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OVERVIEW OF MACHINE VISION APPLICATIONS IN WASTE RECYCLING

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ABSTRACT

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Overview of Machine Vision Applications in Waste Recycling

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This project involves discovering how machine vision techniques are applied to the different aspects of sorting and recycling waste. The goal is to shed a light on the main algorithms used for inspecting many kinds of materials such as plastic, paper, glass and metal. This has been done by analysis of different types of scientific articles devoted to the use of machine vision in area of recycling. It was revealed that there are many techniques and algorithm of pattern recognition and image analysis used for detecting different types of waste that could be recycled. It has been shown that machine vision could significantly improve the process of sorting and make recycling more effective and easier.

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1 INTRODUCTION

1.1 Background

1.2 Objectives and Delimitations

1.3 Structure of the Thesis

2 SORTING SYSTEMS OF RECYCLABLE MATERIALS

2.1 Plastic recycling

One of the common problem of recycling is separation and recycling of plastic recycling and techniques of machine vision have takes significant part in this process. The most common systems are based on optical sensors, X-Ray and Near Infrared cameras. Although these methods show effectiveness, they can be too expensive and redundant for facilities with low and high throughput. The idea to overcome this issue is presented in this section based on ideas from [1].

Modern Technologies of Plastic Recycling

Plastic materials are very lightweight and can be used to contain many different kinds of liquids or utilized as packaging. Usually, plastic is divided in several categories of resins, the most common ones are PET, HDPE, LDPE, PVC, PP and PS, as can bee seen from Table 1. Some of this types have various kinds of recyclable applications. Generally, there are two ways of sorting plastic: manual sorting and automated sorting. Due to very high cost and small efficiency, companies are concerned of automating this process. Noteworthy, that for proper recycling process types resins should not be mixed, otherwise it can lead to emission of hydrochloric gases.

Manual sorting relies on workers who are walking along the conveyor belt, picking up bottles of different types and putting them in different containers. However, method turned out to be not effective for facilities with high throughput. Also, it was revealed that workers tend to make mistakes in course of sorting.

Automated sorting utilizes detection systems which are build using modern machine vision methods to separate plastic by type, shape or color. Sorting can be divided on bottle sorting (macro-sorting) and flake sorting (micro-sorting). The second type is performed on granules and can process considerable amounts of plastic mass.

Although micros-sorting is starting to gain popularity in recycling area, whole-bottle sorting is still prevails in industry. During macro-sorting process bottles are sorted in different containers using information about resin type, size or color. The common systems

Table 1. Plastic bottle recycle code system and material [1].

Code System	Material	Code System	Material
1	1-PETE Polyethylene terephthalate	5	5-PP Polypropylene
2	2-HDPE High-density polyethylene	6	6-PS Polystyrene
3	3-PVC Polyvinyl chloride	7	7-O Other
4	4-LDPE Low-density polyethylene		

involved are usually optical, using X-Ray or Near Infrared signals (NIR).

Camera systems that operate in visible spectrum can be used to separate bottles by color, although for sorting of bottles of the same color black and white camera can be utilized. Modern NIR systems allow to separate even translucent colored materials. Moreover, each resin type absorbs only specific wavelengths emitted by NIR and after that transmits particular signal to sensor. Thus, NIR can be utilized to effectively process different type of plastic. The important property of NIR is that it works correctly even if plastic surface is contaminated with labels. On the other hand, if bottles are placed too dense and overlap each other, it can lower the positive effect. Hence, to make system reliable bottles should be processed one by one. PVC plastic can be identified using X-Ray technology, although it requires registration and should satisfy norms of Occupational Safety and Health Administration.

Since 1989 the development of automatic plastic sorting systems has started and just in two years one introduced a system for separating PVC resin from PETA. It was a starting point, when the problem of the recycling of the materials got more attention.

Modern automated systems tend to be rather efficient, although quite often it requires considerable amount of scientific and technological investments. Because of this reason it may not be suitable for small or medium size manufacturers. Considering this issue the authors of [1] propose imaging systems that allows separating materials in two classes: PET and non-PET resin types. The first type is normally used for storing juices, mineral water and other kinds of drinks while second type is mostly appropriate for storing chemical liquids.

Proposed System Description

Two main aspects which are equally important for any sorting facility: detection system and mechanism for handling material. Moreover, for both micro-sorting and macro-sorting the proper managing of feed stream. Hopper, conveyor belt, the ejector and the collecting bins make up the handling system, the detection system is implemented using of machine vision. The whole scheme of the system is shown on Figure 1.

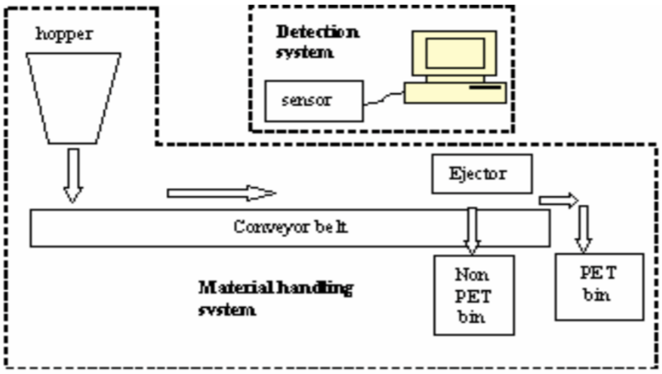

Figure 1. A diagrammatic illustration of the automated sorting system [1].

The sorting process can be described as follows, first image is digitalized using internal camera mechanisms. Next, digital image is going through pre-processing where it adjusts to particular task, applies filters and removes defects. After that starts process of feature extraction which leads classification.

On the pre-processing step image is converting to binary format using thresholding. The next step is the usage of morphological operations for edge detection. The most known morphological operations are erosion and dilation. The combination of these two can help to avoid discontinuity in shapes on image. The output of this process is black-white image of the same size.

The pre-processed image is further analyzed and goes as an input to feature extractor which converts given image to small set of particular features. In presented work main parameters for extraction were color and shape of bottles.

Boundary or contour-based, region or area based and skeleton based are three main approaches for shape representation. In this system, authors have chosen the first method and implemented it using Freeman Chain Codes introduced in 1961 by Herbert Freeman.

For the classification task authors used wide range of different methods. The first option were to measure Euclidean distance between image being processed and set of images from stored dataset. This method has been characterized as reliable even in case of bottles with identical shapes. Also, authors considered several artificial neural networks, utilizing sizes of shapes in pixels. In addition, the perimeter in polar coordinates was chosen as a input for trained neural network. The output of each method were the value which represented the probability of belonging to particular class. Hence, the output of pattern recognition technique with highest quality can be taken as final answer to classification.

Results

The system was tested and proved its efficiency. Thus, at least 80% of the bottles were classified correctly in poor lightning conditions. In contrast, using appropriate lightning environment the system reaches 5% error rate utilizing combination of all presented algorithms. The advantage of developed system is that it can be used on facilities with low and medium load. Moreover, the resulting system can be run on common personal computer, which turns out to be much cheaper solution in comparison with X-Ray, Near Infrared and Infrared systems.

2.2 Paper recycling

The key idea in paper recycling is to sort paper accordingly to its quality. Thus, it can be used to produce different kinds of materials. Moreover, less damaged paper demands smaller amount of chemicals, electricity and time. Hence, by sorting paper we can achieve better efficiency and resulting product quality. In this section will be considered state-of-the art techniques for paper sorting systems, in particular, the method base on Template Matching [2].

Modern Technologies of Paper Recycling

As well as plastic sorting, paper sorting systems have two main option for sorting process: manual and automated. Due to low efficiency of manual sorting we will not be considering it and focus on latest achievements in automated sorting systems.

In 1997 Faibish et al. [3] described a robotic system for sorting paper waste using two types of two types of sensors. The first one is stereoscopic vision system that consist of two CCD cameras. Another one is ultrasonic sensor which includes emitter and receiver attached to vacuum gripper. The time delays between sending and receiving ultrasound signals allow to reconstruct form of the object. For classification purpose authors used different non-parametric pattern recognition techniques, such as Fisher's linear classifier [4], Nearest- Neighbor classifier, Condensed Nearest-Neighbor classifier and Perceptron classifier. Fisher's algorithm appeared to be the most effective. However, further analysis of results revealed several issues. Although the visual system seemed to be reliable with small changes of illumination, usage of this system straggled to overcome noises with poorly illuminated environment. The second issue is unacceptable throughput (80 msec/sub-frame) for industrial applications.

In other work of Ramasubramanian et al. [5] introduce lignin sensor effectively separating newspapers from other kinds of paper, but is influenced by color and distance between sensor and sample. Following that, Hottenstein et al. [6] publish method of sorting newspaper in three main categories: white papers containing optical brighteners, white papers without optical brighteners and other types of paper. To distinguish these categories authors used brightness sensor. Venditti et al. [7] proposed stiffness sensor for sorting paperboards. The series of experiments revealed that sensing is able to sort cardboards into three main classes: light weight paper, medium weight cardstock, and heavy cardboard. The disadvantage of the system is that sometime it could not distinguish a stack of newsprints from single paperboard. Eixelberger et al. [8] developed a system for separating paper waste into two classes based on reflected from the surface of the paper radiation which simplified scheme is illustrated on Figure 2.

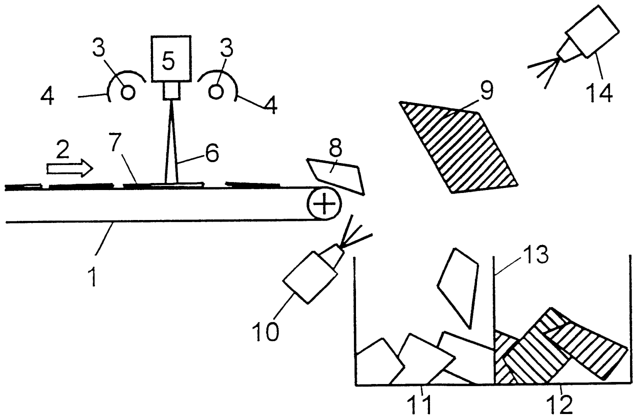

Figure 2. Scheme of apparatus for sorting waste paper of different grades and conditions [8].

In 1999, Gschweitl [9] patented sorting system that uses combination of visible light, ultraviolet light, x-rays and/or infrared light to illuminate the paper for sorting. However, Gschweitl utilized mechanical system for picking paper which results in serious performance restrictions.

While definitely being a serious improvement in terms of high-volume recycling, mentioned methods still lack of reliability, rather complex, expensive and cannot process more than two types of paper at a time. In addition, feature extraction was performed without usage of image processing and intelligence techniques.

Template Matching Based Waste Paper Sorting System Description

In the work of MO Rahman et al. [2] the papers sorting system based on electronic image. The method is based based on selection of four supporting points on the image and extracting features around these points. However, during extraction procedure no information about the texture of the object is used what can lead to wrong assumption about the paper grade. Hence, the main goal of the work presented by Rahman et al. [2] is to separate different types of paper utilizing algorithm of template matching [10]. In developed system authors use RGB channels of the paper sample image to construct RGBString for N-cell to overcome an issue with previously developed system.

As can be seen from block diagram presented on Figure 3 the system consist of two main modules, namely identification module and enrollment module. Both of these phases share some of the steps. Every module starts with image acquisition, preprocessing, and feature extraction. The enrollment phase continues with construction of RGBString for initialization of reference database. The indention phase continues with RGBString construction for N-cells, matching, and decision.

The size of the taken images in describing system is 320×240. Images taken by common webcam in the RGB mode. The webcam's settings such as the brightness, contrast and saturation are set to 50%, 50%, 100% accordingly. It was revealed that performance strictly depends on quality of illumination. Once calibration was done, for this experiment authors chose front lighting-directional-darkfield illumination [10]. The speed of the conveyor belt was set to 14 feet per minute. In course of scanning, system generates two types of signals, such as presence of object (PObj) and absence of object (AObj). Those two signals are used to properly handle separation of objects on conveyor belt in such manner that if presence signal is followed by absence signal then camera is making

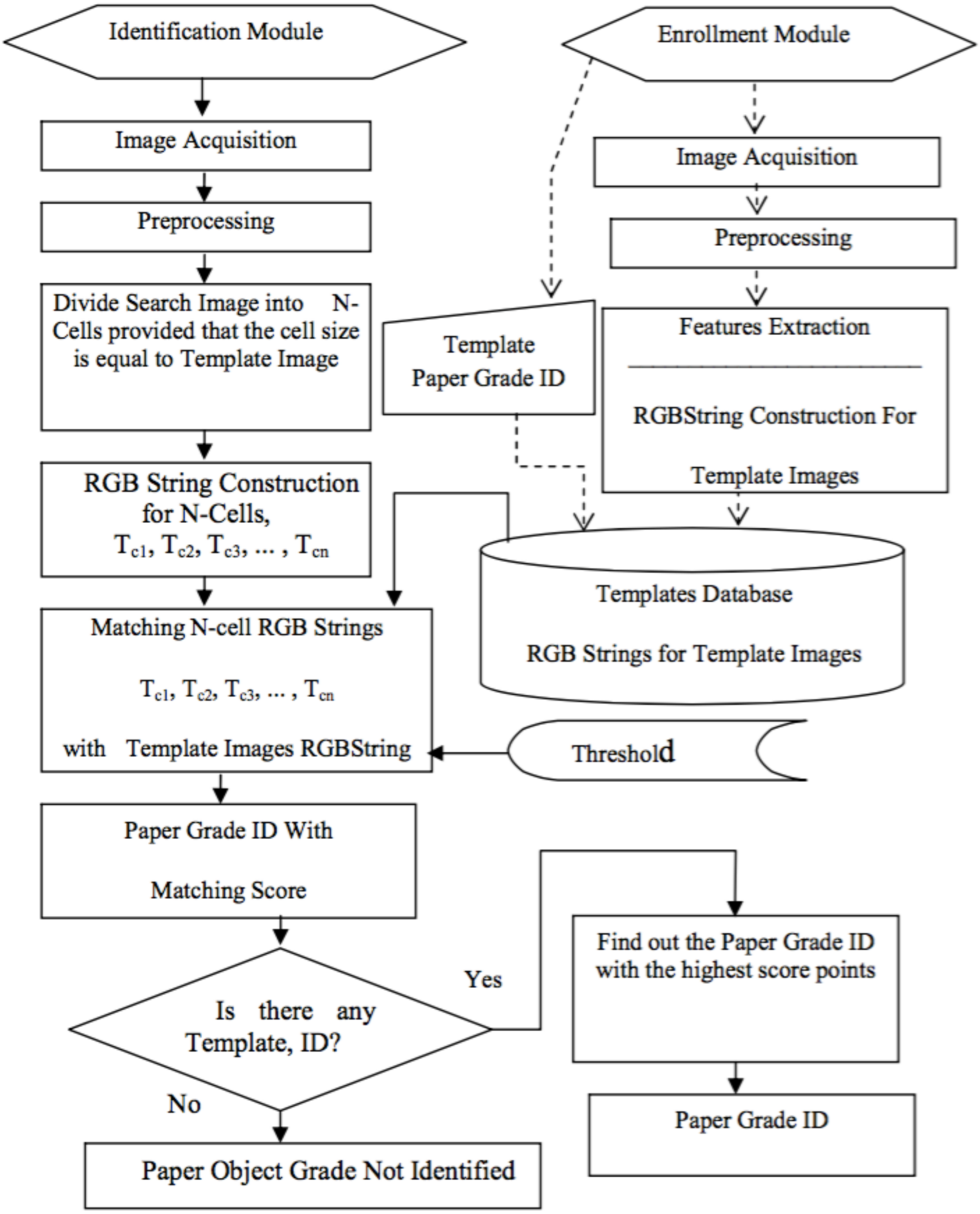

Figure 3. Block Diagram of the Paper Grade Identification System Using Template Matching [2]

a photo of inspected zone.

The image preprocessing is done after making a photo of inspection zone a trimming unnecessary boundaries. Once this step is performed, the next action is to remove background noise by applying the combination of thresholding and morphological operation erosion using 3×3 convolution filter.

The paper image uses 3 channels for its representation, namely R (red), G (green) and B (blue). To obtain gray scale image standard transformation is performed (1).

$$Y = \frac{R \times G \times B}{3} \tag{1}$$

The Y component is named this way to avoid collisions with green channel. To construct RGB string authors use maximum of 3 color channels as first part of RGBString, then second channel and finally channel with lowest value. The Y channel has reserved fourth place in RGBString. The frequency of appearance of the certain color component is related to its value, because ranges of values for different components are distinct for different types of paper. The color repetition process is described by Listing **??**.

```
# Color repetition in RGBString

if color_value <= 63: color_repetition = 1
elif color_value <= 184: color_repetition = 2
elif color_value <= 229: color_repetition = 3
else: color_repetition = 4
```

Listing 1. Color Repetiotion Calculation

To construct template, the system obtains the information related to region of interest and RGBString after getting template width (TW) and template height (TH) values of the template image. As it illustrated on figure 4, the search image is partitioned into N-cells. The cell image should have equal size to template image. All of the redundant cells are filtered beforehand.

The core idea of the template matching procedure is based on string matching algorithm. The process can be described as follows. For every template image and every cell from the grid the matching score is calculated using string matching. If the score is greater than

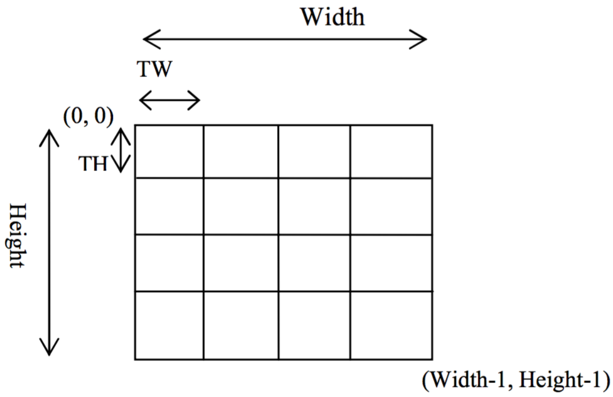

Figure 4. Search Image and Template Image [2]

threshold then template is increased by one (Listing 2). For their implementation authors use 92% as threshold value.

```
# Template matching
for template in templates:
    for cell in cells(image):
        score = compare_rgbstrings(template, cell)
        if score >= threshold:
            templateOccurance[template] += 1
```

Listing 2. Template Matching Procedure

Once matching process is finished, the next step is decision making. In this procedure, templates are iterated one by one retrieving occurrence, if occurrence of the certain template is higher than others then paper is graded by the index of this template.

```
# Decision making
tmax = 0
length = len(templates) # number of templates
papergrade = 1
for i in range(1,length):
    if templateOccurance[template] > tmax:
        tmax = templateOccurance[i]
        papergrade = i
```

Listing 3. Decision Making Procedure

Results

The authors used three types of paper for testing purposes, namely Old Corrugated Cardboard (OCC), Old News Paper (ONP) and White Paper (WP). Those types are chosen for testing purposes because of their often occurrence in usual tasks. For experiments authors selected one hundred paper samples per grade.

The paper object is constructed from three color channels, this model is able to describe over 16 millions colors. From the experimental points of view OCC, ONP, WP colors are fully distinctive, although for subtractive printing model cyan, magenta, yellow, and black colors are used. Due to this peculiarity, not all paper samples use the same color configuration and it was harder to distinguish deferent paper objects. In presented experiment, authors used not only different templates for each type of paper, but also different template for each size of the same paper grade. The performance of the system is inversely proportional to the template size. Thus, the less template size then bigger number of image cells should be considered which results in greater computational time.

Table 2. Experiment resutls [2].

Method	**Template Size**	**Name of the Paper Grade**	**Correct Identification Rate**
Template Matching	5×5	WP	96%
		ONP	92%
		OCC	96%
	10×10	WP	86%
		ONP	82%
		OCC	84%
	20×20	WP	78%
		ONP	72%
		OCC	76%

The success rate of the developed algorithm is presented on Table 2. The rate has been calculated as ratio between correctly classified paper grades and misclassified grades. The best result achieved using 5×5 template size which is 96% for WP, 92% for ONP, and 96% for OCC.

3 CONCLUSION

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