has been expanded. As shown in the figure, when a collaborator stays in the inner area for a certain period of time, it is judged to have entered the sensing area, and when the collaborator who is judged to have entered stays outside the outer area for a certain period of time, it is judged to have left the sensing area. For this certain period of time, a value of 5 s has been set on a trial basis, but it is necessary to reset the optimal value through evaluation experiments. The introduction of an area margin also aims to deter the initiation of sensing when the collaborator stays only for a very short time, such as passing through the sensing area.

When a collaborator enters the sensing area during the time period specified in the project, a sensing request notification is sent. Tapping the heads-up notification and opening the application will display the detailed screen of the sensing request notification in Fig. 6. The detailed screen shows the current location and designated sensing area on a map, the time of day on a range slider, and the contents of the project in a box with a scroll bar. The map display of the requester location and the designated sensing area is a device to make it easier for the collaborator who has entered the space-time to understand the location of the current location.

After sensing is completed, the sensing-data is registered in the database with a file name and an un-uploaded flag. We only upload the data after verifying a Wi-Fi connection and then update the un-uploaded flag. The reason for this

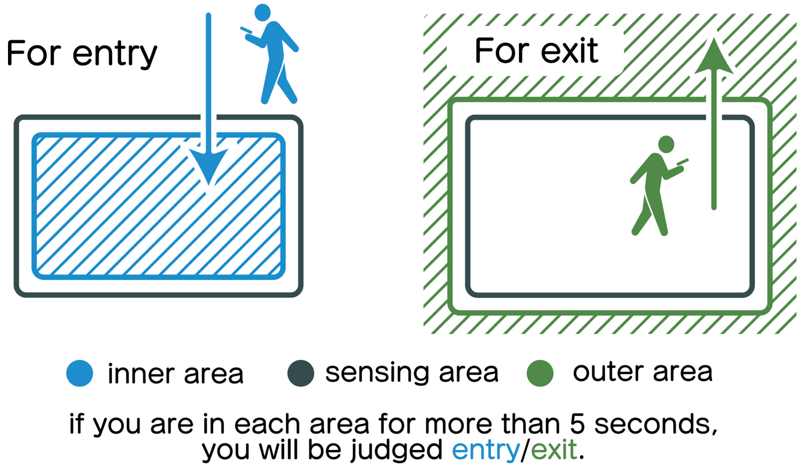

Fig. 5. Overview of area margin

is that uploading sensing-data while connected to a cellular connection would use the mobile communication volume of the collaborator, placing a burden on the collaborator. If there is no Wi-Fi connection, the upload is put on hold, and when the Wi-Fi connection is confirmed, the data is uploaded at once.

Security Measures. Since Lavlus is a platform that handles sensitive information such as sensing-data, we have implemented several security measures. First, the server uses JWT token authentication as a security measure. This prevents unauthorized access to each endpoint and prevents unintended access or falsification of information by third parties.

Next, due to the limitation of spatio-temporal fencing, which is the design basis, we do not perform sensing without specifying a time or sensing area. In addition, we do not perform sensing without the requester consent, even when the time and sensing area are specified. This minimizes the risk of privacy violations associated with the provision of unintended sensing-data by the collaborator.

Finally, the handling of sensing data will be strictly managed in accordance with the GDPR [15], which is the law governing the protection and handling of personal data in the EU. According to the definition of personal data in the GDPR (Article 4), each sensing-data itself provided by a collaborator is not classified as personal data. However, it may be classified as personal data if it is combined with information that accompanies the sensing-data. In addition to sensing data, Lavlus acquires metadata, which is terminal information such as the name of the terminal and the model number of the sensor, as environmental information about the sensing process. Therefore, metadata such as the IMEI, which is a device identification ID, will not be acquired when sensing-data is provided by the collaborator, as it is considered personal data. In addition to the IMEI, metadata that can be used to identify an individual by referencing sensing-

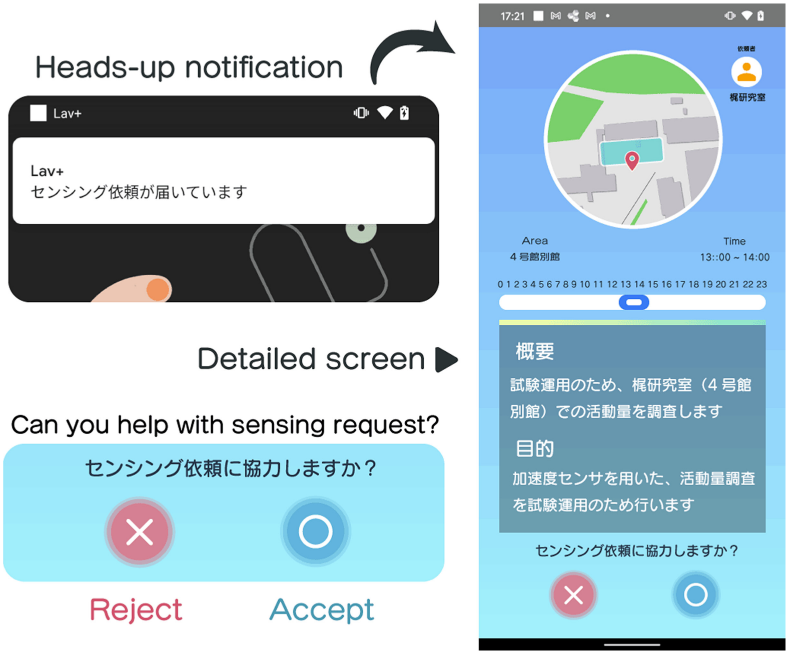

Fig. 6. Sensing request notification

data and metadata is also considered personal data, so only information that can identify the environment in which sensing was performed will be acquired.

3.3 Verification of Lavlus Operation

We set up a situation in which we investigate the amount of activity in the annex of Aichi Institute of Technology Building No. 4 from 13:00 to 14:00 using an acceleration sensor. Since this verification is in the initial stage of implementation, we do not assume complex situations such as exceptions to operations, but rather simple situations. As a preliminary preparation, the requester registered as a new requester with the web-app, and the collaborator installed a new the smartphone-app.

First, we verified that the server, the web-app, and the smartphone-app could requester and receive projects normally. After creating a project using the web-app, we checked the server and confirmed that it was created normally. After that, the smartphone-app received the project from the server. Since the project defined in the server was received without any problem, it is judged to be normal.

Next, based on the received project, the operation of the spatio-temporal fencing and sensing of the smartphone-app is verified. The sensing request notification was not sent even if the collaborator entered the operation verification sensing area before the specified start time, but was sent when the specified start time arrived. When the request was approved from the sensing request notification, sensing started normally. After leaving the sensing area, sensing was terminated, and after re-entering the area, sensing was started again. When the specified end time was reached while still in the sensing area, sensing was terminated. In the operation verification, since the sensing area was indoors, there was a location error in the area determination by GPS, but the operation was confirmed. As a result, we can conclude that the time judgment, area judgment, and sensing are normal.

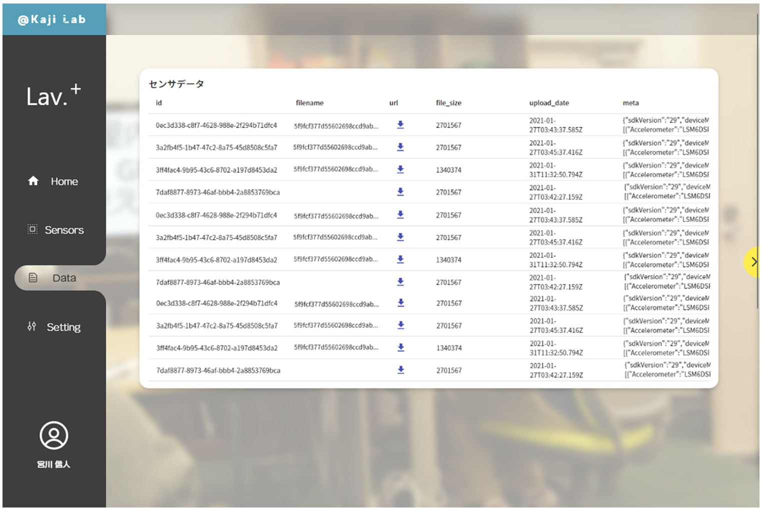

Fig. 7. Collected sensing-data confirmed using the web-app

Finally, we verified that the smartphone-app could upload sensing-data and the web-app could view sensing-data normally. Sensing was completed with no Wi-Fi connection. When we checked the server, we could not see any upload of sensing-data. After that, we reconnected to the Wi-Fi connection and checked the server again, and found that the sensing-data had been uploaded. In addition, when we checked the sensing-data using the web-app, the acceleration sensing-data was collected as per the situation in Fig. 7, so we consider the operation verification a success.

4 Conclusion

We aimed to build a platform that can be applied to various researches and surveys by collecting various data using crowdsensing. In conventional platforms, there are problems such as privacy violation concerns for collaborators and complicated definition of requests for requester. To solve this problem, we proposed the concept of spatio-temporal fencing and built a crowdsensing platform Lav.$^+$(Lavlus) based on it. Spatio-temporal fencing is a unique fencing method that extends geofencing by adding a time element and delimiting the boundaries by time and area. Spatio-temporal fencing reduces privacy barriers for collaborators by making it clear when and where sensing will take place, and simplifies the definition of requests for requester. We have implemented and verified Lavlus and verified that the system works properly.

Through operational verification, we found that GPS based area determination is not accurate enough in indoor areas where GPS information is unstable or in narrow spaces where GPS determination is difficult. Therefore, it is necessary to use radio wave positioning using Wi-Fi or BLE beacons, or geomagnetic positioning using magnetism emitted from a steel frame indoors to define the area in more detail. In addition, Lavlus is not yet ready for operation and evaluation. One of the issues for operation and evaluation is the establishment of terms of use. For example, in order to protect the privacy of collaborators, it is necessary to delete the provided sensing-data on the server upon their request. However, Lavlus method of providing sensing-data is through downloading. Therefore, we will establish terms of use that prohibit the retention of sensing-data beyond a certain period of time. In addition to solving the current issues, it is necessary to build a system that can be operated as a platform after conducting evaluation experiments using actual crowdsensing.

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