Detecting Garbage Collection Duration Using Motion Sensors Mounted on Garbage Trucks Toward Smart Waste Management

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***Abstract*—Solid waste collection is one of the fundamental services provided by local governments in support of our daily lives. In this paper, we describe a basic framework for estimating the amounts of solid waste and propose a method for detecting the time required for garbage collection with a view to realizing smart waste management. The proposed method recognizes garbage collection duration by using motion sensors mounted on a garbage truck. We also report a preliminary evaluation of the proposed method using actual motion sensor data.**

***Keywords*–Smart city; Activity recognition;**

I. INTRODUCTION

Solid waste collection is one of the fundamental services provided by local governments in support of our daily lives. Efficient waste management is important if we are to sustain stable waste collection service in the future. The optimization of waste collection operations and domestic waste reduction are key factors related to efficient waste management. At the same time, we are investigating smart city sensing using car-mounted sensors. Smart waste management using garbage trucks equipped with sensors could provide a powerful solution. In this paper, we propose a method for detecting the time required for garbage collection with a view to realizing smart waste management.

In conventional waste management, the amount of solid waste for a given region is summarized by weighting the waste delivered by garbage trucks assigned to the region to incineration plants. In fact, one truck collects solid waste in multiple separated areas to allow workload balancing, and therefore the summarized result includes some degree of error and waste collection operations are planned based on human intuition.

We propose a method for estimating regional amounts of solid waste based on the garbage collection duration in each area and the waste weight measured at incineration plants. The garbage collection duration is estimated from the vibration of the garbage truck when it scoops up the garbage with a rotating plate. We mounted motion sensors on garbage trucks and measured the changes in vibration. This paper reports a preliminary evaluation of our estimation of garbage collection duration and discusses the feasibility of the proposed method.

Determining the estimated amounts of regional amounts of solid waste enable us to realize the following applications.

- Support when planning future solid waste collection: We can obtain the long-term fluctuation and regional seasonal variations in the amount of solid waste by measuring the amounts in small areas such as those covered by a residents' association. This information will also enable us to estimate future solid-waste amounts in detail thus allowing waste management planning.
- Feedback garbage amounts to citizens:
  Most residents know neither the amount of garbage that they produce nor the total amount of garbage in their area. If a resident knows that he produces more than the average amount of garbage, he will try to reduce it. Moreover, if a resident knows that the total amount of garbage produced by his residents' association is less than the average, he may try to persuade his neighbors not to exceed the average. In this way, regional feedback regarding the amount of solid waste will promote its reduction.

This paper describes a method for detecting the time taken by a garbage truck during garbage collection and a method for estimating the amount of solid waste that is collected. We also report a preliminary evaluation of the collection duration detection method using actual motion sensor data.

II. RELATED WORK

Activity recognition research using motion sensors started with human activity recognition [2] and studies are under way with a variety of targets such as animals, buildings, cars [6]. Moreover, most recent smartphones are equipped with motion sensors. We can easily develop such activity recognition systems for use in various fields.

Recently, a road surface quality monitoring system using a mobile device was proposed [7]. This system allows us to monitor road surface quality without the need for a dedicated car. Although we use dedicated sensor nodes for field trials, we consider that we can detect the time taken for garbage collection using a smartphone equipped with a motion sensor.

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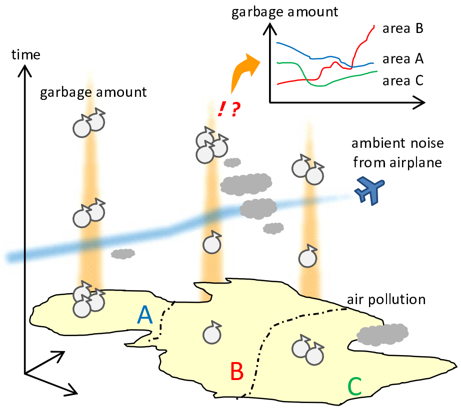

Figure 1. Spatio-temporal event detection using car mounted sensors

In the future, it is possible that we will be able to monitor road surface quality and measure regional solid-waste amounts simultaneously using motion sensors mounted on the garbage trucks that travel around cities every day.

There is another type of smart waste management in which smart sensors are attached to garbage carts [3]. We can monitor the number of garbage carts remotely, and the best garbage collection route is provided by the service providers. However, this approach is not available for some types of garbage collection system such as where residents place their garbage in bags in front of their house and the bags are regularly collected by trucks.

III. Sensorized Garbage Truck

We are investigating city event detection technology using environmental data collected via car-mounted sensors. Car-mounted sensors provide significantly more detailed data both in space and time than fixed monitoring stations. Figure 1 shows an image of spatio-temporal event detection. Such fine-grained environmental data help us to detect spatio-temporal city events in more depth, for example the emergence of air pollution hot spots, the generation of ambient noise, and sudden increases in residential solid waste.

We have installed dozens of car-mounted sensors on garbage trucks that travel daily around Fujisawa city, Kanagawa, Japan [1], [5]. Figure 2 is a picture of a sensorized garbage truck. The truck is equipped with four microphones, a GPS receiver, a motion sensor, and a sensor node to manage these sensors. We also installed various types of sensors such as NO_2, CO, $PM_{2.5}$, temperature, humidity, UV sensors on other garbage trucks. Sensor data measured by these sensorized garbage trucks are sent to a data server via a mobile Internet connection service.

IV. Residential Solid Waste Collection in Japan

This section describes residential solid waste collection in Japan in detail. Garbage bags are put out in front of houses facing the road or at collection sites and are regularly collected by garbage trucks. Solid waste is separated into several types such as combustible waste, incombustible waste, glass bottles, recyclable plastic, and paper. Each type of waste is collected on a designated day of the week.

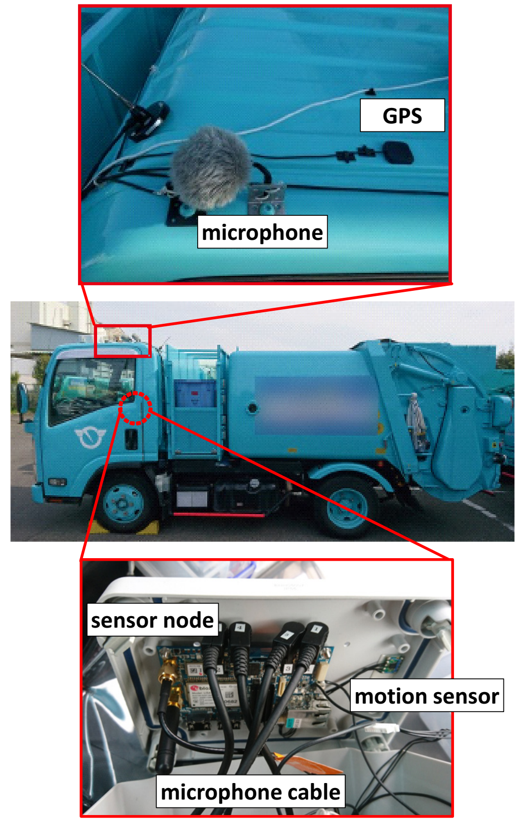

Figure 2. Sensorized garbage truck

Regarding residential solid waste collection, a garbage collector drives a garbage truck to the assigned area. He stops the truck at each collection site or in front of a house and loads garbage bags into the truck by hand. Actual examples of garbage collection in Japan are shown in [8]. When the opening at the back of the truck is full, the garbage collector starts the rolling plate and the garbage bags are packed into the container. Before the container of the truck is full, he drives to an incineration plant or a recycle plant. The weight of the collected solid waste is measured at the plant.

In Fujisawa city, the site of our experimental facility, the garbage collector plans a detailed garbage collection route at his discretion, and he also decides when to visit the incineration plant depending on traffic condition, road construction schedule, and the amount of garbage. Sometime a garbage collector is asked to collect forgotten garbage from another garbage truck temporarily. Thus, we cannot obtain the regional solid-waste amount in detail using only the measured weight of solid waste in incineration plant.

V. Solid Waste Weight Estimation Scheme

We assume that the operating duration of the rotating plate is in proportion to the amount of solid waste and we estimate the regional solid-waste amount by distributing the weight from the operating duration of the rotating plate. Figure 3 shows a simple example of this approach.

The examined rear loader type garbage truck operates its rotating plate and packer blade by using a power take-off (PTO). The engine speed and vibration pattern are switched when the rotating plate and packer blade are operated. The

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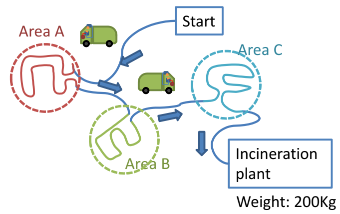

	Area A	Area B	Area C	Total
Collection duration	20 min.	10 min.	10 min.	**40 min.**
Estimated garbage weight	100Kg	50Kg	50Kg	**200Kg**

Figure 3. Garbage amount estimation

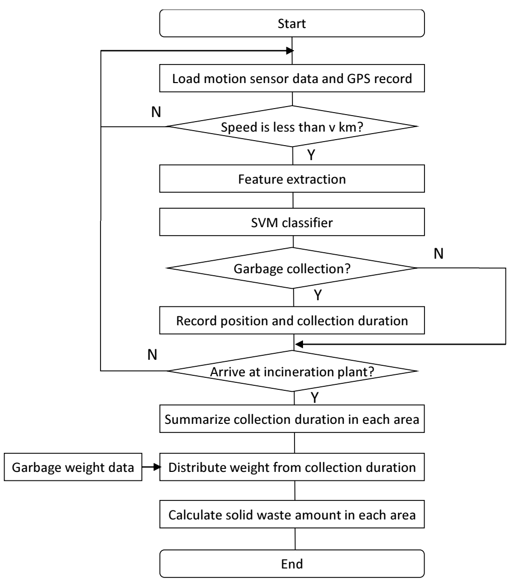

Figure 4. Flowchart of proposed solid-waste amount estimation

proposed method recognizes the difference in the vibration pattern using a motion sensor.

We also discuss a method that estimates the regional solid-waste amount from the trip times for each area using only GPS records. However, with actual garbage collections, narrow roads require additional time to allow the garbage collector to reach a secluded collection site on foot. Alternatively garbage collectors may be able to load large amount of solid waste quickly at a large collection site in a large apartment. Thus, it is difficult to estimate regional solid-waste amounts in detail using GPS records.

Moreover, we also discussed a method using sound to detect rotating plate operation and a method by garbage bag detection from camera image. However, these methods require additional devices outside of the truck. In addition, these microphone and camera approaches may violate citizens' privacy by capturing their voice and face. Our method can be implemented by using a recent smartphone equipped with motion sensors and it is easier to install in a garbage truck.

A. Garbage collection duration detection using motion sensor

Figure 4 shows a flowchart of our proposed method for estimating the amounts of solid waste.

1) Garbage-truck motion measurement: We mounted motion sensors on garbage trucks and measured garbage truck

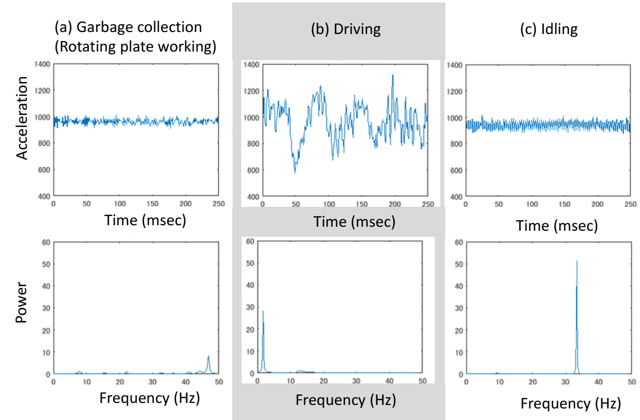

Figure 5. Acceleration sensor data and power spectrum

vibration. In the proposed method, acceleration data and gyro data are adopted. Figure 5 shows examples of acceleration sensor data and their power spectra. As the figure shows, we can find different peak acceleration frequencies depending on the garbage truck's situation (collecting garbage, driving, or idling). The peak frequencies differ according to the engine speed in each situation. We collected motion sensor data at 100 Hz, because the peak frequency during garbage collection was approximately 45 Hz.

2) Feature Extraction: Feature vectors are generated from motion sensor data by applying a sliding window framework. In the sliding window framework, features are calculated on N sample windows of sensor data with M samples overlapping between consecutive windows. We decided on $N = 1024$ and $M = 100$ in the latter evaluation. The sliding width M corresponds to the interval of GPS records.

LPC (Linear Predictive Coding) based cepstrum coefficients for each axis of the acceleration sensor data are extracted as features. LPC-based cepstrum coefficients are commonly used for speech recognition. We use the variations in the cepstrum coefficients obtained with the motion sensor depending on the situation of the truck. The feature extraction method is based on [4] where we provide more details.

3) Labeling: We selected a typical garbage collection day and annotated the sensor data with a "rotating" label. "Rotating" means that a garbage collector is operating the rotating plate. Closing door vibration causes a large noise regarding rotating duration detection. A garbage collector sometimes closes the door while another garbage collector is loading garbage. Thus, we do not annotate "rotating" labels to avoid the effect of the noise.

We annotated the labels by listening to sound recorded by microphones mounted on the garbage truck.

4) Supervised learning: We adopted SVM (Support Vector Machine) with a polynomial kernel as a classifier. We selected the same numbers of feature samples randomly for "rotating" and no-label.

We assume that the garbage bags are loaded on the garbage truck while the truck is stationary. We calculated the speed of the garbage truck using GPS records, and selected feature vectors whose speed was less than v km. We used $v = 10$ in the latter evaluation.

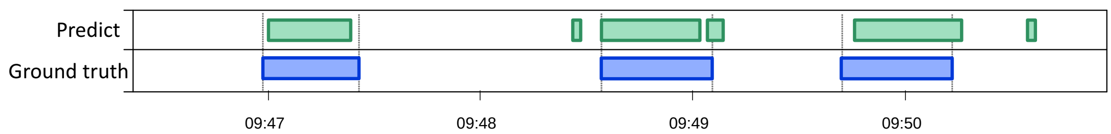

Figure 6. Part of garbage collection duration estimation result

TABLE I. RECOGNITION RESULT

		Recognition result		
		Rotating	No-label	Accuracy (%)
Ground truth	Rotating	662	138	82.8
	No-label	63	737	92.1

5) Garbage collection duration detection: The garbage collection duration is estimated by aggregating time samples classified as "rotating" by the SVM. We record the detected garbage collection duration and its locations. When the garbage truck arrives at the incineration plant, we summarize the data and then estimate the amount of solid waste by region as described next.

B. Estimation of solid waste amount

We estimate the amount of solid waste by region using the solid waste weight measured of incineration plants. We assume that the operating duration of the rotating plate is proportional to the amount of solid waste. We calculate the amount of solid waste by region by distributing the weight from the operating duration of the rotating plate. We total the amount of solid waste in each city block or each resident association.

VI. EVALUATION

First, we extracted feature vectors from acceleration and gyro sensor data and annotated them using sound data recorded by microphones mounted on the outside of the garbage truck. Then, we evaluated the recognition accuracy of the estimated garbage collecting duration.

We selected two days' motion sensor data where the same garbage truck collected the same type of solid waste. The garbage truck collected combustible waste during the morning. We selected 400 labeled feature vectors randomly for each label ("rotating" and no-label) and for each day.

Table I is the confusion matrix of cross-validation using 3-axis acceleration sensor data and 3-axis gyro sensor data. We created a classifier by using one day's motion sensor data and tested the motion sensor data of the other day. The precision was 88% and the recall was 87%.

Figure 6 shows the result of our garbage collection duration estimation. Some errors occurred at the start and the end of the garbage collection. Developing a post-processing technique to reduce estimation error is our next goal.

The result shows that the proposed method can accurately recognize garbage collection duration. However, we used motion sensor data from just one garbage truck in this evaluation, and the garbage was all the same. Further evaluation of, for example, difference between garbage trucks and the difference between different types of garbage constitutes our future work.

VII. CONCLUSION AND FUTURE WORK

In this paper, we proposed a garbage collection duration detection method and a framework for solid waste estimation using the detected duration and total solid waste weight. We also reported a preliminary experiment and showed that the proposed method could detect the garbage collection duration accurately for one garbage truck and one type of garbage.

As the next step in this research, we plan to evaluate the proposed method in more detail and extend the method to detect garbage collection durations for multiple types of garbage trucks and multiple types of garbage. We will also develop a post-processing technique to reduce noise such as the vibration of a closing door. Moreover, we are planning to create a system to feed back the estimated regional amount of the solid waste to citizens and to examine the effectiveness of our proposed approach for waste reduction.

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