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Selection of construction waste using sensor fusion

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Abstract

In recent years, buildings in urban areas are frequently being demolished for a variety of reasons. For example, demolitions happen when buildings are rebuilt because the building was sold during an asset sale by a corporation in financial difficulties, because the building was built during the period of high economic growth and was aging, or because the building was damaged in a natural disaster, which happens frequently in recent years. However, construction waste is still being sorted by hand. Therefore, it is desired to reduce labor costs and to improve safety of workers. In order to overcome these issues, this study investigated methods for automatically recognizing waste materials. However, these methods had several problems, such as low recognition accuracy and an inability to handle metals, such as iron.

In this research, we propose a method for automatically recognizing waste materials using sensor fusion. In the proposed method, information regarding the color, brightness, and shape of the object is acquired from images obtained using imaging sensors. In addition, we also focus on differences in the thermal conductivity of different materials and use a thermal sensor to measure the temperature of the target object to obtain thermal information.

We performed a material recognition experiment in which only camera images were used, and a material recognition experiment in which sensor fusion was used. The results show that the recognition accuracy was approximately 10% higher overall in the experiment conducted using the latter method compared to the experiment conducted using the former method. These results show that the proposed method is effective.

Research background

In recent years, buildings in urban areas are frequently being demolished for a variety of reasons. For example, demolitions happen when buildings are rebuilt because the building was sold during an asset sale by a corporation in financial difficulties, because the building was built during the period of high economic growth and was aging, or because the building was damaged in a natural disaster, which happens frequently in recent years. In Japan, under the "Construction Material Recycling Act", it is mandatory to dispose of construction waste that is generated during demolition work in an appropriate manner in order to move towards a recycling society. [1] In addition, awareness regarding environmental issues is growing within society. There is a need for further advances in methods for appropriately disposing of construction waste.

Large pieces of waste can be sorted into different materials based on differences in their weights. However, small pieces of waste are sorted by hand in assembly lines in factories. A photo is shown in Figure 1.

Figure 1 Sorting of construction waste[2]

However, the quality of the environments in which workers sort construction waste is poor. The sorting work happens at the actual demolition site or at intermediate treatment facilities. In order to solve the problems described above, it is necessary to develop technology that automatically recognizes materials within construction waste. There is much development work underway in this area.

Previous research

Sorting process using camera images [3]

These systems identify the material of a piece of construction waste through image processing. The systems automatically sort the waste by material for each material that needs to be sorted and recovered. The following pieces of information are calculated from the captured image in the box.

1. Calculate the saturation from the captured color image
2. Calculate the shine and roughness of the material's surface based on the brightness in the image
3. Calculate the shape and the size of the waste area in the image

We estimate the probability that the target object is made out of a certain material by applying Bayes' theorem, which is a method of estimating the probability of a phenomenon.

However, the system is not able to reach the expected detection rate of 60%, which was our initial target for actual use.

Sorting method using hyperspectral cameras [4]

Hyperspectral cameras (HSL) evaluate properties and conditions of materials that are difficult to evaluate with the human eye. Hyperspectral cameras evaluate the characteristic spectrum of objects through spectroscopic analysis. Figure 3 shows how a HSL camera works.

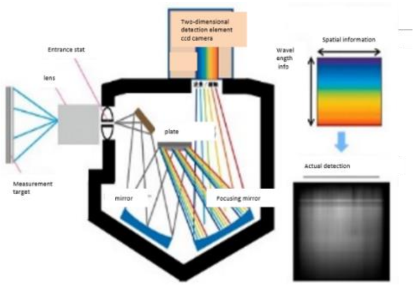

Figure 3 How Hyperspectral cameras work[5]

There are several methods for performing material ecognition using HSLs. The methods are able to recognize many materials, including wood, gravel, concrete, and brick, with high accuracy. However, the method does not yet handle metals, such as iron and aluminum. In addition, hyperspectral cameras have an extremely high-cost of approximately $90,000. Therefore, it is difficult to install these systems in construction waste processing assembly lines, which would require a large number of these systems, due to their high cost. Due to these reasons, these systems are not used in practical applications yet.

Proposed method

In order to address the problems that arise in the previous method, our goal for this research is to implement a sorting system that is low-cost, has a high recognition rate, and that can handle metals, including iron and aluminum.

We were able to successfully sort construction waste made out of materials that the previous method could not handle and with a level of accuracy that the previous method could not achieve by using information obtained through sensor fusion. Sensor fusion refers to combining information from multiple sensors. A flowchart of this method is shown in Figure 4.

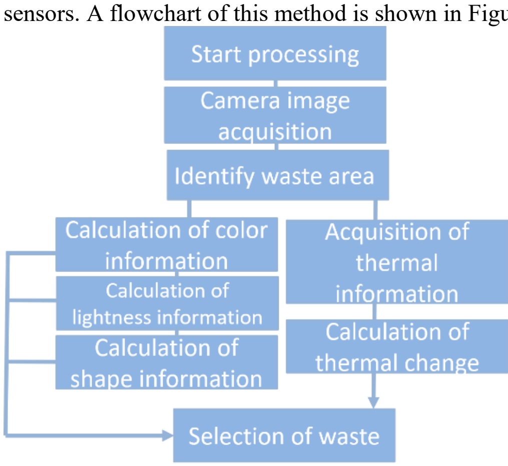

Figure 4 Flowchart

Sorting using imaging sensors (cameras)

We use imaging sensors (cameras) to acquire information for sorting construction waste. Although waste comes in a variety of materials, the shapes and colors of pieces of waste made out of each particular material are similar. Therefore, information that is collected from camera images through image processing technology is used for identifying the materials.

Information that is acquired includes information regarding the color of the target object's surface, the brightness the surface based on the contrast of the target object, and the shape of the target object. We explain the details of each process in the following sections.

Color information

For color information acquisition, we use the L*a*b* color display system known as the uniform color space. In this color system, equivalent changes in the value of the color are perceived to be equivalent by the human eye. Therefore, the arrangement of the colors is uniform, and the reproducibility of colors is greater than in other color spaces, and it is possible to measure color differences of the target object more accurately. A diagram of the color space is shown in Figure 5.

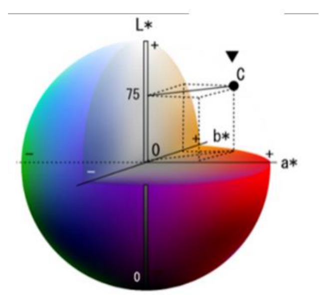

*Figure 5L*a*b* color display system[6]*

Using this color space, we calculate the average within the waste region of the metric saturation, which represents the color in the L*a*b* color space of the waste region, and use it as one piece of sorting information.

Brightness information

By quantizing the variance in the brightness of the surface of the piece of waste material, we measure the texture of the material surface. In materials such as wood, concrete, and iron, the unevenness and variation in the surface can be determined from the brightness difference. On the other hand, for materials such as aluminum and plastic, it is possible to identify shiny and smooth surfaces.

Shape information

Construction waste comes in a diverse variety of shapes. Waste that is discharged from demolition sites often deforms into indefinite shapes since the waste is broken down into small pieces during demolition. We calculate the general shape of the target object as a numeric value using an ellipse to approximate the shape. This information is used for extracting materials of a unique shape from a diverse variety of shapes, such as the shapes found within construction waste. Here, we measure the shape and the size of the form.

Sorting using thermal sensors

We acquire information for sorting construction waste using other types of sensors in addition to cameras as well. As explained earlier, waste comes in a variety of materials, and each material has unique shapes and colors.

However, since the waste is generated at the demolition site, the surfaces of many pieces are dirty and covered in mud or dust, and many pieces have rust or deformations due to aging. Due to these factors, identifying construction waste using the camera images alone could lead to reduced accuracy in recognition.

Therefore, we used additional sensors other than cameras as a way to suppress the decrease in recognition accuracy.

We focused on differences in thermal conductivity of construction waste materials, and acquired information using thermal sensors.

Thermal information

For target materials in construction waste, it is known that there are differences in the thermal characteristics of different materials, depending on differences in the condition of the surface and the temperature. Differences in the thermal information for various materials are shown in Table 1.

Table 1 Differences in thermal properties of materials[7]

Material	Thermal conductivity[λ]	Thermal emissivity
Wood	0.12	0.99
Plastic	0.17	0.90
Iron	83.5	0.08
Aluminum	236	0.05

Table 1 shows that different materials have different thermal conductivities. In other words, since the rate at which the target object holds heat is different, there is a difference in the rate at which the target object heats up when heated for a constant amount of time. In order to use thermal information, we use a thermal sensor that can measure thermal energy, which cannot be perceived using the human eye. By applying heat to the waste object and by using this sensor to acquire thermal information, it is possible to handle metals, which are difficult to identify based on images alone.

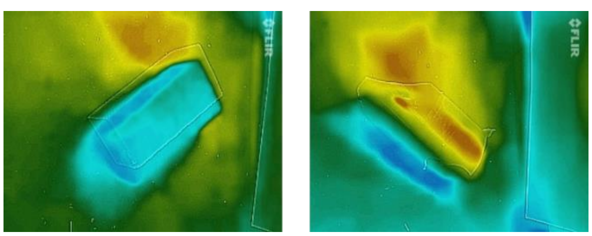

Figure6 Thermography

Waste information analysis (cluster analysis)

We integrate the various types of information about the target object that were acquired in the previous sections. In this research, we identify the material using cluster analysis.

Cluster analysis is a classification method for creating clusters by grouping objects that have similar characteristics from group data. There are a variety of methods for performing cluster analysis. In this method, we use Ward's method, which has high classification sensitivity in general.

Experiment

In order to verify the effectiveness of the proposed method, we conducted two experiments.

1.Material sorting using camera images

2.Material sorting using sensor fusion

Experiment apparatus

The details of the apparatus used in the experiment are shown in Tables 2 - 3. A photograph of the actual apparatus that was used is shown in Figure 7.

Figure 7 Thermal sensor that was used

Table 2 Thermal sensor specifications

FLIR ONE	
Photographable temperature range	-20℃～120℃
Temperature resolution	0.1℃

Table 3 Camera specifications

Camera	
Resolution	3024×4032
Field of view	90°× 69（° f=7.5 mm）

The experiment was performed with four types of materials, which were wood, plastic, iron, and aluminum. These materials are often found at demolition sites. The materials that were used in this experiment are shown in Figure 8.

Figure 8 Experiment material

Since the results of photographs taken by imaging sensors are influenced by the ambient light, it is necessary to prepare a photographing environment where the ambient light is blocked. In addition, since there is a possibility that the thermal information results could be affected by the air, it is necessary to prepare an environment in which the air is blocked.

Based on the above considerations, we created a box for measuring the material information for the experiment. In this experiment, we installed incandescent lamps in the box in order to light the material for photography and to heat the material at the same time. An image of the heating method is shown in Figure 9. In this experiment, we heated the object for 30 seconds.

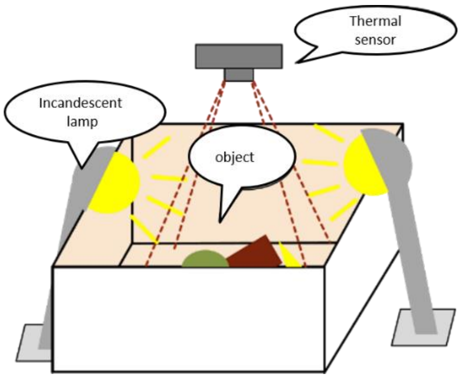

Figure 9 Heating environment

Experiment results

Material sorting using camera images

First, we performed a material sorting experiment using camera images alone. In order to perform cluster analysis using 2-dimensional data, we performed the experiment using two types of combinations of the color information and the brightness information and combinations of the shape information (shape and size). The results of actual sorting are shown in Figure 10.

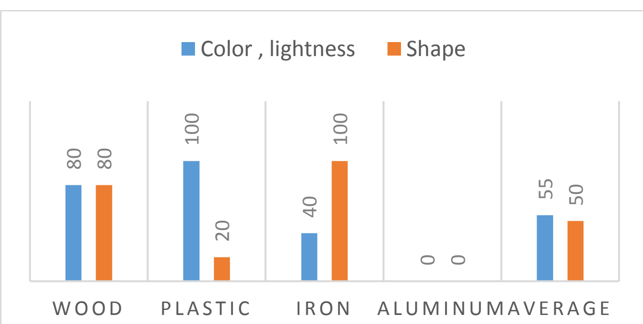

Figure 10 Experiment results 1

Material sorting using sensor fusion

Next, we performed sorting using the proposed method, which consists of sensor fusion. We performed cluster analysis using 3-dimensional data, which consisted of combinations of color information and brightness information used in the experiment that was just mentioned, combinations of shape information (shape, size), and thermal information. The results are shown in Figure 11.

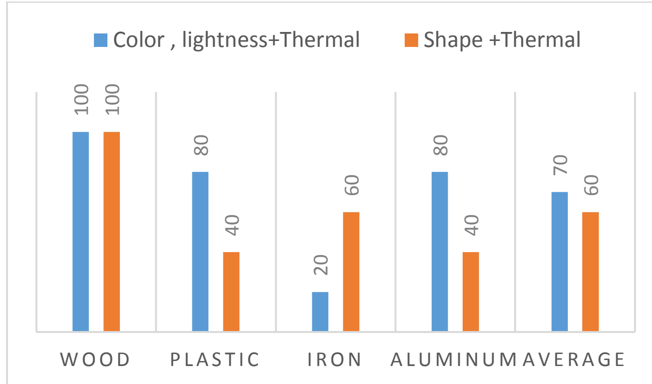

Figure 11 Experiment results 2

Discussion

The results in Figure 10 and 11 show that adding thermal information increases the recognition accuracy for wood and plastic by approximately 20%. In addition, the proposed method also made it possible to recognize aluminum, which was not recognizable in the method that used camera images alone. However, the recognition rate for iron decreased. This is thought to be due to the properties of thermal reflection possessed by the material. Iron and aluminum have very high values for their heat reflectivity. The reflected heat is detected directly by the thermal sensor, which makes the sensor unable to measure the temperature of the target object accurately. This causes the object to be incorrectly recognized.

The overall recognition rate increased by approximately 10%. This shows that the proposed method is effective.

Conclusion

In recent years, buildings in urban areas are frequently being demolished for a variety of reasons. For example, demolitions happen when buildings are rebuilt because the building was sold during an asset sale by a corporation in financial difficulties, because the building was built during the period of high economic growth and was aging, or because the building was damaged in a natural disaster, which happens frequently in recent years. In Japan, under the “Construction Material Recycling Act”, it is mandatory to dispose of construction waste that is generated during demolition work in an appropriate manner in order to move towards a recycling society. However, construction waste is still being sorted by hand. Therefore, it is desired to reduce labor costs and to improve safety for the workers.

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We performed a material recognition experiment in which only camera images were used, and a material recognition experiment in which sensor fusion was used. The results show that the recognition accuracy was approximately 20% higher for wood and plastic in the experiment conducted using the latter method compared to the experiment conducted using the former method. In addition, the recognition accuracy increased by approximately 10% overall. These results show that the proposed method is effective.

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