

Labor-Saving Technologies for Municipal Waste Treatment Facilities and Recycling Facilities



Because of the declining workforce, municipal waste treatment facilities and recycling facilities are expected to face greater difficulty in securing a sufficient number of operators, and it is increasingly important to develop labor-saving technologies for economical and efficient facility operation.

In response to this situation, we have developed systems for reducing the burden of operators by using ICT (Information Communication Technology) and robot technology, including KEEPER, a system for remotely monitoring and supporting the operation of municipal waste treatment facilities, and K-Repros, a support system for hand-sorting recyclable waste in recycling facilities.

Introduction

Due to changes in Japan's social environment in recent years, such as the decreasing workforce and the prevalence of large-scale disasters and infectious diseases, it is predicted that securing operators will become increasingly challenging in the future. Society has a growing need for more efficient operations to be performed by fewer operators, and municipal waste treatment and recycling facilities are no exception.

1 Background

Municipal waste treatment and recycling facilities are crucial social infrastructure facilities that support the foundation of daily life; they must be operated safely and reliably. To ensure stable facility operations, the presence of operators who manage and assist the operational status is essential. To operate facilities efficiently in the face of a decreasing workforce, it is necessary to develop a driving system that can ensure stable operation independently of an operator's experience.

At present, we are advancing the development of labor-saving technologies such as a remote monitoring and operation support system as well as a support system for hand-sorting recyclable waste for municipal waste treatment facilities and recycling facilities. These technologies are designed to augment human perception,

decision-making, and tasks performed in the course of operating such facilities. We are working on technological development aimed at systematizing the expertise of operators to reduce their burdens, thus enabling resources to be shifted to tasks that require more human involvement.

2 Remote monitoring and operation support system for municipal waste treatment facilities

Waste treatment facilities reduce and render harmless general combustible waste, including household waste, through incineration treatment. Collected waste is placed in a waste treatment facility's waste pit, where it efficiently undergoes complete combustion in an incinerator to reduce its volume. The incineration exhaust gases are neutralized in an exhaust gas treatment system and then released through the chimney. Additionally, the heat energy generated during incineration is utilized for power generation or heat supply.

(1) Challenges to achieving labor-saving operation at municipal waste treatment facilities

Waste treatment facilities are controlled using a Distributed Control System (DCS), and incinerator operation is automated through Automatic Combustion Control (ACC). Due to the heterogeneous nature of the

waste being processed, manual operation may be necessary to assist in achieving stable combustion when there are significant fluctuations in the characteristics (quality or heat generation amount) of the waste. Therefore, to ensure stable operation of waste treatment facilities, experienced operators who can monitor the incinerator's combustion status and assist in automatic combustion control are indispensable.

To achieve labor-saving operation at waste treatment facilities, challenges include ① remote monitoring support for incinerator supervision and operation by on-site operators, ② stabilization of the characteristics of the waste to be fed into the incinerator, and ③ correction of ACC according to fluctuations in combustion conditions.

(2) Labor-saving technologies for municipal waste treatment facilities

① Remote monitoring and operation support system KEEPER

In FY2016, we introduced KEEPER (Kawasaki Expert Environmental Plant Engineered Remote support system), a system for remotely monitoring the operation of municipal waste treatment facilities. In this system, the environmental remote monitoring room within our Kobe Works is connected to the operation monitoring systems of various facilities throughout Japan via an IP-VPN (Internet Protocol-Virtual Private Network, a virtual dedicated line) to enable centralized monitoring to be performed remotely. Initially, the

system targeted four facilities, but with the order for the DBO (Design-Build-Operate) project, the number of targeted facilities has been increased to 12 as of March 2023.

This system is built on top of NTT PC Communication's Master's ONE IP-VPN platform, ensuring security. Efforts are made continuously to maintain and enhance high-security measures on the hardware side, including the network. Moreover, as a countermeasure against attacks on security by surveillance personnel or employees, regardless of whether or not they are malicious, Cyber Security Management System (CSMS) certification was obtained in October 2020 (as of March 2023, it has been obtained by three companies), as shown in **Figure 1**, and is now being implemented.

KEEPER utilizes the extensive operating experience of our veteran operators to provide support services for monitoring and checking/diagnosis of operating conditions at each facility (on-site) via 24-hour surveillance. Additionally, it also functions as a data center for collecting, storing, and analyzing operational data from each facility, and operates an AI-powered operation support system. This system replicates the manual operations performed during incinerator operation using AI with the aim of stabilizing combustion and reducing operators' workloads; it recommends the optimal manual operations to operators. As shown in **Figure 2**, the AI associates and learns from facility operation data such as process data,



Fig. 1 CSMS certification logo and remote monitoring room

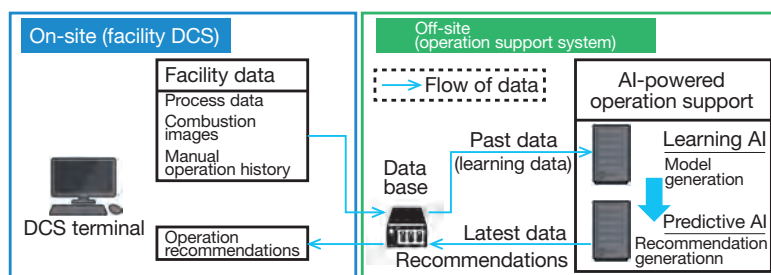


Fig. 2 Overview of operation support system using AI

combustion images, and the history of manual operations that have been performed. When the AI determines that the current operational situation is similar to past instances in which manual operations were performed, it automatically outputs recommendations for such operations¹⁾.

The learning AI accesses the database of the remote monitoring system, in which each facility's operational data is stored, to generate computational models by learning the accumulated data. The predictive AI generates operation recommendations based on these computational models and the latest data. The learning AI can generate computational models as needed, which enables the system to perform additional learning whenever operational data from each facility is added.

② Stabilization of waste incineration using an optimal operation system for waste cranes

The fundamental point to achieve stable combustion in an incinerator is to stabilize the waste quality (heat generation amount) as much as possible, and a major factor causing significant variations in waste quality is moisture. Conventionally, it has not been possible to quantitatively understand waste quality in a waste pit. Therefore, it was necessary for operators to perform manual mixing of the waste pit by visual inspection (such as the color of the waste, the weight when grabbed by a waste crane, etc.) As a system for optimizing waste crane operations, we have developed an automatic operation technology that combines quantitative measurement of moisture in the waste with the optimal mixing method of the waste pit by the waste crane.

Using a moisture camera, we quantify the moisture index in the waste by capturing images with a near-

infrared camera; we then compare the difference in brightness between the moisture absorption band and the non-moisture absorption band, where the impact of water is minimal. Utilizing the distribution data of moisture indices across the entire pit, as shown in **Fig. 3**, the optimal mixing to homogenize the distribution of moisture indices in the waste pit is performed automatically and efficiently by the waste crane.

③ Automatic correction of ACC by the AI-assisted operation support system

The operation recommendations sent from the operation support system are used in both guidance mode, in which the operation terminal and operation direction are displayed qualitatively in the facility's DCS, and AI correction mode, in which automatic correction is applied to the ACC, as shown in **Fig. 4**. The range of manipulated variables corrected by the AI can be set for each operation terminal on the facility DCS (on-site). By using ACC to integrate the operation recommendations reproducing the combustion monitoring and manual operations of operators based on past operational data, the scope of automatic operation can be expanded, reducing the burden of manual operations imposed on operators.

(3) Demonstration experiment

From January to March 2021, we experimentally conducted remote operation by taking over operations in the environmental remote monitoring room in order to demonstrate the system. When performing remote operation using KEEPER, the environmental remote monitoring room can receive the same information as the central control room (operation control screens, ITV images). However, it cannot obtain the operating status of each piece of equipment in the machine room. Therefore,

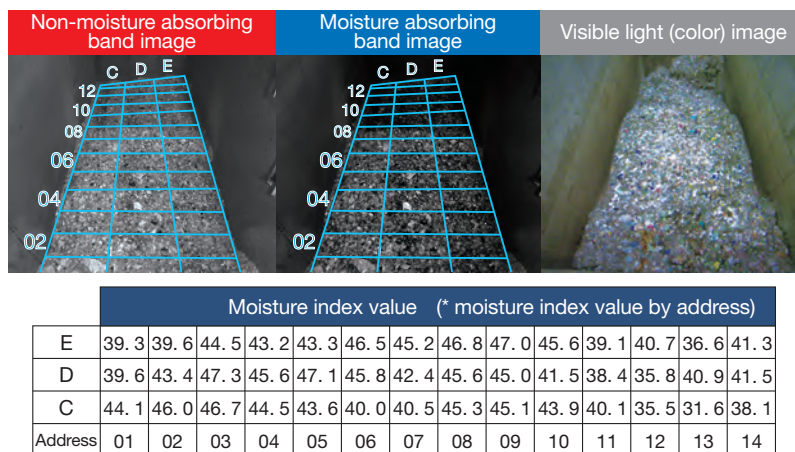


Fig. 3 Moisture content camera image and moisture content index map

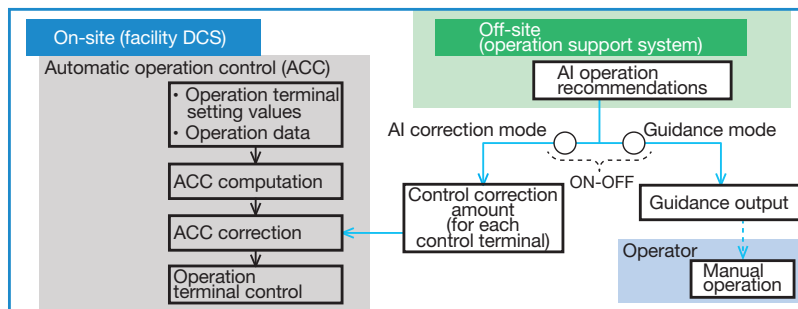


Fig. 4 System using operation recommendations

to address this limitation, remote operation was performed in collaboration with the actual site.

At the Chita Southern Broad Area Environment Center, which was completed in March 2022, an automatic ACC correction system using the waste crane optimal operation system and AI-powered operation support system has been adopted. The demonstration experiment for this system verified stable operation that eliminates the need for manual operation for two weeks. In addition, backup operation by operators in the environmental remote monitoring room via 24-hour monitoring is performed in combination, thus realizing labor-saving operation by utilizing labor-saving technologies.

3 AI-powered support system for hand-sorting recyclable waste K-Repos

To recycle glass bottles, cans, plastic bottles, and the like, recycling facilities perform sorting treatment as well as compaction and packaging. Among these items, glass bottles must be sorted by color for recycling. Generally, they are divided into the three categories of brown bottles, clear bottles, and bottles of other colors.

(1) Issues for labor-saving in the bottle sorting process

In the glass bottle sorting process, recovered materials vary in size from small bottles, such as energy drink

bottles, to heavy bottles, such as 1.8 L bottles, and the sorting targets consist of numerous combinations of colors and sizes. Additionally, materials collected as glass bottles may include foreign objects such as caps that cannot be recycled into glass bottles, necessitating a process for removing such foreign objects during the sorting process. Given such circumstances, hand-sorting by multiple workers has been widely adopted to improve sorting accuracy.

K-Repos, an AI-powered support system for hand-sorting recyclable waste, was developed with the aim of assisting in color sorting work in collaboration with the manual sorting work performed by operators, as depicted in Fig. 5. The challenges to developing this system were ① facilitation of coexistence and collaboration between robots and humans, ② the glass bottle identification technology, and ③ development of a hand that can grip a bottle.

(2) AI-powered support system for hand-sorting recyclable waste K-Repos

Fig. 6 shows a system overview of K-Repos. This system is composed of a recognition unit that automatically detects and identifies the sorting target bottles based on image data and a gripping unit that picks up bottles based on signals sent from the recognition unit. The gripping unit is composed of a robot and a hand attached to the end of the robot arm. To overcome the

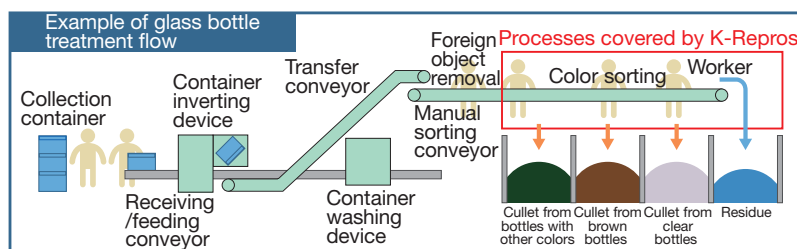


Fig. 5 Processes covered by K-Repos

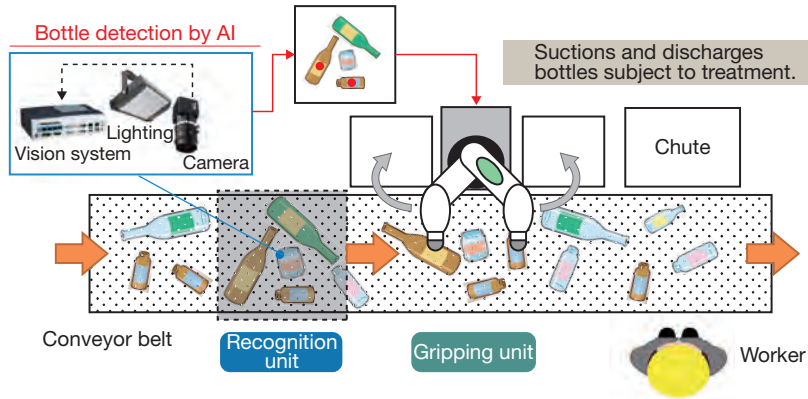


Fig. 6 Overview of K-Repros system



Fig. 7 Example of detection using AI

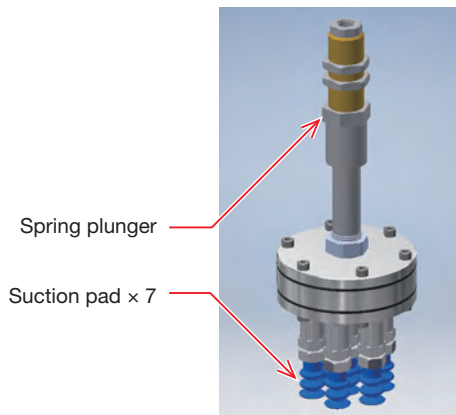


Fig. 8 Construction of hand



Fig. 9 Demonstration experiment

Table 1 Verification results of accuracy of identification using AI

Glass bottle type	Precision ((B-D)/B)	Detection rate (B/A)	Number of treatment targets (A)	Number of detected targets (B)	Number of undetected targets (C)	Number of false detections (D)
Brown	100%	97.4%	534	520	14	0
Clear	100%	97.3%	515	501	14	0
Other colors	100%	96.6%	298	288	10	0
Average (total)	100%	97.2%	(1347)	(1309)	(38)	(0)

mentioned challenges, the following three aspects have been developed and implemented.

① Coexistence and collaboration achieved by duAro2

The gripping unit adopts our cooperative robot duAro2, which enables workers and robots to work together in the same space. duAro2 can coexist and collaborate with humans due to its various functions that ensure safety, including a collision detection function and the use of parts made of soft materials for the robot's surface. In addition, it does not require isolation fences and is sufficiently compact to be installed in a space for a single person. Moreover, it can easily be moved by a dolly with casters using the built-in controller.

② Bottle identification by AI

The recognition unit adopts our proprietary AI that specializes in identifying bottles. The unit can extract targets from input image data by deep learning. As shown in **Fig. 7**, the AI automatically identifies the bottle color from features such as the color and shape based on image data captured by the camera and then determines the gripping point for the target.

③ Bottle gripping by a vacuum suction hand

The hand of duAro2 adopts the vacuum suction system shown in **Fig. 8**. Differences in the suction surface height due to differences in bottle size are absorbed by the spring plunger, and bottles are suctioned by the suction pads placed at the end of the hand. Compared to the gripper system that sandwiches the target by opening and closing multiple claws, this system has superior gripping speed and is capable of gripping bottles regardless of their orientations, shapes, and sizes. It can grip the target object alone even in a situation in which the treatment targets are concentrated, thus ensuring highly reliable gripping.

(3) Demonstration experiment

To verify the identification accuracy and processing capacity of the AI, this system was installed on the manual sorting conveyor of a recycling facility where a manual bottle sorting process is actually performed, as shown in **Fig. 9**. and an experimental demonstration was conducted. In manual glass bottle sorting at recycling facilities, high accuracy is often required to achieve purity (the mixing ratio of bottles with different colors) after color selection; therefore, in constructing an AI model, emphasis was placed on minimizing the number of false detections, such as color mismatches, rather than maximizing the bottle detection rate.

The verification results of identification accuracy using AI are listed in **Table 1**. The precision, which indicates the



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extent of mixing other colored bottles into the target colored bottles, was 100% for all types. A precision of 100% indicates a state in which there are no color mismatches, and all instances have been correctly sorted by the relevant target color. In addition, the detection rate, which indicates the percentage at which the AI identified bottles, averaged 97.2%. This demonstrates high accuracy in color recognition while achieving satisfactory performance with respect to the bottle detection rate. The ratio of the processing capacity of one robot to the workload of one worker is maintained at around 50%, confirming the anticipated result for the capabilities of this system, which is designed to enable coexistence and collaboration between humans and robots through the deployment of a cooperative robot.

Conclusion

To achieve stable operation of facilities over an extended period, it is essential to build an operation system that ensures stable operation without relying exclusively on the experience of veteran operators. Furthermore, it is predicted that it will become increasingly challenging to secure operators; therefore, labor-saving technologies will become more and more important in municipal waste treatment facilities and recycling facilities. We will continue to work to develop these technologies while considering the progress in Information and Communication Technology (ICT) and other relevant factors.