Chapter XI
Digital Watermarking of Speech Signals

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ABSTRACT

The main objective of the chapter is to provide an overview of existing speech watermarking technology and to demonstrate the importance of speech processing concepts for the design and evaluation of watermarking algorithms. This chapter describes the factors to be considered while designing speech watermarking algorithms, including the choice of the domain and speech features for watermarking, watermarked signal fidelity, watermark robustness, data payload, security, and watermarking applications. The chapter presents several state-of-the-art robust and fragile speech watermarking algorithms and discusses their advantages and disadvantages.

INTRODUCTION

Digital watermarking is the process of embedding data (comprising the watermark), ideally imperceptibly, into a host signal (the coversignal) to create a stegosignal. Although the term “coversignal” is commonly used in watermarking literature (Cox, Miller, & Bloom, 2002) to denote the host signal (data to be protected), the name used for the watermarked result, the “stegosignal,” is borrowed from steganography (Johnson, Duric, & Jajodia, 2000). In the last decade many algorithms have been proposed for multimedia watermarking. Early work emphasized watermarking algorithms that could be universally applied to a wide spectrum of multimedia content, including images, video, and audio. This versatility was deemed conducive to the implementation of multimedia watermarking on common hardware (Cox, Kilian, Leighton, & Shamoon, 1997). However, many watermarking applications, such as copyright protection for digital speech libraries (Ruiz & Deller, 2000), embedding patient information in medical records (Anand & Niranjan, 1998; Miaou,
Digital Watermarking of Speech Signals

Hsu, Tsai, & Chao, 2000), or television broadcast monitoring (Kalker, Depovere, Haitsma, & Maes, 1999), involve embedding information into a single medium. Also, the attacks and inherent processing distortions vary depending on the nature of the multimedia content. For example, an attack on watermarked images may involve rotation and translation operations to disable watermark detection. However, such an attack is not applicable to audio data. Watermarking algorithms that are specifically designed for particular multimedia content can exploit well-understood properties of that content to better satisfy the robustness, fidelity, and data-payload constraints. Unlike general audio, speech is characterized by intermittent periods of voiced (periodic) and unvoiced (noise-like) sounds. Speech signals are characterized by a relatively narrow bandwidth, with most information present below 4 kHz. Broadband audio watermarking algorithms involving human auditory system (HAS) based perceptual models (Boney, Tewfik, & Hamdy, 1996) may not be effective for speech. Also, well-established analytical models for speech production exist (Deller, Hansen, & Proakis, 2000) and can be effectively exploited in the watermarking process.

The main objective of the present chapter is to provide a comprehensive overview of the factors to be considered while designing a speech watermarking system and the typical approaches employed by existing watermarking algorithms. The various speech watermarking applications and the algorithmic requirements will also be described in detail. The speech watermarking techniques presented in this chapter are presently deployed in a wide range of applications including copyright protection, copy control, broadcast monitoring, authentication, and air traffic control. The algorithms presented in this chapter are classified into robust watermarking and fragile watermarking categories according to the intended application. Furthermore, the chapter will describe the (commonly employed) signal processing, geometric, and protocol attacks on speech watermarking techniques. The chapter also discusses existing methods for objectively evaluating and controlling the quality/fidelity of watermarked speech.

Figure 1. A general watermarking system
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