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# Develop of Auto-Sort System for LIB Products in Auto-Sort System for Waste Small Appliances

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**Abstract:** Amid global efforts to conserve resources and transition toward a circular economy, Japan is focusing on "urban mines," where discarded small home appliances are treated as sources of valuable materials. However, domestic recycling has stagnated due to the high cost and inefficiency of manual sorting—especially for low-profit items like small appliances. To address this challenge, we are currently developing an automated sorting system designed to improve the efficiency of resource recovery and reduce recycling costs. This paper reports on the development and evaluation of the Auto-Sort system for lithium-ion battery equipped products, which are a major cause of fires and explosions in stockyards.

**Keywords:** Safety, Environment and Eco-Systems, Process Automation, Robotic and Automation Systems

## 1. INTRODUCTION

Amid rapidly growing global demand for resources and worsening environmental issues such as global warming, transitioning from the current linear economic model to a circular economy has become an urgent priority. Japan relies heavily on overseas resources, and establishing a resource-independent economic structure necessitates a transition to a circular economy based on the reliable reuse of discarded products.

In constructing a circular economy, Japan has been focusing on "urban mines"—a concept that regards discarded electronic devices as mines due to the metal resources they contain, which can potentially be recovered. However, Japan's urban mines are not currently being effectively utilized. The main reason is poor economic viability: resource recovery from stockyards requires manual sorting by human workers, leading to high recycling costs.

In recent years, some studies have explored AI- and robot-assisted automation in waste appliance recycling. However, most focus on specific tasks such as post-shredding material sorting [1] or disassembly of selected product types [2][3], mainly for large appliances on fixed lines [4]. In contrast, autonomous systems that recover and classify mixed small appliances before shredding in stockyards remain largely unexplored.

To address this issue, the authors are currently participating in a NEDO project [5] that aims to develop an "Auto-Sort System for Waste Small Appliances," which automates the traditionally manual sorting process conducted in the pre-shredding stage. This system seeks to recover valuable resources such as precious metals, copper, rare metals, base metals, and plastics from discarded small home appliances—regarded as urban mines—and establish fundamental technologies for circular utilization. The NEDO project aims to create and promote the growth of circular economy-related industries that balance economic activity with environmental impact reduction.

This study primarily reports on the automatic sorting system for LIB-equipped products—those that contain lithium-ion batteries, which are a major cause of fires—in the above-mentioned "Auto-Sort System for Waste Small Appliances."

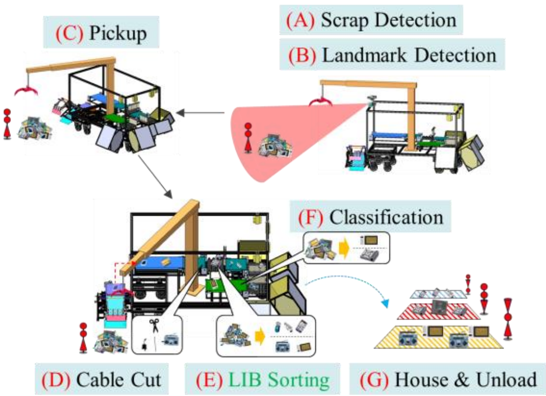


Fig.1 Process of auto-sort system for waste small appliances

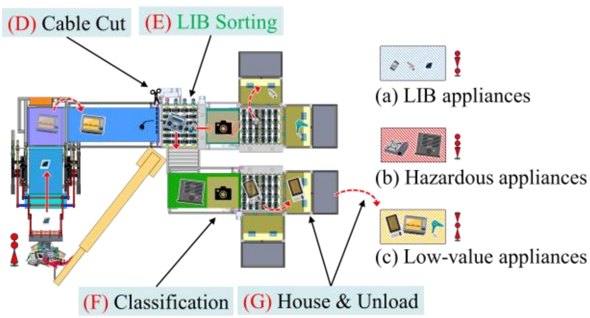


Fig.2 Function of waste small appliances classification system

## 2. OVERVIEW OF THE AUT-SORT SYSTEM FOR WASTE SMALL APPLIANCES

### 2.1 Current Conditions in Stockyards

In stockyards, pre-shredding sorting operations are currently performed manually. Waste small home appliances collected under the Small Home Appliance Recycling Act [6] and other laws are stored stockyards in a mixed state and then classified into (a) LIB-equipped products, (b) hazardous waste appliances, and (c) low-value waste appliances. LIB-equipped products are devices that contain lithium-ion batteries, such as smartphones, laptops, and power tools. In particular, the risk of fire and explosion from LIB-equipped products in stockyards has become a serious issue [6], making their early removal from waste appliances essential.

Hazardous waste appliances include items like gas stoves, kerosene heaters, and water dispensers that may contain gas or oil, requiring special handling precautions. Low-value waste appliances refer to bulky items unsuitable for recycling due to the difficulty of resource recovery; these typically include large home appliances and metal parts, and recovering valuable resources from them is labor-intensive. Additionally, cable-cutting work is performed to prevent cable entanglement. All of these operations are currently done manually, posing a significant bottleneck in improving the efficiency of waste appliance recycling.

Due to the aforementioned fire and explosion risks, early removal of LIB-equipped products from waste appliances is indispensable.

### 2.2 System Configuration

The process of automatically sorting small waste home appliances from a scrap yard is shown in Fig. 1, the functions of each unit are illustrated in Fig. 2, and the system components are outlined in Fig. 3. (A) The Scrap Pile Detection Unit detects the presence of scrap by comparing yard images with and without scrap. (B) The Landmark Detection Unit estimates the system's position by detecting landmarks placed around the scrap pile and at the drop-off points for home appliances. (C) The Pickup Unit recovers relatively large appliances using a grapple and collects small appliances—those not retrievable with the grapple—using a raking mechanism. (D) The Cable Cutting Unit detaches cables from appliances and collects them for recycling. (E) The LIB-equipped Product Sorting Unit automatically sorts appliances containing lithium-ion batteries using a mecanum conveyor. (F) The Appliance Recognition Unit identifies whether an appliance is hazardous or non-hazardous and classifies it accordingly, also using the mecanum conveyor. In addition, it classifies some LIB products that could not be sorted in the previous process (E) LIB Product Sorting Unit. (G) The Storage & Unloading Unit stores the classified appliances in boxes, moves them to designated locations, and unloads them by opening the boxes with a winch.

In this study, we report on the LIB-equipped Product Sorting System (E).

### 2.3 Mecanum Conveyor

The mecanum conveyor is composed of commercially available mecanum wheels and performs appliance sorting using their operating principle. As shown in Figure 4, the wheels have independent barrels mounted at a 45° angle to the axle. When appliances moving along the wheels come into contact with a guide, they are deflected to either side by the angled barrels.

Brushless DC motors are used for driving power, and rotation speed is controlled by inverters. Power from the motor is transmitted to each shaft via a coupling and double-sprocket chain mechanism, ensuring equal power distribution and load balancing. Each shaft has six mecanum wheels, fixed with shaft holders and keys. To prevent small appliances like smartphones from falling through, the wheel gaps are set to 5 mm, considering typical smartphone thicknesses of 6-10 mm.

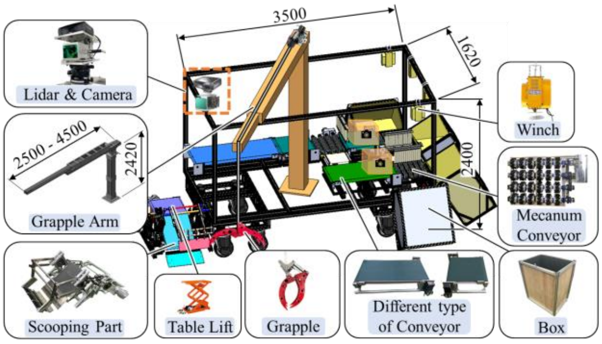


Fig.3 Elements of classification system

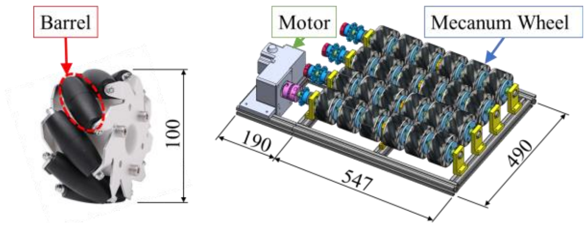


Fig.4 Structure of Mecanum Conveyor

## 3. APPLIANCE CLASSIFICATION

### 3.1 Classification Based on the Recycling Act

Based on the 28 categories defined in the Small Home Appliance Recycling Act [7], at least one appliance from each category was measured, covering a total of 243 appliances including those researched online. Appliance dimensions were defined such that width $w \geq$ depth $d \geq$ thickness $t$, with width $w$ as the x-axis and thickness $t$ as the y-axis, as shown in Figure 5. Figure 6 shows a detailed breakdown focusing only on LIB-equipped products.

From Figures 5 and 6, the appliances were subjectively classified into four regions, using the boundary condition $t = w = 250$ mm. Region (3) predominantly includes LIB-equipped products, indicating they are relatively small compared to other appliances. Region (4) includes appliances like LIB-equipped rice cookers, handheld vacuum cleaners, stick-type vacuum cleaners, laptops, and tablets. Among these, vacuum cleaners tend to be cylindrical, while laptops and tablets are thin.

Assuming that these thin or cylindrical appliances never stand vertically (i.e., with their maximum dimension upright), their effective height is considered to be 250 mm or less. Therefore, height ≤ 250 mm can be used as a sorting criterion to distinguish LIB-equipped products from others.

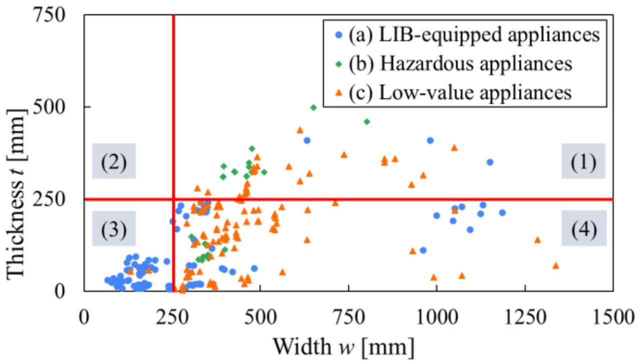


Fig.5 Size of Appliances

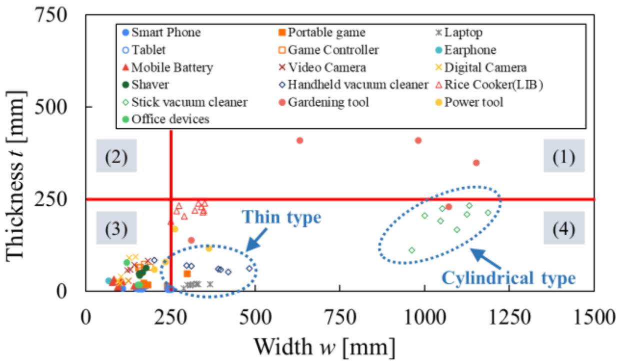


Fig.6 LIB-equipped appliances

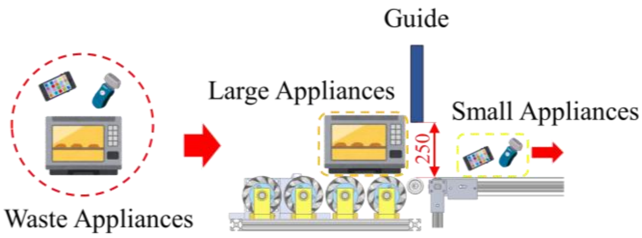


Fig.7 LIB classification method

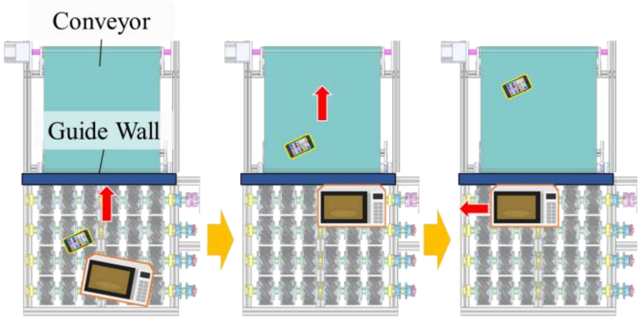


Fig8. Sorting Process

### 3.2 LIB Product Sorting Unit

Based on the characteristic "height ≤ 250 mm" of LIB-equipped products, this study proposes a physical sorting method using a mecanum conveyor and a guide with a 250 mm gap, as shown in Figure 7. Appliances collected via the grapple or raking mechanism are transferred to the (E) LIB-equipped product sorting system after passing through the (D) Cable Cutting Unit (Figure 2). Within the system, the appliances are transported along the conveyor to a location with the 250 mm high guide barrier.

This guide functions as an upper barrier to determine whether an appliance can pass underneath. Appliances with an effective height of 250 mm or less—likely LIB-equipped products—continue straight under the guide. Larger appliances, unable to pass, are diverted left or right by the conveyor and directed to different processing lines (Figure 8).

Appliances such as certain LIB-equipped rice cookers and electric gardening tools, or hazardous and low-value waste appliances smaller than 250 mm that pass with LIB-equipped products, are sorted later at the (F) Appliance Recognition Unit.

## 4. VERIFICATION EXPERIMENTS

### 4.1 Experimental Setup

To verify the sorting capability of the mecanum conveyor, the following appliances were prepared: A smartphone from region (3); a microwave and kerosene heater from region (1); a laptop and gas stove as thin appliances, and a handheld vacuum cleaner as a cylindrical appliance from region (4). Additionally, a canister-type vacuum cleaner, which exhibited stacking issues, was also tested. These appliances are shown in Figure 9, and their dimensions are listed in Table 1.


Fig.9 Prepared appliances

### 4.2 Experimental Results

The test results are shown in Table 1. The smartphone, laptop, and handheld vacuum cleaner passed under the guide, while the microwave and kerosene heater were diverted sideways, confirming that the LIB sorting system functions correctly. The absence of smartphone drops confirmed the adequacy of the 5 mm wheel gap. The results also supported the assumption that thin or cylindrical appliances do not stand vertically. Although the gas stove passed through the guide similarly to the LIB products, it will be classified as hazardous by the Appliance Recognition Unit.

On the other hand, as shown in Figure 11, the canister-type vacuum cleaner got stuck. Its hose passed through the gap, while the body was blocked and diverted sideways, causing a jam. This occurred because the hose was small enough to fit through the gap, whereas the main body was not. To resolve this issue, the installation of a cutter on the guide to sever the hose and separate the components is under consideration.

Table 1 Dimensions of prepared appliances

| Appliance | Width $w$ [mm] | Depth $d$ [mm] | Thickness $t$ [mm] |
|---|---|---|---|
| smartphone | 150 | 75 | 10 |
| laptop | 270 | 220 | 25 |
| portable gas stove | 340 | 230 | 90 |
| handheld vacuum cleaner | 340 | 130 | 105 |
| canister vacuum cleaner | 270 | 250 | 230 |
| oil heater | 480 | 400 | 240 |
| toaster oven | 380 | 270 | 230 |

Table 2 Results of experiment

| Area | Appliance | Category | Result |
|---|---|---|---|
| (1) | smartphone | (a) | Passing through |
| (2) | laptop | (a) | Passing through |
| | portable gas stove | (b) | Passing through |
| | handheld vacuum cleaner | (c) | Passing through |
| | canister vacuum cleaner | (c) | Stuck |
| (3) | oil heater | (b) | Moved along |
| | toaster oven | (c) | Moved along |

## 5. CONCLUSION AND FUTURE WORK

This study developed an automatic LIB product sorting system, along with a grapple and collection containers. Sorting tests using various waste appliances confirmed the feasibility of the system. Future work includes improvements to the mechanism and solutions to the identified issues, based on the findings from the experiments.

In addition, the Cable Cutting Unit and the Pickup Unit require further verification and refinement. The ultimate goal is to develop a fully automated, single-machine system capable of operating 24 hours a day under any environmental conditions and performing all tasks outlined in Section 2.

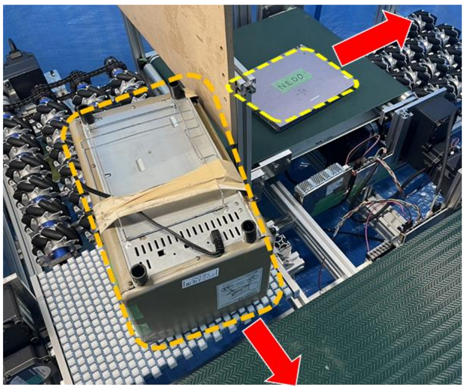

Fig.10 Laptop and Toaster oven

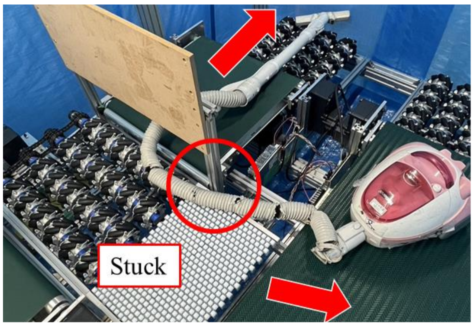


Fig.11 Stacked Vacuum cleaner

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