Available online at www.sciencedirect.com
ScienceDirect
Signal Processing 88 (2008) 539–557
SIGNAL PROCESSING
www.elsevier.com/locate/sigpro

An interpolation-based watermarking scheme

V. Martin*, M. Chabert, B. Lacaze

ENSEEIHT/IRIT, National Polytechnic Institute of Toulouse, 2 Rue Camichel, BP 7122, 31071 Toulouse Cedex 7, France

Received 5 April 2007; received in revised form 2 August 2007; accepted 28 August 2007
Available online 4 September 2007

Abstract

Interpolation techniques are often designed to provide a good perceptual quality from known sample values. However, interpolation is essentially considered as a source of decoding errors for watermarking schemes. Conversely, this paper proposes an informed watermarking scheme based on interpolation. This scheme takes advantage of interpolation to generate imperceptible marks in the spatial domain. It can be related to random binning schemes with particular codebook and decoding rule. Theoretical performances are derived and informed embedding strategies are proposed. Two particular implementations based on bilinear and spline interpolation are then applied to image watermarking. The good robustness of these schemes to noise and valumetric attacks is confirmed by simulations. Finally, an attack is specifically designed to check the algorithm security.

Keywords: Digital watermarking; Interpolation; Informed embedding

1. Introduction

1.1. Digital watermarking

Digital watermarking consists of embedding data at the content-level of digital media under constraints on imperceptibility, security and robustness to attacks. Its applications range from digital rights management to integrity protection. This paper considers scenarios where document-dependent watermarks can be embedded. This includes the copyright protection application. The host document is not used at the detection.

In direct sequence (DS) spread spectrum watermarking [1], the additive mark is the message modulated by a pseudo-noise. The message can be decoded by correlation with this pseudo-noise. Classical spread spectrum methods are subject to host interference. Extensions provide improved performance thanks to Wiener prefiltering before decoding (DS + W) or optimal decoding for a given host statistical model [2]. Informed watermarking provides better performance when the host signal is known to the embedder [3]. In informed coding, a watermark template is directly generated from the host document. It can be combined with informed embedding, which uses knowledge upon both the host and the decoding technique. Specific strategies are designed to improve imperceptibility, robustness or detection receiver performance. For instance, linear improved spread spectrum (LISS) [4] is a modulation technique derived from DS. It removes

*Corresponding author. IRIT-ENSEEIHT, 2 rue Charles Camichel, B.P. 7122, 31000 Toulouse, France.
Tel.: +33 561588072; fax: +33 561588306.
E-mail addresses: vincent.martin@enseeiht.fr (V. Martin), bernard.lacaze@enseeiht.fr (B. Lacaze).

0165-1684/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.sigpro.2007.08.016

Nomenclature

$\mathbf{x}$	original document
$\mathbf{y}$	watermarked document
$\mathbf{z}$	received document
$\mathbf{m}$	message
$\mathbf{d}$	dither vector or security parameters
$\hat{\mathbf{m}}$	message estimation
$\mathbf{u}$	any input vector
$\tilde{\mathbf{u}}$	result of an interpolation of $\mathbf{u}$
$\varepsilon(\mathbf{x})$	interpolation error on $\mathbf{x}$
N	document length
L	payload
P	total rate
$\mathscr{S}$	watermarked sample coordinates
$\mathscr{S}_l$	subset of $\mathscr{S}$ associated to m_l
$\mathscr{G}$	interpolation grid
$\mathscr{K}$	secret key
$N_{\mathscr{S}}$	cardinality of $\mathscr{S}$
$P_{\mathscr{S}}$	embedding redundancy
g	interpolation operation
f	interpolant
N_v	interpolant support length
η^3	cubic spline interpolant
β^3	B-spline synthesis function
ρ_l^2	decoding mean square error on $\mathscr{S}_l$
v	detection threshold
v_{th}	optimum decoding threshold
$v^{(0)}$	empirical decoding threshold
$v^{(t)}$	iterative decoding threshold
α	scalar weighting factor
a	range of d_k
Δ	associated to noise influence at decoding or quantization step size
N_{o}	number of observations (security attack)

a part of the host signal interference, as a compromise with robustness to a given attack. Recent advances focus on random binning inspired from Costa work in information theory [5]. The inserted mark is selected in a random codebook divided into bins. Each bin is associated to a possible message. For a given message, the inserted mark is the bin element which is closest to the host data. The decoding identifies the bin which is closest to the received document. In practice, acomputationally tractable binning codebook can be constructed using structured quantization [6]. A popular scalar quantization-based watermarking scheme is called scalar Costa scheme (SCS) [7]. It improves the robustness by an informed embedding strategy: the quantization step is increased, while additional distortions are compensated. In spread transform scalar Costa scheme (ST-SCS) [7], the robustness to noise is improved by quantizing the projection of the data onto a pseudo-random vector. Classical quantization-based watermarking schemes are fragile to valumetric attacks such as gain or histogram modifications. Host-proportional embedding techniques [8,9] such as rational dither modulation (RDM) offer invariance to linear amplitude scaling by using locally adaptive quantization step-sizes. This paper contains comparisons to DS, DS + W, LISS, SCS, ST-SCS and RDM schemes.

Imperceptibility of the mark is a major concern in watermarking. Thus, most watermarking schemes must be combined with the so-called perceptual masks. These masks often weight spread spectrum watermarks. They also apply to spread transform-based schemes such as ST-SCS. In other quantization-based schemes, the quantization step must be locally adapted to the host according to a perceptual analysis, as suggested in the conclusion of [9]. In image watermarking, most popular spatial masks consist of weighting by a local variance computed with the noise visibility function (NVF) [10], subtracting a portion of second derivatives by a Laplacian filter [11] or weighting by filtered horizontal and vertical first derivatives [12]. All masks are based on empirical properties of the human visual system, combined with a statistical analysis. Spatial masks favor edges and regions of high local variance, that may concern few pixels. These masks often lead to high-pass watermarks. On the other hand, frequential masks such as DCT-domain masking are based on contrast and texture masking [2].

Interpolation techniques, widely studied in digital signal processing, are often designed to provide a good perceptual quality from known sample values. However, interpolation is essentially considered as a source of decoding errors for watermarking schemes, as detailed in Section 1.2. Conversely, this article proposes to take advantage of the perceptual properties of interpolation to generate imperceptible marks in the spatial domain. An informed watermarking algorithm is proposed. It shares some