Automatic Sorting Machine for Material Recycling

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Many laws on recycling are being enacted and attempts made to build a "recycling" society in all fields. Mitsubishi Heavy Industries, Ltd. (MHI) has developed automatic separators for recyclable waste and installed a recyclable refuse recycling demonstration plant concentrating waste recycling technology at the Yokohama Dockyard and Machinery Works of MHI in March 1997. Recyclable waste and collection methods are different among local governments. MHI uses the recyclable refuse recycling demonstration plant to determine the most suitable separation system for each local government and verifies the required performance. Separation system consists of magnet separation, particle size classification, and vibration wind classification, bottle color separators, and plastic bottle separators. This report focuses on bottle color and plastic bottle separators.

1. Introduction

MHI has developed automatic sorters for recyclable waste conforming to the Packing Waste Recycling Law on the basis of sorting technique, image processing technique and near-infrared ray utilizing techniques that have been accumulated over the years in bulky-waste treatment plants[(1)].

Local governments are currently promoting separate collection of garbage in the background of the heightening consciousness of resource recycling, and are demanding more accurate color sorting in collection of glass bottles to enhance the purity of easy-to-recycle clear cullets, by separating "light blue" bottles from "clear" bottles, which is difficult with existing technology. In plastics, it is required to improve the material discriminating accuracy so as to minimize the mixture of polyvinyl chloride, which is hard to recycle because it contains chlorine. To meet such needs, MHI has been developing corresponding techniques, assembling the latest machines in demonstration plants, and testing them.

2. Bottle color sorter

This is a system for separating and conveying bottles individually by the array apparatus, sorting colors by the shooting section, and separating bottles by color by means of pushers. In particular, the problems of sorting "clear" and "light blue" bottles, which are hard to discriminate, together with bottle dirt and handling technique, are discussed herein.

2.1 Shooting section

The transmitted light of bottles is taken by a color CCD camera, RGB components in the image are transformed into lightness, chroma, and hue, and colors are discriminated. In this case, when a light blue bottle is taken by the sensitivity of three-color sorting of clear, brown, and bluish green, its color difference from a clear bottle is small, and it is likely to be mistaken for a clear one. To prevent this, a two-camera method is employed.

In this system, the image taken by camera 1 is analyzed by conventional 4-color sorting, and only bottles judged to be clear are taken again by camera 2, which has an enhanced color-separation power of clear and light blue, and the color is finally determined. As a result, clear and light blue bottles are accurately sorted, and discrimination of dirty clear bottles is also enhanced.

2.2 Bottle separating section

In the conventional system, bottles are taken by camera while sliding on an inclined section, and are sorted by color at a gate immediately after it, but there are rare occasions the sorting gate and the sliding timing are mismatched, and errors occur. This is because the falling speed is not uniform due to friction between bottle and the inclined rail.

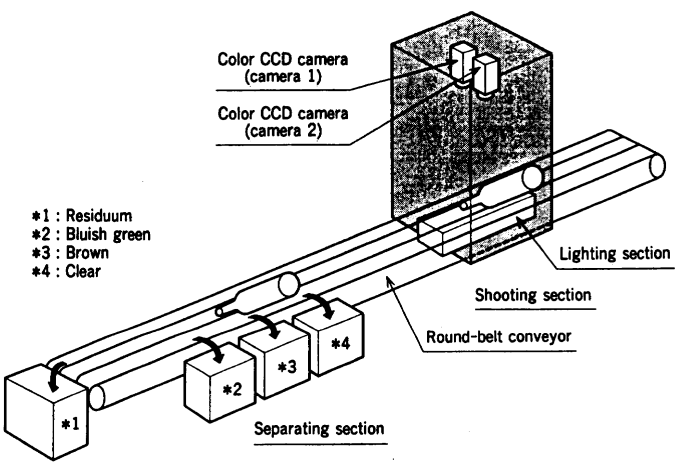

Fig. 1 Glass bottle sorting system
This system consists of shooting section with two color CCD cameras, and separating section using pushers.

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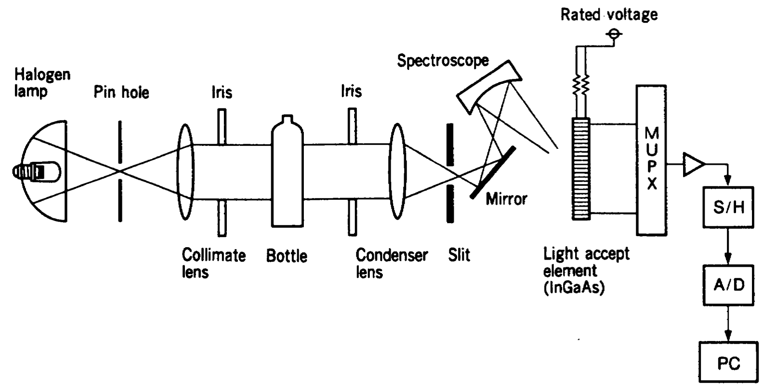

Fig. 2 Plastic bottle material discriminating system
This system consists of optical system from halogen lamp to light accept element, and signal processing system from light accept element to personal computer.

Table 1 Results of color sorting test

Result \ Color	Clear	Brown	Bluish green
Purity	99.9%	99.9%	99.3%
Recovery rate	92.7%	99.5%	97.4%

In an improved design, bottles are photographed on a round-belt conveyor, and sorted by pushers extruded from round belts. Ten pushers are arranged in each separating section at intervals of 40 mm in the conveying direction, and a specific number of them are put into operation depending on the bottle length, so that short bottles conveyed after long bottles can be correctly sorted.

2.3 Performance test results

The improved system is shown in **Fig. 1**. In the bottle shooting section, CCD cameras are arranged above the round-belt conveyor, lighting is arranged at the lower side, and bottle colors are sorted by image processing on the basis of the transmitted light image of bottles.

The sorting performance by this system is shown in **Table 1**. In clear bottles of high commercial value for recycling, the purity is 99.9% and recovery rate is 92.7%. It is now being attempted to improve the sorting accuracy of "extremely light blue" color, which is paler than light blue.

3. Plastic bottle sorter

The purpose of this sorter is to discriminate plastic bottles for beverages into polyethylene terephthalate (PET), polyvinyl chloride (PVC), and other materials. This system rejects PVC which contains chlorine, picks up PET bottles for PET material recycling, and presents other bottles for thermal recycling such as oil forming.

The plastic bottle material discriminating sensor, which is the key unit of this system, is described below.

3.1 Principle of material discrimination

The plastic bottle material discriminating system developed by MHI is shown in **Fig. 2**. In the operating principle of this sensor, radiated light from a halogen lamp is beamed at a plastic bottle, the near-infrared ray region of the transmitted light is separated, and the light intensity is converted into an electric signal by a light accept element. The light accept element is a 256 array element of InGaAs (indium gallium arsenic) having excellent S/N characteristic, and a discrimination rate of over 99% and processing speed of over 3 bottles/sec are achieved.

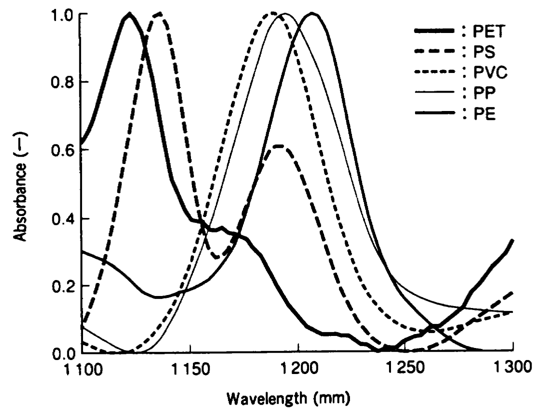

Fig. 3 Example of absorbance spectrum by plastic bottles
The absorbance is normalized in the shown spectrum in order to clarify the peak wavelength.

The value of each pixel converted into an electric signal is sent into a multiplexer (MUPX) and a sampling-and-hold device (S/H) to be converted from analog to digital, and is then input into a personal computer as a light intensity spectrum $S(\lambda)$.

When starting up the sensor, the following operation is executed automatically.

(1) Measurement of dark current spectrum $D(\lambda)$
(2) Measurement of reference spectrum $R(\lambda)$

The first step is a measurement for canceling the dark current of the light accept element so as to eliminate noise, and the second step is a measurement of the reference spectrum calculating the absorbance. From these measured data upon start and the spectrum of the quantity of transmitted light of each bottle, the absorbance at each wavelength (λ) is calculated in the following formula, and the absorbance spectrum $A(\lambda)$ is determined.

$$A(\lambda)=\log_{10}\{[R(\lambda)-D(\lambda)]/[S(\lambda)-D(\lambda)]\}$$

In plastics, the characteristic absorption of material is observed in the near-infrared to infrared region, and the absorption band is set at around 1 100 to 1 300 nm in this system. When bottles are conveyed by the conveyor, the sensor measures the quantity of transmitted light and absorbance spectrum in every measuring position at 1 ms intervals. In the measuring position of small quantity of transmitted light, the cap and label are judged, and the material of the bottle itself is determined together with the measured results in other positions.

3.2 Results of measurement

Fig. 3 shows results of measurement of absorbance spectrum $A(\lambda)$ of five materials in general use for beverage and other plastic bottles.

The material is identified from the peak waveform and spectrum profile of the absorbance spectrum. By capturing the characteristic spectrum of each material, bottles made of plastics other than PET and PVC can be discriminated, such as polyethylene (PE), polypropylene (PP) and polystyrene (PS).

When bottle dirt is present, the quantity of light received by the sensor decreases and the S/N ratio is impaired, but effects on the absorbance spectrum are small, and the material can be successfully determined in the case of ordinary dirt.

4. Conclusion

For recycling of glass and plastic bottles, systems for sorting bottle colors or discriminating plastic materials by sensors and separating them mechanically have been developed. In the bottle color sorter, an important problem at present is improvement of sorting accuracy of clear and extremely light blue bottles, and use of the spectrum method, which is excellent in color difference separation power, is now being considered.

With regard to the plastic bottle material discriminating system, a reflex-type discriminating system is being developed at present in order to handle opaque bottles frequently used for non-beverage products, which do not pass near-infrared rays, and packing waste plastics other than bottles[2].

References

(1) Ohnishi, T. et al., Automatic Color Sorting Techniques for Glass Bottles, Proceeding of The 4th Annual Conference of The JSWME (1993) p.277

(2) Yoneda, K. et al., Development of PVC Films Sorter in Plastics, Proceeding of The 9th Annual Conference of The JSWME (1998) p.292