Sorting Based on Bits – The Technical Background of Digital Markers in the Context of High-Quality Recyclate Generation

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Abstract

The entire plastics value chain is currently looking for new processes to produce high-quality recyclates. One measure is to add relevant product-specific information that can be retrieved during the sorting process. For this purpose, the utilization of digital watermarks is being considered. However, as of now, expertise of this technology is rather limited within the recycling industry. This paper first gives a brief overview of the theory and principles of digital watermarking. Secondly, the characteristics of watermarks are presented to enhance the understanding of strengths and limitations of this technology. Finally, the encoding and decoding process of physical products regarding sensor-based sorting are highlighted.

Introduction

The quality requirements for plastic recyclates are increasing due to new regulatory requirements of the European Union, climbing ambitions of companies regarding their impact on climate change, growing resource consumption and consumers 'desire for a sustainable lifestyle. This is reflected in the demand for material streams that consider not only the polymer type, but also other, non-inherent (material) properties, such as food grade or the respective distributor. As a result, the entire value chain is looking for new processes that enable plastic packaging waste to besorted according to properties beyond the polymer type. In principle, this can be achieved either through alteration of the evaluation process during sorting (e.g., the usage of machine learning) or by manipulating the product itself (e.g., through adding tracer substances or digital watermarks). This contribution addresses the technical background of digital watermarks since there is only a limited understanding within the recycling industry of the principles behind this technology - a technology which has been used for a long time in digital systems.

Background and Definition

A digital watermark can be defined as an altered cover work, such as an image, audio, video, three-dimensional model, executable code, or text, to embed a message about said cover work (Cox et al. 2008). Metadata which is stored within the watermark could allow for identifying the source, creator, owner, distributor, authorised consumer, or even additional information about that cover work (Shih 2017). The idea for using watermarks for authentication purposes emerged in the late 1990s on digital systems (Cox et al. 2008). In the context of "smart packaging", their usage has been discussed since the early 2010s (e.g., Simske 2011).

In principle, a watermarking scheme Ω can be defined as the 7-tuple:

$$\Omega = (E, D, R, M, \text{Þ}_E, \text{Þ}_D, \text{Þ}_R) \quad (1)$$

Here, E represents the embedding function, D the detection function, R the recovery function, M the hidden message domain and Þ_E, Þ_D, Þ_R the domains for the parameter settings employed for embedding, detection, and retrieval (Dittmann et al. 2006). Fig. 1 depicts such an information hiding system on a high-level with the main components, an embedder and detector. The embedder's input is the original, unaltered cover work – in this example, a bottle. During the watermark embedding process, embedding parameters (e.g., a secret key) are applied in combination with a message, forming a digital watermark. During this phase, noise or distortion can influence the cover work by adversaries' intent of removing the watermark, deformation of the object, adhesion of dirt, blurring or – during decoding – an attack.

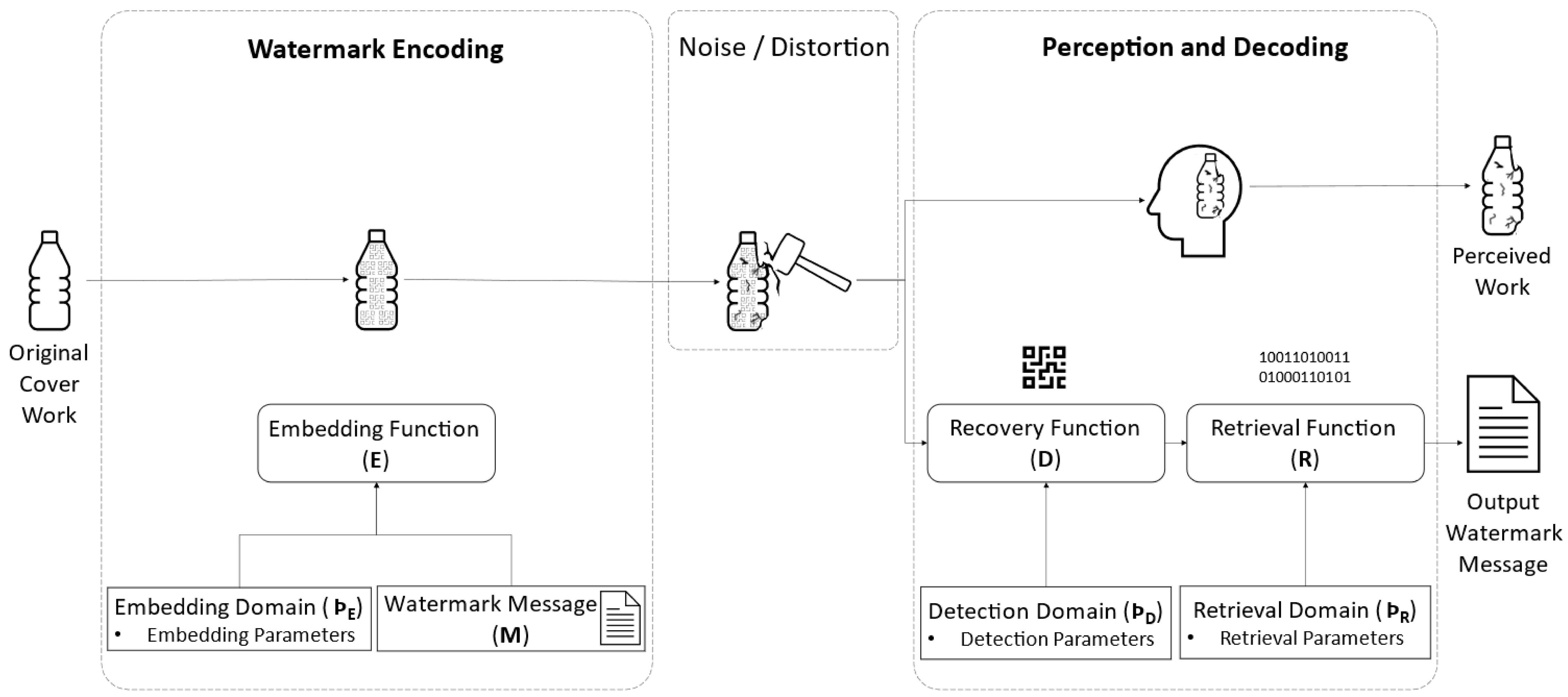

Figure 1: Working principle of an embedded watermarking system on a physical product which is perceived through the human visual system and a watermark detector system. Own work based on Cox et al. 2008, Shih 2017 and Dittmann et al. 2006.

Embedding Digital watermarks onto Products

Watermarks can be embedded in spatial domains and frequency domains. In the spatial domain, pixels in the host image are replaced with pixels from the watermark image. For example, by altering the gray levels of selected pixels in the host image or by transforming a single channel image to a halftone image through pixel swapping (Zhao et al. 2013). Advantages of this approach include simplicity and comparatively easy implementation. However, this approach is more susceptible to attacks and errors and may easily be detected using computer analysis.

As an alternative, the watermark can be embedded in the coefficients of a transformed image in the frequency-domain. To achieve this, discrete Fourier transformation, discrete wavelength transformation and discrete cosine transformation can be used. This type of embedded watermark is typically hard to discover. Yet, the image quality may be severely diminished when too much data is incorporated into the frequency domain. As a result, the embedding capacity is comparatively low as excessive data would distort the host image. Furthermore, the watermark needs to be smaller than the host picture.

Decoding Digital Watermarks with Sensor-based Sorting Systems

For decoding digital watermarks, commercially available cameras operating in the visible spectrum and a processing unit are required. Both elements can already be included in commercially available sensor-based sorting systems. To ensure ideal exposure conditions, additional light sources should be installed. After the watermark has been captured by the camera, the images are transferred to a computer, where the watermarks are decoded, and the respective metadata is obtained from a database and a sorting decision is made. The sorting process itself follows the principles of sensor-based sorting where the objects are separated by an acceleration belt, pass the decoding device, and are finally separated by means of compressed air nozzles.

Conclusion

It could be shown that digital watermarks could enable higher recyclate qualities. This is due to their imperceptibility which does not reduce the space available for advertising the product but also gives the possibility to link a plethora of information that can be considered during the sorting process. At the same time, the sorting process could generate new data which could in turn be used for optimizing production and marketing etc. Nevertheless, some barriers still need to be overcome. For example, there is currently no institution that guarantees public access for all stakeholders (e.g., for encoding, decoding, access to external database). Furthermore, data sovereignty must be clarified, since – especially for a digital product passport – partly sensitive information is deposited, over which the respective stakeholders may lose control. Finally, the increasing demand for recyclates could also lead to a shift in quantities and qualities for MRF output streams due to the correlation between recovery and purity. As a result, the quality of individual fractions could increase in relative terms, but the quantity of recyclable fractions could decrease in absolute terms.

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