Available online at www.sciencedirect.com

ScienceDirect

Signal Processing 87 (2007) 1363–1383

SIGNAL PROCESSING

www.elsevier.com/locate/sigpro

A robust image watermarking technique based on quantization noise visibility thresholds

Florent Autrusseau*, Patrick Le Callet

IRCCyN lab. Polytech'Nantes, Rue Ch. Pauc, BP 50609, 44306 Nantes, France

Received 6 July 2005; received in revised form 20 November 2006; accepted 21 November 2006
Available online 14 December 2006

Abstract

A tremendous amount of digital multimedia data is broadcasted daily over the internet. Since digital data can be very quickly and easily duplicated, intellectual property right protection techniques have become important and first appeared about fifty years ago (see [I.J. Cox, M.L. Miller, The First 50 Years of Electronic Watermarking, EURASIP J. Appl. Signal Process. **2** (2002) 126–132. [52]] for an extended review). Digital watermarking was born. Since its inception, many watermarking techniques have appeared, in all possible transformed spaces. However, an important lack in watermarking literature concerns the human visual system models. Several human visual system (HVS) model based watermarking techniques were designed in the late 1990's. Due to the weak robustness results, especially concerning geometrical distortions, the interest in such studies has reduced. In this paper, we intend to take advantage of recent advances in HVS models and watermarking techniques to revisit this issue. We will demonstrate that it is possible to resist too many attacks, including geometrical distortions, in HVS based watermarking algorithms. The perceptual model used here takes into account advanced features of the HVS identified from psychophysics experiments conducted in our laboratory. This model has been successfully applied in quality assessment and image coding schemes M. Carnec, P. Le Callet, D. Barba, An image quality assessment method based on perception of structural information, IEEE Internat. Conf. Image Process. **3** (2003) 185–188, N. Bekkat, A. Saadane, D. Barba, Masking effects in the quality assessment of coded images, in: SPIE Human Vision and Electronic Imaging V, **3959** (2000) 211–219. In this paper the human visual system model is used to create a perceptual mask in order to optimize the watermark strength. The optimal watermark obtained satisfies both invisibility and robustness requirements. Contrary to most watermarking schemes using advanced perceptual masks, in order to best thwart the de-synchronization problem induced by geometrical distortions, we propose here a Fourier domain embedding and detection technique optimizing the amplitude of the watermark. Finally, the robustness of the scheme obtained is assessed against all attacks provided by the Stirmark benchmark. This work proposes a new digital rights management technique using an advanced human visual system model that is able to resist various kind of attacks including many geometrical distortions.

Keywords: Image watermarking; Perceptual model; Quantization noise; Visibility thresholds; Geometrical distortions

*Corresponding author. Tel.: +33 240683041; fax: +33 240683232.
E-mail address: Florent.Autrusseau@univ-nantes.fr (F. Autrusseau).

0165-1684/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.sigpro.2006.11.009

1. Introduction

1.1. Invisibility versus robustness: HVS and spread spectrum

Data hiding has been used for several purposes such as steganography, indexing, authentication, fingerprinting copyright protection, copy control and more recently has even been utilized in quality assessment [1,2]. The requirements strongly differ for each of these applications [3]. Concerning digital rights management, the main requirements are copyright invisibility, embedded data capacity and robustness against most attacks the image could undergo. The first watermarking schemes performed slight luminance modifications [4,5] or less significant bits substitutions [6]. These techniques easily ensure the watermark invisibility and a high embedding capacity, however, the robustness requirements are not fulfilled. Ensuring the best invisibility versus robustness trade-off is not obvious, for instance it is well known that a watermark embedded into perceptually insignificant data components would easily be removed by an appropriate perceptually lossy compression [7]. This observation brought the spread spectrum theory into watermarking techniques. In spread spectrum theory, the media (images, videos, ...) are considered as a communication channel and the embedded watermark is viewed as the signal to be transmitted through this channel. The goal is then to spread the watermark data over as many frequencies as possible. This ensures a good invisibility versus robustness trade-off. Since most watermarking techniques are actually based on ideas from spread spectrum communications [8], we will not provide the details of this theory here, but rather recommend readers to refer to these pioneering works using spread spectrum in watermarking context [9,7,8]. In fact, such techniques don't guarantee the optimal invisibility, which could only be provided by using a HVS model. The interoperability between spread spectrum techniques and HVS models remains a complex issue.

1.2. Visibility and watermarking

Concerning visual aspects, the invisibility of the watermark is usually either empirically assumed or only tested with simplified quality metrics such as peak signal to noise ratio (PSNR) or root mean square error (RMSE). Most watermarking approaches aiming in the optimization of the robustness versus invisibility trade-off are inspired on well-known perceptual properties from a qualitative point of view rather than on advanced quantitative visual models. This is all the more surprising since several image processing applications, such as quality assessment [10], or compression [11] made the implementation of complex perceptual models possible. In watermarking applications, a few studies were conducted on the creation of perceptual masks in a data hiding context. A perceptual mask or JND (just noticeable difference) mask is supposed to indicate the maximum amount one can add or subtract at every image site without producing any visible difference. A typical example of the exploitation of qualitative HVS properties is addressed in [12], where the authors made the following heuristic assumptions: the noise sensitivity is weak on the image edges, smooth areas are very sensitive to variations and textured areas have a high noise sensitivity level. An edges-texture classification is then used in order to create masks. The so obtained content based watermarking technique was found to be robust against several attacks, such as JPEG compression, cropping, or Gaussian noise addition. An original method addressing higher levels of the HVS to define suitable masks has been defined in [13]. The method is based on a qualitative approach to regions of interest. Basically, the watermark is inserted in regions that have either high motion (because such regions are not trackable by the HVS) or slow relative motion (because they are not relevant). A similar study was also conducted in [14], investigating in which region an artifact is noticeable based on color saliency. However, although such heuristic properties can be exploited to implement simple masks, some very useful HVS features are not taken into account. For instance, using an advanced HVS model could allow to fully exploit the masking effects, and thus, to optimize both the invisibility and robustness of the mark.

1.3. HVS properties regarding visibility

To create a JND mask we should address low level parts of the HVS related to visibility mechanisms. Unfortunately, even the low level parts are not easy to model and several decades of psychophysics have been necessary to provide elements of visibility prediction. Experiments on sine-wave gratings have driven the emergence of the contrast sensitivity